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Identifying Nonwords: Effects of Lexical Neighborhoods, Phonotactic Probability, and Listener Characteristics

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Abstract

Listeners find it relatively difficult to recognize words that are similar-sounding to other known words. In contrast, when asked to identify spoken *nonwords*, listeners perform better when the nonwords are similar to many words in their language. These effects of sound similarity have been assessed in multiple ways, and both sublexical (phonotactic probability) and lexical (neighborhood) effects have been reported, leading to models that incorporate multiple stages of processing. One prediction that can be derived from these models is that there may be differences among individuals in the size of these similarity effects as a function of working memory abilities. This study investigates how item-individual characteristics of nonwords (both phonotactic probability and neighborhood density) interact with listener-individual characteristics (such as cognitive abilities and hearing sensitivity) in the perceptual identification of nonwords. A set of nonwords was used in which neighborhood density and phonotactic probability were not correlated. In our data, neighborhood density affected identification more reliably than did phonotactic probability. The first study, with young adults, showed that higher neighborhood density particularly benefits nonword identification for those with poorer attention-switching control. This suggests that it may be easier to focus attention on a novel item if it activates and receives support from more similar-sounding neighbors. A similar study on nonword identification with older adults showed increased neighborhood density effects for those with poorer hearing, suggesting that activation of long-term linguistic knowledge is particularly important to back up auditory representations that are degraded as a result of hearing loss.

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executive control, hearing impairment, individual differences, neighborhood density, phonotactic probability, speech processing

Introduction

One factor that seems to influence lexical processing is how similar an item is to other known words. This similarity has been assessed in multiple ways, and may actually reflect a number of distinct properties. One type of similarity is referred to as lexical neighborhood. Similarity neighborhoods are often operationalized as including all words that can be derived from an item by adding, deleting, or substituting a single phoneme. Thus, a word like “cat” has many neighbors (rat, hat, cut, cap, scat, etc.) while a word like “void” has very few. Research underlying the Neighborhood Activation Model of spoken-word recognition (Luce & Pisoni, 1998) has shown that monosyllabic real words with few similar-sounding neighbors in the mental lexicon (words such as “void”) are recognized faster and more accurately than words from dense lexical neighborhoods (such as “cat”), all other things being equal. The effect of neighborhood structure on word recognition is attributed to the recognition system having to overcome more lexical competition when a greater number of similar-sounding words have been activated, yielding slower and less accurate recognition.

A second type of similarity is referred to as phonotactic probability. Phonotactic probability refers to the frequency of the phonemes and phoneme combinations that make up a given word. Thus, “cat” has a high phonotactic probability because both the individual phonemes that make up the word (/k/, /æ/, /t/) and the combinations of those phonemes (/kæ/, /æt/) are highly frequent (that is, they occur in many other words). As will be discussed further below, these two forms of “similarity” to known words are theoretically distinct concepts that appear to have their effects at different levels of language processing (Vitevitch & Luce, 1998, 1999).

Research with listener groups other than university students has shown that lexical similarity effects may interact with characteristics of the listeners. Sommers (1996) found that older adults showed larger effects of neighborhood density on lexical identification than young adults, even when the two age groups were equated on performance for a set of easy words (i.e., words with few lexical neighbors). The increased lexical neighborhood effect for older adults was argued to be related either to a reduction in processing speed, or to reduced inhibitory mechanisms that are required to resolve lexical competition. Aging has indeed been argued to be accompanied by a decline in inhibitory functioning (Hasher & Zacks, 1988) and by a reduced ability to suppress lexical competitors (Balota & Duchek, 1991; Hasher, Stoltzfus, Zacks, & Rypma, 1991). Further evidence for a link between an age-related decline in inhibitory functioning and increased neighborhood effect size was found in a study on neighborhood density effects in individuals with dementia of the Alzheimer’s type (Sommers, 1998). The participants with dementia of the Alzheimer’s type (DAT) showed larger inhibitory deficits than the healthy older control participants. Moreover, increased neighborhood density effects were found in older individuals with more advanced DAT, relative to the age-matched control group. Most importantly, individual inhibitory abilities were found to be correlated with lexical identification performance on words with many neighbors in a study with young and older adults (and not with performance on the “easy” words with few neighbors), again suggesting that inhibitory abilities play a role in the auditory recognition of words with many similar-sounding neighbors (Sommers & Danielson, 1999). Consistent with these results, Taler, Aaron, Steinmetz, and Pisoni (2010) found that poorer inhibitory function (as indexed by performance on a Stroop paradigm) is associated with a greater difference between performance on high vs. low neighborhood density words at poor signal-to-noise ratios. Note that this relationship between inhibitory function and lexical recognition exists even though the type of inhibition assessed in a Stroop task is under the participant's control to a greater extent than is inhibition in the word recognition system. Taler et al. (2010) also found that neighborhood density effect size correlated with individual hearing sensitivity (hearing threshold at 2 kHz in participant's better ear), suggesting that decreased auditory sensitivity may also contribute to the generally larger neighborhood density effects seen in older adults, compared to young adults. Thus, neighborhood density effect size may differ among individual listeners, depending on both the listener's auditory and cognitive abilities.

Differences between adult listener groups or between individual listeners have mainly been investigated with respect to identification of spoken real words. When nonwords are presented for identification, effects of how similar they are to real words in the language actually go in the reverse direction than the neighborhood effects in real words. For example, nonwords composed of common segments and sequences of segments were repeated faster than nonwords composed of less common (but still legal) segment sequences (Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997; Vitevitch & Luce, 1998, 1999; Vitevitch, Luce, Pisoni, & Auer, 1999). These facilitatory effects of phonotactic probability were found both when the task involved producing/repeating the nonword and when the task did not involve a production component (cf. the results for the speeded same/different task in Vitevitch & Luce, 1999). High-probability nonwords consisting of familiar phoneme sequences were also shown to be remembered better than low-probability nonwords (Gathercole, Frankish, Pickering, & Peaker, 1999; Frisch, Large, & Pisoni, 2000).

In order to explain these seemingly contradictory effects of neighborhood density/phonotactic probability on words and nonwords, Vitevitch and Luce (1998) suggested that there were actually two different levels at which an item's similarity to words in the language could have an effect. They suggested that facilitatory effects of probabilistic phonotactics might reflect differences among the activation levels of sublexical units, whereas effects of similarity neighborhoods may arise from competition among lexical representations. In the absence of strong lexical competition effects associated with word stimuli, higher activation levels of sublexical units (associated with higher phonotactic probabilities) afford an advantage to high-probability nonwords. Both sublexical and lexical effects are presumably happening simultaneously, but aspects of the task and materials can emphasize one type of process over another. When the task requires lexical access, as, for example, in lexical decision, *lexical competition* mechanisms are seen at work, such that high-probability/high-density nonwords are responded to more slowly than low-probability nonwords. In tasks that do not strictly require *lexical* representations, such as perceptual identification of nonwords (Pisoni, 1996) or same/different judgments on item pairs, *sublexical frequency* mechanisms can be seen at work: high-probability nonwords are responded to more quickly than low-probability nonwords (Vitevitch & Luce, 1998, 1999). However, the distinction may not be so clear cut. Participants in a same/different matching task may again predominantly rely on lexical, rather than sublexical, representations and mechanisms when the test materials contain few nonword pairs and many real-word pairs (Vitevitch, 2003). Furthermore, nonword recall has also been argued to be particularly influenced by lexical knowledge (Roodenrys & Hinton, 2002; Thorn & Frankish, 2005). Roodenrys and Hinton (2002) argued that serial recall of nonwords is facilitated by lexical, rather than sublexical knowledge, as their results showed no effect of biphone frequency (as a proxy of phonotactic probability) when the number of lexical neighbors was controlled for, whereas they did find neighborhood density effects when biphone frequency was controlled for. These results were challenged by Thorn and Frankish (2005) who argued that the lack of a phonotactic probability effect in Roodenrys and Hinton (2002) should be attributed to a specific selection of items. When neighborhood size was controlled at the level of neighbor type, *both* lexical and sublexical knowledge influence nonword recall (Thorn & Frankish, 2005).

Thus, lexical processing seems to be influenced by how “similar” an item is to other known words, but this effect can be the result of several different factors acting at different levels of processing. Both properties of the task at hand, and properties of the set of stimuli being presented, can bias the listener towards showing greater effects of either sublexical (phonotactic probability) or lexical (neighborhood) processing.

The existence of such complex interactions brings us to the question of how best to model these “similarity” effects on nonword processing and recall. Taking the sublexical perspective, Vitevitch and Luce (1998) adopted Grossberg’s adaptive resonance theory (Grossberg, Boardman, & Cohen, 1997) to model probabilistic phonotactic effects for nonwords. In this theory, a resonance develops when bottom-up signals interact with top-down expectations (or prototypes), that have been learned from prior experience. Grossberg et al. (1997) distinguish between *items* in working memory and *lists* in short-term memory. Items are assumed to be feature clusters (auditory/acoustic representations in working memory), while list chunks are assumed to correspond to possible groupings of items (segments, subsyllabic segment sequences, syllables, words). The list chunks compete among one another via lateral inhibitory links (as word candidates do in the Neighborhood Activation Model of spoken-word recognition). Furthermore, longer list chunks inhibit smaller sublist chunks. For words, this would mean that strongly activated lexical chunks would inhibit sublexical chunks. For nonwords, the lexical chunks are not activated to as great of an extent (as there never is a perfect match between a novel nonword and any stored representation), and hence will not inhibit the sublexical chunks as strongly.

Vitevitch and Luce (1999) illustrate how phonotactic probability is modeled to affect processing of the high-probability nonword *sove* (rhyming with ‘love’) as compared to the low-probability nonword *jush* (same vowel as in ‘love’). Auditory input activates a set of items in working memory, which in turn activate list chunks (the largest ones in the case of nonword input being sequences of segments). Activation levels of list chunks are assumed to be a function of frequency of occurrence because resonances develop on the basis of prototypes that have been learned from prior experience. Hence, stronger resonances between sublexical list chunks and items in working memory will be established when the input is a high-probability nonword such as *sove* than when the input is a low-probability nonword such as *jush*.

Both lexical and sublexical mechanisms have also been implicated in models of nonword recall (rather than online processing). Clearly, presentation of a nonword results in the partial activation of real-word neighbors in long-term memory. Activation of these lexical representations then helps to reconstruct a nonword’s decaying memory trace in short-term memory (Schweickert, 1993; Gathercole et al., 1999). Possibly, this prevention of memory trace decay may come about through activation of multiple lexical representations being passed down to sublexical representations (such as phoneme nodes, cf. Roodenrys & Hinton, 2002). Thus, the existence of neighbors benefits identification and recall of nonwords because activation of multiple neighbors is being passed down to sublexical representations, which in turn help to maintain the memory trace of the presented nonword. Thorn and Frankish (2005), who found both lexical and sublexical effects on nonword recall, argue that reconstruction of a degraded temporary memory trace may be achieved through two separable reconstruction processes: one using lexical representations and one using probabilistic knowledge of the phonotactics of a language. Alternatively, rather than only having their effects during reconstruction, the two processes could already operate during the earlier stage of *storage* of the nonword item in short-term memory (Gathercole & Martin, 1996; Thorn &

Frankish, 2005), such that effects are not only seen in recall of nonword lists, but already seen during perceptual identification of single nonwords.

Studies on individual differences have so far typically focused on recognition of words (Sommers & Danielson, 1999; Taler et al., 2010), and their results have highlighted the importance of individual inhibitory abilities. Yet, the latter accounts of nonword processing and recall suggest that working memory abilities, rather than inhibitory abilities, should matter. Inhibitory abilities might not matter for nonword identification, as this identification need not involve a competition process among word candidates. From the different accounts on nonword processing discussed above, the same prediction can actually be derived with respect to interactions with listener characteristics. Both the link between sublexical list chunks and items in working memory modeled in Vitevitch and Luce (1999), and that between activated (sublexical) representations and auditory traces in short-term memory in Roodenrys and Hinton (2002) and Thorn and Frankish (2005), raise the hypothesis that working memory plays an important role in nonword identification: depending on their working memory skills, individuals may differ in their ability to identify nonwords and, more interestingly, in the size of the phonotactic probability/density effect. We expect that individuals with poorer working memory abilities may show larger effects of phonotactic probability/density.

As said, the two components of similarity (lexical neighborhoods and phonotactic probability) are generally having effects at the same time. Therefore, exploring how a number of listener characteristics interact with both types of similarity effects simultaneously would allow a more detailed explanation of these effects. In our study, we selected a set of items in which phonotactic probability and lexical neighborhood were not significantly correlated. This allowed us to investigate the two effects separately (at least to some degree) to see whether and how each type of similarity effect interacted with individual listener characteristics.

Based on the accounts of nonword processing discussed above, the hypothesis is tested that there are differences among individuals in the size of the phonotactic probability effect as a function of working memory abilities. Likewise, if activated lexical representations help processing and storage of a nonword in short-term memory, then individuals with poorer working memory abilities may also be affected more by neighborhood density than those with better working memory. The only evidence of differences in the size of the phonotactic probability effect in nonword processing comes from studies on language impairment, in which individuals with specific-language impairment (SLI) are compared to their typically-developing age-matched peers (Munson, Kurtz, & Windsor, 2005; Alt & Plante, 2006). Interactions between individual cognitive abilities and the two types of similarity effects will be the main focus in the first study in which we test nonword identification in young adults.

In the second study, we investigate interactions between item characteristics and listener characteristics in nonword identification in a population of older adults. In this population, hearing impairment may play a role. In addition, there is potentially greater variability in memory abilities in this group than in a younger adult sample mainly consisting of university students. The literature reported above suggests that hearing impairment may be partially responsible for the increased neighborhood density effects on spoken-word recognition in older, compared to young, adults. We will investigate whether individual hearing sensitivity on the one hand, and memory and other cognitive abilities on the other, modify the effect of phonotactic probability or lexical neighborhood size on perceptual identification and will provide an account for why such interactions arise.

Additionally, we will investigate individual differences in normalization for talker differences in identification of nonwords. Talker normalization has been suggested to be another case in which characteristics of the stimuli and characteristics of the listener interact (Sommers, 1997; McLennan, 2006). Different talkers do not produce the same sounds in the exact same manner, and the listener needs to adjust for these differences in order to recognize individual words (e.g., Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). Having to compute talker characteristics when there is a change in talker on every trial may require additional effort and/or attention. Indeed, studies have found that both older adults (Sommers, 1997) and adults with dementia of the Alzheimer's type (Sommers, 1998) have more difficulty with talker normalization than do younger or unimpaired listeners, and that young adults showed poorer normalization when they are faced with increased cognitive load (Nusbaum & Morin, 1992). Despite these global differences between participant groups or conditions, there are no reports, at least to our knowledge, of relationships between talker normalization and listener-individual characteristics. Wong, Nusbaum, and Small (2004) addressed this same issue by investigating cortical mechanisms underlying talker normalization (using fMRI). Brain areas associated with phonological working memory were not found to be more active in their talker-normalization condition, but there was more activation in temporal-parietal brain regions, possibly associated with selectively attending and processing acoustic cues. We will also address the cognitive demands of talker normalization processes in the present study by investigating relations between characteristics of the listener (such as performance on attentional and memory measures) and perceptual identification of nonwords in talker-blocked and in mixed-talker conditions.

2 Study 1: Nonword identification in young adults

2.1 Method

2.1.1 Participants. Forty young adults (10 M, 30 F) participated in the study. Most of them were students at Radboud University Nijmegen, or were enrolled in Bachelor programs at other institutions. All participants received a small payment for their participation. They were aged between 17 and 25 with a mean age of 21 years (*SD* = 1.7). Background information on hearing sensitivity and cognitive performance is provided below.

2.1.2 Hearing sensitivity. Hearing sensitivity (air conduction thresholds for pure tones) was assessed with a portable Maico ST 20 screening audiometer in a silent booth. All participants had normal hearing: hearing thresholds at octave frequencies from 250 Hz up to 8000 Hz in their better ear were all below 20 dB HL. Individual hearing sensitivity was determined as the participant's pure-tone average hearing threshold over the frequencies of 500, 1000, and 2000 Hz in their better ear. Mean pure-tone average was 6.6 (range -1.7 to 15 dB HL, *SD* = 3.4).

2.1.3 Spatial short-term memory. The visual Corsi block tapping task (Corsi, 1972) measures visuospatial short-term memory performance. In the computerized variant of this task used here, the participant always sees a pattern of nine identical blocks, irregularly positioned on the computer screen. A subset of the blocks is then highlighted at a rate of one block per second. Subsequently, the participant clicks the same blocks in their order of presentation. The task gradually becomes more challenging as the length of the block sequences increases from 2 to 9, with two trials for each block sequence length (resulting in 16 trials). Individual performance on this task was determined by computing the proportion of correctly imitated trials (out of the total of 16 trials): the higher the proportion, the better spatial short-term memory. Mean proportion correct in this task was 0.56 (*SD* = 0.13).

2.1.4 Working memory. A digit span task (with backward recall, a subpart of the Wechsler Adult Intelligence Test, 2004) was used to measure individual working memory capacity. In the computerized variant of this task used here, a series of digits would flash up in the center of the computer screen. Each digit was presented for 1 second, with 1 second in between consecutive digits. Digits were presented in a large white font against a black background. After presentation of the digit sequence (e.g., 3 6 2), the participant was prompted to recall the digits in the reverse order (e.g., 2 6 3). The participant was first presented with two trials with 3-digit sequences each to become familiarized with the task. They were then tested on 2- up to 8-digit sequences (two trials for each sequence length, resulting in 14 trials total). Individual performance on this task was determined by computing the proportion of correctly recalled digit sequences (out of 14 test trials): the higher the proportion, the better working memory. Mean proportion correct in this task was 0.56 (*SD* = 0.14).

2.1.5 Selective attention. In this computerized variant of the classic flanker task (Eriksen & Eriksen, 1974), participants responded to visual stimuli by clicking either the “z” or the “/” key on the keyboard. A row of five white symbols was shown. The middle symbol in the row (the target) was a leftward- or rightward-pointing arrowhead. The target was flanked on either side by two congruent or incongruent arrows (same or opposite direction), or by neutral lines (e.g., for a > target: > > > > > as the congruent condition; < < > < < as the incongruent condition; and - - > - - as the neutral condition). The task of the participant was to indicate the direction of the central (middle) target symbol by pressing the “z” key for leftward pointing and the “/” key for rightward pointing as quickly as possible, without sacrificing accuracy. In the incongruent condition, participants have to inhibit pressing the key they see in the flanking symbols. As such, the task measures selective attention to the target key, or the ability to inhibit the response to the other “dominant” key.

Each trial started with a beep and a fixation cross that remained on the screen for 250 ms. Following this fixation cross, the symbol string was presented for 1500 ms. After these 1500 ms, the string was removed and participants could no longer respond. The intertrial interval was 1000 ms. There were 6 different stimuli (2 pointing directions for the target, times 3 different flanker conditions). These 6 different stimuli were each presented 12 times in the test phase (order of trial presentation was randomized for each participant) to make 72 trials. Before the test phase started, 6 practice trials were presented (one for each of the 6 different stimuli).

Mean accuracy of the responses (pooled over participants) was 97% correct (*SD* = 5). Mean response times (computed only over correct responses) in the three conditions were 481 ms (from visual presentation onset) in the congruent condition (*SD* = 143), 600 ms in the incongruent condition (*SD* = 191), and 470 ms (*SD* = 143) in the neutral condition. Results were analyzed with linear mixed-effect models implemented in the R statistical program (version 2.8.0; R Development Core Team, 2007) by using the lmer function of the lme4 library (Bates & Sarkar, 2009). A simple model with Condition and Trial as simple effects and Participant as a random effect (and no further interactions) turned out to fit the data best. Relative to the congruent condition (which was mapped on the intercept), responses in the neutral condition were significantly faster, $b = -.019$, $SE = .008$, $p < .05$, and responses in the incongruent condition were significantly slower, $b = .223$, $SE = .009$, $p < .001$. Individual performance on this task was determined by computing the flanker interference cost: the ratio was taken of the participant’s mean response time in the incongruent condition, divided by the participant’s mean response time in the neutral condition. Mean interference cost ratio was 1.040 (*SD* = 0.016). The higher this interference cost ratio, the poorer selective attention.

2.1.6 Attention-switching control. Participants received the paper-and-pencil Trail Making Test (Reitan, 1958) as an index of executive control, or more specifically of the ability to switch attention. The Trail Making Test consists of two parts: Trail A asks participants to connect 25 consecutive printed numbers. This part of the test provides a baseline measure of the time participants needed to search and connect the items along one dimension. In Trail B participants are asked to connect 13 consecutive numbers and 12 consecutive letters alternatingly (1-A-2-B-3 etc.). Trail B therefore requires the shifting of attention between these two dimensions (numbers and letters), and the place-holding of the current item of one dimension while processing items from the other dimension. The test thus provides information on visual search, scanning, speed of processing, mental flexibility, and executive function (attention switching). Mean time to complete Trail A was 36 s ($SD = 9.4$). Mean time to complete the Trail B part was 59 s ($SD = 16$). Attention-switching cost was calculated as a ratio, rather than a difference score, following Salthouse (2011), to reduce the effect of speed on the index. The ratio of the time to complete Trail B, divided by the time to complete Trail A was 1.68 ($SD = 0.53$). Individual attention-switching cost scores were used as a measure of flexibility in controlled attention switching: the higher the ratio measure, the poorer attention-switching control.

The four cognitive measures, and age and hearing sensitivity, were evaluated as predictors for performance in the identification study. Any intercorrelations between these predictors are provided in Table 1.

Table 1 shows that, for the present sample of 40 young adults, the two memory measures were significantly correlated ($r = .438$, $p < .01$): the better the participant's spatial STM, the better his or her digit recall performance. The only other significant correlation was that between working memory and attention switching: the better the participant's working memory, the less trouble the participant had in the switching attention task ($r = -.311$, $p = .05$).

2.1.7 Materials. The stimuli were 120 monosyllabic nonwords that were all phonotactically legal syllables in Dutch. Syllable structure was CVC ($N = 23$), CCVC ($N = 40$), or CVCC ($N = 57$). Both neighborhood size and phonotactic probability were calculated. Phonotactic probability and neighborhood density are often highly correlated (Vitevitch et al., 1999): by definition, familiar segments or segment sequences are those found in many words. For each nonword, neighborhood size was established by counting the number of real-word neighbors by following the rule for what counts as a neighbor in the Neighborhood Activation Model (Luce & Pisoni, 1998): a word that can be derived from the nonword by removing, adding, or replacing

Table 1. Intercorrelations between predictor measures for the young adults.

	Age	Hearing	Spatial STM	WM	Selective attention
Age					
Hearing sensitivity	n.s.				
Spatial STM (Corsi block)	n.s.	n.s.			
Working memory (digit span backwards)	n.s.	n.s.	$r = .438$**		
Selective attention (flanker)	n.s.	n.s.	$r = -.264$†	n.s.	
Attention-switching control (TMT)	n.s.	n.s.	n.s.	$r = -.311$*	n.s.

†$p < .1$; * $p < .05$; ** $p < .01$.

a phoneme in the CVC, CCVC, or CVCC string. The number of neighbors for each nonword was established by running a Perl script on a Dutch lexicon database (the CELEX_DPL.txt file, containing a phoneme transcription of all Dutch lemmas in the CELEX database: Baayen, Piepenbrock, & Gulikers, 1995). Neighborhood density count ranged from 0 (for *gluun*: IPA transcription /xlyn/) to 23 (for *toor*: IPA transcription /tor/). Mean neighborhood density over the 120 nonwords was 7 ($SD = 5$). Two different measures were calculated as a proxy of phonotactic probability, both depending on biphone frequencies. In one measure, token frequency of each adjacent biphone in the CELEX lexical database of word types was calculated over all Dutch lemmas (both monosyllabic and polysyllabic lemmas, as in, e.g., Vitevitch & Luce, 1998; Thorn & Frankish, 2005). For a CCVC word, mean biphone frequency was computed over the C_1C_2, C_2V, and VC_3 combinations. Similarly, for a CVCC word, mean biphone frequency was calculated over the C_1V, VC_2, and C_2C_3 sequences. Mean biphone frequency by this first measure (collapsed over the nonword items' biphones) was 4243 ($SD = 3092$). In the other biphone frequency measure, the number of monosyllabic lemmas in the lexicon that contained the biphone in that specific position was tallied. There are two differences between the measures: first, the measures differ on which lemmas they were based upon (monosyllabic only or monosyllabic and polysyllabic) and second, they differ on whether they use a type or a token count. Mean biphone frequency by this second measure (collapsed over the nonwords' biphones) was 20.9 ($SD = 11.7$). The two phonotactic probability measures were significantly correlated ($r = .58$, $p < .001$).

Importantly, neighborhood size counts were not correlated with either phonotactic probability measure ($r = 0.1$, *n.s.* for the general biphone frequency measure, and $r < 0.1$ for the measure based only on monosyllabic lemmas). This is contrary to many other findings (e.g., Vitevitch et al., 1999), but may be due to several factors. First, if we leave out the nonwords that had many neighbors (15 or more neighbors, which excludes 14 out of 120 nonwords), correlations are significant ($r = 0.19$, $p = 0.05$ for the correlation between neighborhood size and the general measure, and $r = 0.32$, $p < .001$ for the measure based on the monosyllabic lemmas only). Second, the present study uses a mixture of CVC, CCVC, and CVCC items, whereas many others studies have focused on CVC nonword processing and recall (Vitevitch & Luce, 1998, 1999; Gathercole et al., 1999; Roodenrys & Hinton, 2002; Thorn & Frankish, 2005). This choice of syllable structure may influence correlation strength between measures of phonotactic probability (based on all constituent biphones) and neighborhood size.

The 120 nonwords were each recorded by 20 native speakers of Dutch, 10 male and 10 female speakers, with a Sennheiser microphone, and were saved directly on a computer at a sampling rate of 48 kHz (16-bit resolution). The nonwords were each saved as separate files and their mean intensity was equalized at 70 dB SPL. The nonwords were embedded in speech-shaped noise that was created on the basis of this sample of 20 speakers. The speech-shaped noise was created by concatenating 5 nonwords from each of the 20 speakers (different nonwords for each of the different speakers) into a single nonword chain. From this concatenated audio file, a long-term average spectrum was made, which was then multiplied with white noise in PRAAT (free speech editing software available at www.praat.org, Boersma & Weenink, 2012). By doing this, we created a noise file that was unintelligible, but had the long-term average spectrum of the speech of these 20 speakers. Mean intensity of this noise file was set to 70 dB SPL as well. For each target nonword, a matching noise file was created. First, a fragment of the speech-shaped noise file was taken that had the same duration as the target nonword. Then, the intensity contour of the target item was overlaid on the noise file, in order to make the noise amplitude-modulated. The target nonword and its matching noise file were then mixed at an SNR of 0.

Participants were presented with the 120 nonwords in two conditions: single-talker and mixed-talker. These two conditions were blocked in an ABBA or BAAB fashion, which means that the first 30 trials would be in either condition (all spoken by a single talker, or with a talker switch on every consecutive trial), the next 60 trials would then be in the other condition, and the last 30 trials again in the condition with which they started. Forty experimental lists were created to make sure that every experimental item was presented in each of the 20 talkers' voices, and, given one particular talker, in each of the two conditions (single- or mixed-talker condition). Over experimental lists, we also ensured that the position of that particular item on the list varied (to avoid having trial effects confounded with item effects).

2.1.8 Procedure. Each trial began with the appearance of a fixation cross which remained on the screen for 250 ms. Then, after 2 seconds, the target nonword was presented, after which participants could type in their response (to spell the nonword they heard). Even though participants might have found it easier to simply repeat after the trial presentation, typed responses were preferred over verbal responses because processing of written responses was less labor intensive than processing voice-recorded responses. When they had finished typing their response followed by the ENTER key, participants proceeded to the next trial. Response times from onset of the target until the participant pressed the ENTER key were also collected. The actual test phase was preceded by the presentation of 8 practice trials (spoken by a single talker who was not a member of the set of 20 actual test talkers). The auditory test items were presented binaurally over closed headphones at an output level of 75 dB SPL to all participants while they were seated in a sound-isolated booth. Thus, each ear received a mix of target and noise. Participants could ask questions regarding the procedure after the practice phase if anything was unclear.

2.2 Results

All typed-in responses were scored manually because there was more than one correct orthographic transcription for most nonwords. Dutch spelling is like English spelling in that there is no one-to-one relationship between graphemes and phonemes (e.g., the letter 'c' is pronounced as either /k/ or /s/, depending on the word, and both the letter combinations 'au' and 'ou' should be pronounced as /ɑu/). Responses were rated by the first author, who had made an *a priori* list of possible spellings of each nonword. Whenever the target sound was /k/ and participants responded with 'c', this was considered to be correct (participants were given the benefit of the doubt). For many Dutch speakers, the voicing distinction in syllable-onset fricatives has been neutralized (/v/ vs. /f/ and /z/ vs. /s/). In scoring the responses, fricative voicing substitutions were therefore not counted as errors: as a result, the list of possible correct spellings for the nonword /fɑux/ was 'faug/foug/voug/vaug'. We also allowed for phonological processes, such as schwa epenthesis in consonant clusters and stop epenthesis in between nasals and /s/ or /t/ (*prince* becoming *prints* due to changed timing of articulatory gestures, cf. Fourakis & Port, 1986; Warner & Weber, 2001). With respect to schwa insertion, the Dutch word *melk* (milk) can be pronounced *mellek* (/mɛlək/). As such, it is difficult for listeners to decide whether a (trace of a) pronounced schwa should be present in the orthographic transcription of nonwords. Stop epenthesis led participants to respond 'hints' to the nonword 'hins' IPA transcription /hɪns/, and some participants even responded 'hinds', analogous to the real word *ginds* ('over there'), because Dutch does not have a voicing distinction in syllable coda position (note that long /i/ is spelled ‘ie’ in Dutch and that the letter ‘i’ in monosyllabic words should always be read as /ɪ/). All such instances of schwa epenthesis and stop epenthesis in the responses were counted as correct (rather than errors), as several of our speakers may have in fact produced these epenthetic sounds.

Identification accuracy was 43% correct in the single-talker condition (*SD* = 9.4) and 38% in the mixed-talker condition (*SD* = 11). Responses were analyzed using mixed-effect models implemented in the R statistical program (version 2.8.0) by using the lmer function of the lme4 library (Bates & Sarkar, 2009). To deal with the categorical nature of the response measure (the transcription being correct or not), a binomial logit linking function between responses (0 or 1) and predictor variables was included into the models (Jaeger, 2008). Models were fit using the residual maximum likelihood criterion. The best-fitting model was established through systematic step-wise model comparisons using likelihood ratio tests. A model’s estimated effect of a categorical factor reflects changes to the intercept when accounting for performance observed under another condition of the factor; an estimate for the effect of a continuous factor reflects an adjustment to the regression slope. The estimates therefore reflect the size of an effect. All best-fitting models included subjects and items as crossed random factors. Models evaluated the categorical design variables Talker variability (2 levels: whether the item occurred in a single- or multiple-talker block), and Talker (20 levels for the 20 different talkers). Trial (from 1 to 120) was evaluated as a numerical fixed predictor. Neighborhood size and phonotactic probability were not correlated over the 120 nonword items, which implies that both variables could be entered as covariates. Number of lexical neighbors for each target nonword item was evaluated as a numerical covariate predictor. The phonotactic probability measure (mean biphone frequency) based on the monosyllabic lemmas was evaluated as a numerical covariate predictor (both phonotactic probability measures were actually tested in separate models, but the type frequency measure based on the monosyllabic lemmas turned out to be the most reliable predictor).

The following listener-individual measures were evaluated as numerical covariates: age, average hearing sensitivity in the better ear (PTA), and performance on the spatial short-term memory task, on the working memory task, on the selective-attention task, and on the attention-switching task (all predictor variables were centralized first such that their mean mapped onto the intercept). We tested for simple effects and for interactions between the design (and item) variables and the individual covariates.

The best-fitting model showed a significant effect of Talker variability: identification accuracy was lower in the mixed-talker condition, relative to the single-talker condition, $b = -.292$, $SE = .065$, $p < .001$. None of the individual-listener characteristics interacted with Talker variability. There were significant Talker effects: several talkers significantly differed in intelligibility, relative to the talker mapped on the intercept. Further, identification accuracy generally improved over the course of the experiment, as shown by a significant Trial effect, $b = .003$, $SE = .001$, $p < .01$. As for the item characteristics, nonwords with higher neighborhood density were identified better than nonwords with lower density, $b = .035$, $SE = .016$, $p < .05$. In addition, nonwords with higher phonotactic probability were identified better than nonwords with lower probability, but this effect only approached significance, $b = .013$, $SE = .007$, $p = .066$. It is worth noting that the effect of lexical neighborhood was facilitatory (with dense-neighborhood nonwords showing more accurate performance), rather than being a measure of lexical competition.

As for the listener characteristics, only attention-switching control was a significant predictor for performance: those with poorer attention-switching control generally had poorer identification performance, $b = -.542$, $SE = .185$, $p < .01$. Importantly, attention-switching control interacted with neighborhood size: those with poorer attention-switching control benefit more from higher neighborhood counts, $b = .027$, $SE = .012$, $p < .05$. Lastly, attention-switching control interacted with the effect of Trial: the more trouble participants had switching their attention, the more improvement they showed over trials, $b = .005$, $SE = .002$, $p < .05$. Note that none of the listener characteristics interacted with the phonotactic probability measure.

To further illustrate these numbers, the neighborhood effect coefficient is $b = .035$ for those with a mean attention-switching control performance: with each additional neighbor, identification increases by .035 (note that these numbers pertain to logits). For participants whose attention-switching performance is two standard deviations ($SD = .53$) above or below the mean, a value of 0.029 (2*.53*.027) should be added to or subtracted from this neighborhood effect coefficient, yielding a neighborhood estimate of .064 for those with poor attention-switching control (2 SDs above the mean), and yielding .006 for those with good attention-switching control (2 SDs below the mean).

We set out to test the hypothesis that working memory abilities relate to the size of the phonotactic probability effect in nonword identification. However, our results suggest that the item effects found here are predominantly lexical neighborhood effects, with relatively weak sublexical effects. Our results first of all replicated Roodenrys and Hinton (2002) and Thorn and Frankish (2005): nonwords with more lexical neighbors were identified better than those with fewer neighbors. The *sublexical* familiarity effect (Vitevitch et al., 1999) only marginally affected identification accuracy and was not modified by any of the listener characteristics. Further, one cognitive measure, attention-switching control, turned out to predict overall identification performance and to modify the neighborhood size effect. Thus, attention-switching control, rather than memory measures such as digit span or spatial STM, was linked to the size of the neighborhood effect. Note, however, that attention-switching control weakly correlated with our working memory measure (cf. Table 1). In conclusion, these results mainly stress two points: the importance of lexical effects on nonword identification, and that attentional abilities interact with the size of this lexical effect.

Before we discuss these results more elaborately, a second study is reported using older adults as participants. We sought to replicate the findings obtained with the young adults in Study 1 in terms of effects of neighborhood size and phonotactic probability. More importantly, given that age-related hearing impairment is expected to impair identification of nonwords in older adults, we investigated whether individual hearing sensitivity modifies the phonotactic probability effect or the lexical neighborhood effect on perceptual identification (or both). Further, hearing loss may modify the interaction between neighborhood size and attention-switching control found here for the normal-hearing young adults.

3 Study 2: Nonword identification in older adults

3.1 Method

3.1.1 Participants. Forty older adults (11 M, 29 F) participated in the study. They had responded to a call for participation in a local newspaper. All participants received a small payment for their participation. Their mean age was 70 years ($SD = 4.4$, range 61–81). Background information is provided below.

3.1.2 Hearing sensitivity. The older adults had varying degrees of hearing loss, but none of them wore hearing aids. Their hearing problems were most likely due to age, as they reported not having had any hearing problems when they were younger. Hearing acuity (air conduction thresholds for pure tones) was assessed with a portable Maico ST 20 audiometer in a silent booth. Only 3 out of the 40 older participants had pure-tone thresholds in the better ear exceeding 25 dB HL in the 250–2000 Hz range, which indicates that this group of older adults had relatively normal hearing, in the lower frequency range at least. Mean hearing thresholds of the participants are given in Figure 1. Mean pure-tone average (calculated over 1, 2 and 4 kHz in their better ear) was 21.6 dB HL (*SD* = 7.1).

3.1.3 Educational level. Educational level in the group of older participants was more diverse than in the younger group of Study 1 and was graded on a five-point scale. The points on this scale reflect the highest education level that the participant had completed, ranging from level 1, indicating that the participant had finished primary school, to level 5, indicating that the participant had obtained either a Bachelor or a Master's degree (at a university or at another institution). Mean educational level in the older group was 3.3 (*SD* = 1.2, range 1–5).

3.1.4 Cognitive measures. Memory measures were not assessed in this study to reduce testing time, particularly since neither measure interacted with lexical similarity effects in Study 1. Participants performed the following two cognitive tasks: the Digit-Symbol Substitution task (part of the Wechsler Adult Intelligence Scale) as a measure of processing speed, and the Trail Making task that was used in Study 1 as a measure of attention-switching control (Reitan, 1958). Both tasks are easy and quick-to-administer paper-and-pencil tasks. The processing speed measure was included here because a number of studies with older adults suggest that processing may be slowed in this group (Salthouse, 1996), and that this reduction in speed may lead to impairments in cognitive functioning.

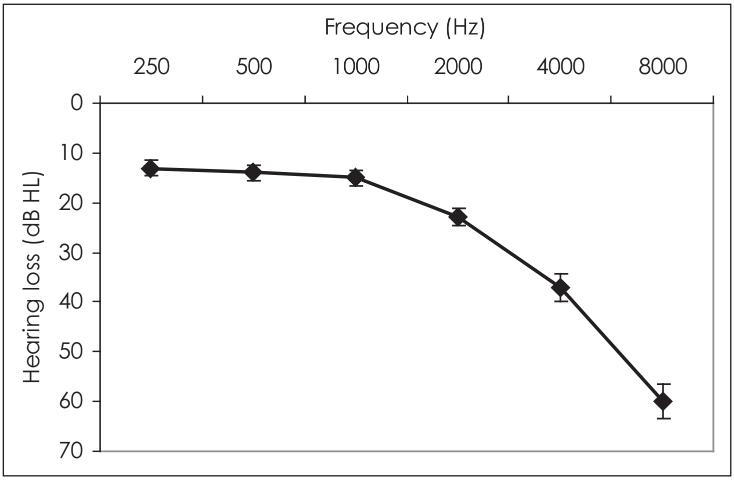

Figure 1. Mean hearing thresholds (dB HL) at octave frequencies from 250 through 8000 Hz. Error bars indicate 1 standard error.

a. *Processing speed*. Scores on the Digit-Symbol Substitution test exhibit strong correlations with measures involving processing speed (Salthouse, 2000; Hoyer, Stawski, Wasylyshyn, & Verhaeghen, 2004). In this paper-and-pencil task, participants are provided with a key (10 digits each having their own symbol), and they then have to substitute as many digits for symbols as possible within a certain time window. Mean substitution time needed per symbol was 2.06 sec/symbol (*SD* = 0.49). This score was entered as a measure of individual information processing speed: the higher the score, the slower the processing speed.
b. *Attention-switching control*. The Trail Making Test (Reitan, 1958) was considered an index of attention-switching control and was described in Study 1. Mean time to complete Trail A was 47.6 s (*SD* = 16.8). Mean time to complete Trail B was 99.8 s (*SD* = 40.5). Switching cost (ratio of Trail B divided by Trail A) was therefore 2.17 (*SD* = 0.75). The latter ratio score was used as a measure of individual attention-switching control: the higher the score, the poorer attention-switching control.

Intercorrelations between the five individual predictors (age, hearing sensitivity, educational level, and the two cognitive measures) were calculated. Most intercorrelations were insignificant: only educational level correlated with attention-switching control. The higher the educational level a participant had, the lower (i.e., the better) the attention-switching control cost ($r = -.472$, $p < .01$). Age and hearing sensitivity may not have been correlated because only older adults with relatively good hearing were included in the present sample.

3.1.5 Materials and design. The stimuli and design differed slightly from those of Study 1 because the present study was initially set up to look at the time course of talker adaptation in older adults. The stimuli were a superset of those used in Study 1: the 120 nonwords of Study 1 were used here, plus an additional 20 nonwords (this different number of stimuli was related to a different design with more experimental conditions). All 140 nonwords were phonotactically legal in Dutch with syllable structures being CVC ($N = 28$), CCVC ($N = 46$), or CVCC ($N = 66$). Number of real-word neighbors was established as described in Study 1. As before, mean neighborhood density over the 140 nonwords was 7 (*SD* = 5, and range 0–23). Phonotactic probability was also calculated in the same way as in Study 1: one measure being token frequency of each biphone in the CELEX Dutch lemma database calculated over monosyllabic and polysyllabic lemmas, and the other being a count of the number of monosyllabic lemmas in which the biphone occurred in that specific position. Mean biphone frequency of the first phonotactic probability measure was 4084 (*SD* = 2987). Mean biphone frequency of the second measure was 20.4 (*SD* = 11.7). The correlation between the two measures of phonotactic probability was significant ($r = .63$, $p < .001$). As in Study 1, neighborhood size was not correlated with either phonotactic probability measure ($r < 0.1$ for both phonotactic probability measures). And again, this lack of a relationship between neighborhood size and phonotactic probability was driven by nonword items with many neighbors. As in Study 1, looking only at nonwords with fewer than 15 neighbors (thereby excluding 19 out of 140 nonwords), the correlation between neighborhood size and phonotactic probability was significant ($r = .26$, $p < .01$ for the more general token measure, and $r = .41$, $p < .001$ for the phonotactic measure based on monosyllabic lemmas only).

Nonwords were mixed with their matching amplitude-modulated noise files, as described in Study 1. For the older listener sample in the current experiment, SNR was set to +5, in order to achieve similar accuracy levels to those obtained in Study 1.

The experimental design comprised three experimental conditions, rather than the two conditions of Study 1. The 140 nonwords formed 14 sets of 10 items. Each experimental list presented the participant with the full set of 140 nonword items in three conditions: a single-talker condition (2 item blocks, thus 20 items), a mixed-talker condition (2 item blocks, thus 20 items), and a blocked-by-talker condition (10 item blocks, thus 100 items). In the mixed-talker condition, there was a talker switch on every trial (the 20 items were each spoken by a different one of the 20 talkers). In the blocked-by-talker condition, each of the 10-item blocks was spoken by a different one of the 20 talkers. On half of the experimental lists, participants would be presented with the single-talker condition trials, then the blocked-by-talker condition trials, and then with the mixed-talker condition trials. On the other half of the lists, participants would be presented with the reverse order of conditions (single-talker condition last). Forty different lists were made to rotate talkers over item blocks and over the three conditions (a full rotation of talkers over blocks, conditions and orders would have required more than 40 experimental lists): we ensured that each talker would be represented in the single-talker condition and crossed this with condition order (single-talker condition being presented either as first two blocks of trials or as last two blocks of trials). Order of the item blocks was also varied over experimental lists to ensure that trial effects would not be confounded with item effects. Item order within each item block was fixed. This design enabled us to investigate performance differences between three presentation conditions (single talker, blocked-by-talker, and mixed talkers).

3.1.6 Procedure. The procedure was identical to that of Study 1. The only difference was presentation level of the stimuli: the test items were presented binaurally at an output level of 80 dB SPL to all participants.

3.2 Results

All typed-in responses were scored manually because there was more than one correct orthographic transcription for most nonwords. Table 2 shows identification accuracy (% correct) in the three conditions.

Results were analyzed in the same way as in Study 1 with linear mixed-models, using both participant and item as random factors. We evaluated the effects of the following variables and covariates. Design variables included Talker variability (3 levels: single, blocked and mixed), and Talker (20 levels for the 20 talkers). The blocked-talker condition was mapped on the intercept (because 100 out of 140 items were presented in that condition). Trial (from 1 to 140) and Position in item block (from 1 to 10) were evaluated as numerical fixed predictors. Number of lexical neighbors for each nonword item was evaluated as a numerical covariate predictor, as well as the phonotactic probability measure (based on monosyllabic lemmas). The following listener-individual measures were evaluated as covariate predictors: age, average hearing sensitivity in the better ear, educational level, performance on the processing speed measure, and performance on the attention-switching task. We tested for simple effects and for interactions between the design and item

Table 2. Identification accuracy of the older adults in the three presentation conditions.

	Accuracy	
	Mean	*SD*
Single-talker condition	47	19
Blocked-by-talker condition	48	14
Mixed-talker condition	39	13

variables and the individual covariates. The best-fitting model showed the following results. Relative to performance in the blocked-by-talker condition (on the intercept), identification performance in the single-talker condition did not differ. This is not surprising as the two conditions are highly similar to the participants. However, again relative to the blocked-by-talker condition, performance in the mixed-talker condition was significantly poorer, $b = -.547$, $SE = .102$, $p < .001$. Identification performance improved over the course of the experiment, as shown by a significant Trial effect, $b = .004$, $SE = .0007$, $p < .001$. Identification accuracy also improved over trials within each item block: this effect may be mainly attributed to adaptation to the talker's voice in the single-talker and blocked-by-talker conditions, $b = .026$, $SE = .010$, $p < .05$. As before, several talkers differed in intelligibility relative to the talker mapped on the intercept. Neighborhood size facilitated identification: the more neighbors a nonword had, the higher the identification accuracy, $b = .046$, $SE = .013$, $p < .001$. As expected, hearing sensitivity also related to performance: the more hearing loss participants had, the poorer their identification, $b = -.044$, $SE = .010$, $p < .001$. More importantly, hearing loss interacted with number of neighbors: the facilitatory effect of having more neighbors was greater for those with more hearing loss, $b = .002$, $SE = .0008$, $p < .01$. Phonotactic probability also affected perceptual identification: the higher the nonword's phonotactic probability, the better it was identified, $b = .015$, $SE = .006$, $p < .01$. Importantly, however, phonotactic probability did not interact with any of the listener characteristics. Further, attention-switching control affected performance: the higher participants' attention-switching cost, the poorer their identification accuracy, $b = -.261$, $SE = .098$, $p < .01$. Finally, the processing speed measure related to identification accuracy: participants who took longer to do the Digit-Symbol recoding task generally had poorer identification performance, $b = -.422$, $SE = .147$, $p < .01$.

Thus, as expected, hearing loss modifies the effect of "wordlikeness" of the nonwords, but note that hearing loss interacted with the lexical effect (neighborhood size) during identification, rather than with the sublexical phonotactic probability effect. The interaction found for the young adults between attention-switching control and neighborhood size was not replicated here. Possibly, the interaction with hearing loss may have interfered with the relation between lexical effects and attention-switching control.

4 Discussion

This study investigated a number of item and listener characteristics in relation to perceptual identification of nonwords. In the model laid out in Vitevitch and Luce (1999), there are two different levels at which an item's similarity to words in the language could have an effect. Vitevitch and Luce (1999) suggested that facilitatory effects of probabilistic phonotactics might reflect differences among activation levels of sublexical units, whereas effects of similarity neighborhoods arise from competition among lexical representations. However, in studies of nonword recall, larger similarity neighborhoods have been shown to *facilitate* nonword processing (Roodenrys & Hinton, 2002; Thorn & Frankish, 2005), which implies that neighborhood effects cannot be accounted for by only a competition mechanism. In the present study, a set of nonwords was used in which phonotactic probability and lexical neighborhood size were not correlated. This allowed us to separate out how each of the two effects interacts with listener characteristics, such as hearing sensitivity, selective attention and working memory skills.

As found by Vitevitch et al. (1997), Vitevitch and Luce (1998, 1999), and Vitevitch et al. (1999), high-probability/density nonwords in our study were identified more accurately than low-probability/density nonwords. Prior research has shown that they tend to be recalled better (Gathercole et al., 1999; Roodenrys & Hinton, 2002; Thorn & Frankish, 2005). Importantly, neighborhood size reliably affected perceptual identification in both our Studies 1 and 2, whereas the effect of phonotactic probability was only reliable in Study 2. Thus, the effects seen here are more in line with the account of lexical knowledge supporting storage or maintenance of auditory traces in short-term memory (Roodenrys & Hinton, 2002; Thorn & Frankish, 2005) than with the phonotactic account provided by Vitevitch and Luce (1999).

Further, on the side of the listener, we found two individual characteristics relating to nonword identification accuracy: hearing sensitivity and attention-switching control. Whereas the first makes perfect sense, the second individual characteristic may be less obviously related to auditory identification accuracy. In both younger and older adults, better attention-switching control related to better perceptual identification accuracy. Furthermore, in the young adults, those who had more trouble switching their attention showed increased effects of neighborhood size. These are the effects we anticipated for working memory, rather than for attention-switching control. Working memory has been claimed to be involved in Trail Making performance because the participant has to keep track of encountered letters and digits (e.g., Crowe, 1998; Sanchez-Cubillo et al., 2009; but also see Salthouse, 2011). Table 1 with intercorrelations between predictors showed that attention-switching control was indeed related to the working memory measure in our young sample. The two memory measures (digit span backward and spatial STM) were not predictive of nonword performance, however, nor did they modify the neighborhood size effect. In the Introduction, we argued that individual differences in working memory may relate to perceptual identification performance and to the size of the neighborhood/phonotactic probability effect. This prediction followed both from the Vitevitch and Luce (1999) model and from accounts of nonword recall (Gathercole et al., 1999; Roodenrys & Hinton, 2002; Thorn & Frankish, 2005). However, we found performance on the Trail Making Task to be predictive, rather than that on memory measures; given this, what aspect of Trail Making actually relates to auditory identification of nonwords?

High-probability/density nonwords were argued to be easier to identify than low-probability/density nonwords as lexical knowledge influences the strength of the nonword's temporary auditory representation through spreading of activation from the lexical representation to the elements of the temporary representation (sounds or sound sequences) (Roodenrys & Hinton, 2002). Having multiple lexical neighbors thus *facilitates* perceptual identification, and hence, there seems to be no need to switch among alternative representations for nonword identification, an act which could be problematic for those with poorer attention-switching control. Yet, participants with poor attention-switching control may find it difficult to focus their attention on transient representations such as auditorily presented nonwords, particularly in an experimental setting which requires that participants focus on a different nonsensical item on every trial. Some support for the idea that controlling the focus of attention might play a role in perceptual identification can also be seen in the interaction between trial and attention-switching control in Study 1: listeners generally improve over trials, but this is more so for listeners with poorer attention-switching control. Further evidence that attention-switching control helps in identifying unfamiliar-sounding stretches of speech comes from Adank and Janse (2010) who found that participants with better attention-switching control were better at comprehension of speech spoken in an unfamiliar accent. It may be easier to focus attention on a novel or unfamiliar item if it activates and receives support from similar-sounding neighbors, such that participants with poorer attention-switching abilities particularly benefit.

These results on nonword identification complement the earlier observation of a link between lexical recognition and inhibitory abilities (as measured by a Stroop color-naming paradigm) in Sommers and Danielson (1999) and Taler et al. (2010). In their studies, individual inhibitory abilities correlated with identification performance for "hard" words with many neighbors. This strengthens the idea that spoken-word recognition depends on a mechanism of lexical competition, and that the recognition system of those with poorer executive control seems to have more trouble overcoming this competition when many word candidates are activated. Importantly, our measure of selective attention (or inhibitory control, as it measures the participant's ability to ignore distraction from the flanking symbols) did not relate to neighborhood density effects in nonword identification, underlining that neighborhood similarity plays a different role in word recognition than in identification of nonwords. In nonword identification, where having more similar-sounding neighbors *facilitates* identification, those with poor executive control show enlarged neighborhood effects: the lexical neighbors do not compete, but jointly strengthen the nonword's transient representation in working memory. Thus, executive control relates to the individual's ability both to recognize words and to identify nonwords, but does so through different mechanisms and through different aspects of executive control. It remains unclear why the interaction between attention-switching control and similarity neighborhoods was not found for the older adults, however.

Inclusion of the older adult group enabled us to investigate whether individual hearing sensitivity interacted with high-probability/density effects on identification. Our results showed that the neighborhood density effect on nonword identification was increased with more hearing loss, as had been found for lexical discrimination by Taler et al. (2010). Dirks, Takanayagi, Moshfegh, Noffsinger, and Fausti (2001) specifically investigated whether the basic claims of the Neighborhood Activation Model (Luce & Pisoni, 1998) could be extended to listeners with sensorineural hearing loss. Even though they reported effects of neighborhood density, neighborhood frequency, and item frequency on word identification for listener groups with and without hearing loss, Dirks et al. (2001) did not report statistics on interactions of these effects with listener group, apart from the note that the performance difference between the easiest and most difficult items was somewhat larger for the hearing-impaired subjects (20%) than for the normal-hearing subjects (15%). It makes sense, however, that when the input signal is degraded as a result of hearing loss, the search for the best match between input and representation in lexical discrimination is complicated by even larger numbers of lexical competitors. Unclear input may in itself yield more competition among alternatives, which is aggravated with items from dense neighborhoods (cf. also Rönnberg et al., 2011, for a discussion of how hearing loss may relate to phonologically mediated abilities). Likewise, an unclear input signal may induce a stronger reliance on wordlikeness in processing nonwords. Hearing loss weakens the strength of the nonword's temporary representation, and support from the lexicon then helps to strengthen this representation by spreading of activation. When the input signal is unclear due to hearing loss, any type of activation from long-term knowledge representations to cling onto is particularly required.

Our results thus suggest that individual differences play a role at the lexical neighborhood level, and not at the phonological level. One could then argue that the phonotactic probability effects may be unaffected by other (cognitive) components. A more likely account, however, may be that this relates to the fact that phonotactic effects observed here were weak in the first place, perhaps due to a specific choice of items.

The measure of processing speed administered in the older population was also predictive of individual performance, but it did not interact with item characteristics. Processing speed may thus affect perceptual identification not only if speech rate is fast (Janse, 2009), but even when participants receive only one nonword at a time, produced in isolation, and spoken at a relatively slow rate. This may have implications for the assessment of speech-related hearing abilities in older adults, which often involves single-word presentation.

As expected, talker variability affected identification performance: both studies show generally poorer performance when talkers changed from trial to trial. However, none of the individual abilities predicted the relative difficulty listeners had with talker variability. This is in line with the results of Sommers (1998) who did not find predictors for performance in a mixed-talker condition either, despite the fact that the older adults in his study performed a rather extensive battery of cognitive tests. More sensitive measures of language processing may be needed to pinpoint the cognitive processes underlying talker normalization.

Summing up, these results extend the literature on individual differences in spoken-word recognition to item and listener effects in nonword identification. Individual differences studies provide insight into the ecological validity of models of language processing (cf. McMurray, Samelson, Hee Lee, & Tomblin, 2010; and Andrews & Hersch, 2010, on reading), and may offer directions to further specify these models so that differences between language users follow more evidently from them.

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