Spoken word recognition in listeners with mild dementia symptoms

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Abstract

Background

Difficulty understanding speech is a common complaint of older adults. In quiet, speech perception is often assumed to be relatively automatic. In background noise, however, higher-level cognitive processes play a more substantial role in successful communication. Cognitive resources are often limited in adults with dementia, which may therefore hamper word recognition.

Objective

The goal of this study was to determine the impact of mild dementia on spoken word recognition in quiet and noise.

Methods

Participants were adults aged 53–86 years with (n=16) or without (n=32) dementia symptoms as classified by a clinical dementia rating scale. Participants performed a word identification task with two levels of neighborhood density in quiet and in speech shaped noise at two signal-to-noise ratios (SNRs), +6 dB and +3 dB. Our hypothesis was that listeners with mild dementia would have more difficulty with speech perception in noise under conditions that tax cognitive resources.

Results

Listeners with mild dementia had poorer speech perception accuracy in both quiet and noise, which held after accounting for differences in age and hearing level. Notably, even in quiet, adults with dementia symptoms correctly identified words only about 80% of the time. However, phonological neighborhood density was not a factor in the identification task performance for either group.

Conclusion

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1 These results affirm the difficulty that listeners with mild dementia have with spoken word
2 recognition, both in quiet and in background noise, consistent with a key role of cognitive
3 resources in spoken word identification. However, the impact of neighborhood density in
4 these listeners is less clear.

5 **MeSH Keywords (4-10):** speech intelligibility, word processing, cognition, hearing,
6 dementia

Introduction

For listeners with good hearing, the experience of understanding speech in quiet often feels relatively automatic. However, when the speech signal is acoustically challenging—for example, due to hearing loss or background noise—successful understanding requires a greater engagement of higher-level cognitive abilities (Dryden, Allen, Henshaw, & Heinrich, 2017; Rönnberg et al., 2013; Tun, Williams, Small, & Hafter, 2012; Wingfield, Tun, & McCoy, 2005). Interactions between hearing and cognitive ability have thus been increasingly at the forefront of hearing science research.

Age-related hearing loss is common, having an estimated prevalence in the United States of 49% in adults 60-69 years (Agrawal, Platz, & Niparko, 2008) and 63.1% for adults 70 years and older (Lin et al., 2011). It is well understood that declines in hearing sensitivity negatively impact speech understanding in several ways, including reduced audibility (how well someone is able to hear a speech signal) and changes to both spectral and temporal processing (Schneider, Daneman, & Pichora-Fuller, 2002). Additionally, environmental conditions (such as listening in reverberant settings or background noise) may further degrade and corrupt the signal received by the central auditory system (Humes, 1996).

Recent research continues to find that these types of acoustic challenges force listeners to engage additional cognitive resources when listening to speech (Peelle, 2018). Expending cognitive resources at this early stage of listening subsequently reduces the availability of those cognitive resources for additional processing, such as encoding the spoken information into memory (Heinrich & Schneider, 2011; Koeritzer,

1 Rogers, Van Engen, & Peelle, 2018; McCoy et al., 2005; Piquado, Cousins, Wingfield, &
2 Miller, 2010; Rabbitt, 1968; Ward, Rogers, Van Engen, & Peelle, 2016). Consistent with
3 these behavioral findings, an increasing number of functional brain imaging studies
4 have associated acoustic challenge with increased activity in the frontoparietal and
5 cingulo-opercular executive attention networks (Davis & Johnsrude, 2003; Lee et al.,
6 2018; Vaden et al., 2013; Vaden et al., 2016; Vaden, Matthews, Eckert, & Dubno, 2017;
7 Wild et al., 2012).

8 A useful perspective on the challenges of spoken word recognition come from
9 lexical competition models, which conceptualize word recognition as involving
10 competition between candidate (Gaskell & Marslen-Wilson, 2002; Luce & Pisoni, 1998;
11 Marslen-Wilson & Welsh, 1978; Norris & McQueen, 2008). The Neighborhood
12 Activation Model (NAM), for example, accounts for the ways in which the structure of
13 the mental lexicon, or the representation of words in memory, will affect the way a
14 listener processes and maps the phonological input of the words they hear (Luce &
15 Pisoni, 1998). Like other activation-competition models, the NAM proposes that as a
16 listener hears a spoken word, activation of the target word occurs simultaneously with
17 activation of competitor words in its similarity neighborhood. Previous studies have
18 shown that target words with dense, high frequency neighborhoods (i.e., frequently-
19 encountered words with many similar sounding competitors) are identified more slowly
20 and less accurately whereas words with sparse, low frequency neighborhoods are
21 identified more quickly and accurately (Luce & Pisoni, 1998; Sommers, 1996; Sommers,
22 1998; Sommers & Danielson, 1999; Taler, Aaron, Steinmetz, & Pisoni, 2010).

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1 In addition to increased difficulty for specific combinations of word frequency and
2 neighborhood density, neighborhood density (words from dense versus sparse
3 neighborhoods) itself has been shown to have an effect on word identification
4 independent of word frequency (Sommers, 1996; Sommers & Danielson, 1999). That is,
5 a word that sounds similar to many other words (for example, the target word “cat” has
6 competitors “cap”, “can”, “hat”, and so on) requires greater involvement in selection
7 (given the many competing alternatives) and/or inhibition of competitors in order to
8 correctly select the target. The effects of neighborhood density on spoken word
9 recognition have been shown to be more pronounced for older adults as compared to
10 young adults (Sommers, 1996; Sommers & Danielson, 1999; Taler et al., 2010) and for
11 older adults with cognitive decline as compared to healthy aging adults independent of
12 peripheral hearing sensitivity (Sommers, 1998). Furthermore, Sommers (1998) showed
13 that while overall performance on a lexical decision task in quiet was worse for
14 individuals with dementia than for cognitively normal peers, this effect was driven by
15 performance on “lexically hard” words. Listeners with reduced cognitive capacity may
16 find words with many phonological neighbors to be particularly problematic.

17 Thus, prior research on spoken word recognition broadly supports an important
18 role for cognition in understanding speech in noise, when the speech signal is degraded
19 (through background noise or hearing loss), and for words with many competitors.
20 Given the cognitive changes frequently associated with many forms of dementia,
21 including Alzheimer disease (AD) dementia, it is perhaps surprising that relatively few
22 studies have investigated simple word recognition in listeners with mild dementia while
23 carefully controlling for hearing ability. In the current study, we used a spoken word

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identification task to examine spoken word recognition in older adults with and without dementia symptoms. We use spoken word recognition as a window to examine the role of cognitive processes during speech perception, focusing on understanding speech in noise and the effects of phonological neighborhood density. Importantly, we use well-validated clinical measures to identify hearing status to determine the contribution of hearing ability to an individual's ability to correctly identify spoken words in quiet and background noise. We hypothesized that individuals with mild dementia (and thus reduced cognitive ability compared to cognitively normal peers) would have greater difficulty identifying words in conditions that require increased cognitive resources, particularly understanding speech in noisier listening conditions. Because identification of words with sparse phonological neighborhoods does not require the same degree of cognitive engagement as identifying words from dense neighborhoods, we expected to see similar performance for sparse words between listeners with normal cognitive function and mild dementia.

Materials and Methods

Raw data and analysis scripts are available at <https://osf.io/k72su/>.

Participants

The research protocol was approved by the Washington University in Saint Louis Institutional Review Board. Participants were recruited from the Charles F. and Joanne Knight Alzheimer Disease Research Center (ADRC) at Washington University in Saint Louis. Dementia symptoms for each participant was categorized using the Clinical Dementia Rating (CDR©) Dementia Staging Instrument (Hughes, Berg, Danziger, Coben, & Martin, 1982; Morris, 1993) which uses a five-point scale to classify

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individuals as normal (0), very mild (.5), mild (1), moderate (2), or severe dementia (3). Individuals with a CDR of 0, 0.5, and 1 were recruited for this study. All participants were native speakers of English with no additional diagnosed neurological disorders. A total of 48 participants aged 53-86 years ($M=74.7$; $SD=6.0$) took part in this study, 32 (18 women) CDR 0, 16 (8 women) CDR 0.5-1. Participants with CDR 0.5 and 1 were combined into a mild dementia group.

Procedure

Hearing Assessment

Participants completed a comprehensive audiometric assessment, including otoscopy and tympanometry to confirm normal outer and middle ear status, pure tone air (octave intervals from 250-8000 Hz) and bone conduction thresholds (octave intervals from 500-4000 Hz), using a validated procedure (McClannahan, Chiu, Sommers, & Peelle, 2021).

Stimuli

Speech materials consisted of 240 monosyllabic words spoken by a single male speaker. We used each word's neighborhood density from the English Lexicon Project (Balota et al., 2007) to characterize each item as coming from a phonological neighborhood that is either sparse (few phonological neighbors, easier to recognize) or dense (many phonological neighbors, more difficult to recognize). The sparse words had an average neighborhood frequency of 7.21 occurrences per million and an average neighborhood density of 5.35. The dense words had an average neighborhood frequency of 8.63 occurrences per million and an average neighborhood density of 28.6. The average log target word frequency was 2.93 for sparse and 3.17 for dense words

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(Brysbaert & New, 2009). A total of 40 sparse and 40 dense words, were presented at 75 dBC SPL using a HSC271 Over-Ear Headset and AudioQuest DragonFly v1.5 amplifier, in three noise conditions: in quiet, +6 dB SNR, and +3 dB SNR. Speech-in-noise stimuli were created by adding speech shaped noise to individual sound files. Stimuli included 500 ms of noise before and after each word (using *jp_addnoise.m* available from http://github.com/jpeeelle/jp_matlab). Words were presented in the same order for all participants.

Task Procedure

The word identification task was presented on a laptop computer using E-prime Version 2 (Psychology Software Tools, Pittsburgh, USA). Instructions for the task were presented both orally and in writing. To initiate each trial, the participants were instructed to press any button on the keyboard, at which time they saw the prompt “LISTEN.” The target word was presented after a 500 ms delay. The participant was then cued to repeat the word, out loud, when they saw a “*****” prompt. If the participant was unsure of the word, they were instructed to provide their best guess. Participants were allowed breaks in between trials when needed. The task included five practice trials for each condition. Word identification accuracy was scored manually by the test administrators. Responses were counted as correct only if they were identical to the target word. An audio recording for each session was reviewed to verify scoring accuracy.

Data Analysis

We analyzed data using R version 3.6.0 (R Core Team, 2020).

Data were checked to determine that no statistical assumptions were violated. Hearing sensitivity was quantified as the better ear 4-frequency (.5, 1, 2 and 4 kHz) pure tone average for each participant. Group level differences in hearing sensitivity and age were assessed using *t*-tests.

Performance on the spoken word identification task was analyzed using a generalized linear mixed-effects model with a logit link function in the R package *lme4* (Bates, Mächler, Bolker, & Walker, 2015) to determine how cognitive status, phonological neighborhood density, and signal-to-noise ratio contributed to word identification accuracy. Fixed effects included in the model were age, hearing sensitivity, neighborhood density (sparse, dense), noise level (quiet, +6 SNR, and +3 SNR), and group (control, mild dementia), and interaction terms. Individual word items were entered into the model as random intercepts to account for variability in how accurately individual word items were identified. Participants were entered as a random intercept to account for variability in individual response accuracy as well as the neighborhood density by participant random slope, to account for differences in the direction or magnitude of the neighborhood density effect on a participant-by-participant basis.

Results

Model selection

A lower order model was built with five fixed effects of interests: age, hearing threshold, neighborhood density, SNR, and group. Two-way and three-way interactions of interests were then added, including neighborhood density $\times$ group, SNR $\times$ group, neighborhood density $\times$ SNR, and neighborhood density $\times$ SNR $\times$ group, which represented our central hypothesis. A likelihood-ratio test indicated that the model

including the three-way interaction (neighborhood density $\times$ SNR $\times$ group) did not provide a better fit for the data than a model without it ($\chi^2(2) = 0.12, p = 0.94$) and it was removed from the final model.

Likelihood-ratio tests indicated that a model including the SNR $\times$ group interaction term provided a better fit for the data compared to a model without it ($\chi^2(2) = 37.12, p < 0.001$), however, neither the neighborhood density $\times$ group nor the neighborhood density $\times$ SNR interaction term improved model fit. Therefore, our final model included the five fixed effects (age, hearing threshold, neighborhood density, SNR, and group) and the SNR $\times$ group interaction term. The lower order model, with all interaction terms removed, was used to interpret the main effects of SNR and group.

Age and Hearing Sensitivity

Groups did not differ in mean age ($t(46) = 0.66, p = 0.51$). Participants' hearing sensitivity ranged from normal hearing to a severe hearing loss in the better ear. Individual and group mean air conduction thresholds are displayed in **Figure 1**. Groups were significantly different in better ear PTA ($t(46) = -2.20, p = .03$), with the dementia group (mean = 36.8, SD = 15.0) having significantly poorer hearing sensitivity than the control group (mean = 28.3, SD = 11.3).

Word Identification Task Performance-Mixed Effects Modeling

Prior to analysis we removed 2 participants, one from each group, because their better ear PTA was above 60 dB HL, which resulted in insufficient audibility of the task stimuli. This reduced our sample size to 46 for all subsequent analyses. **Figure 2** shows percent correct performance on the word identification task. Our final mixed-effects

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model (**Table 1**), previously described, predicted the probability of a correct response on the word identification task.

Analyses revealed that the effects of age and hearing sensitivity, but not neighborhood density, were significant (**Figure 3**). Hearing sensitivity significantly contributed to the total variance in word identification accuracy. More specifically, a one decibel increase in better ear PTA decreased the odds of correctly identifying a target word by a multiplicative factor of 0.92 ($\beta = -0.08$, $SE = 0.01$, $z = -9.78$, $p < 0.001$), with other variables fixed. Age also had a significant effect on word identification accuracy. For every one year increase in age the odds of identifying a target word decreased by a multiplicative factor of 0.94 ($\beta = -0.06$, $SE = 0.02$, $z = -4.01$, $p < 0.001$), with other variables fixed.

Group and SNR had the largest effects on accuracy. Compared to words presented in quiet, the odds of correctly identifying a target word decreased by a multiplicative factor of 0.12 in the +6 dB SNR ($\beta = -2.09$, $SE = 0.25$, $z = -8.52$, $p < 0.001$) and a multiplicative factor of 0.08 in +3 dB SNR ($\beta = -2.57$, $SE = 0.24$, $z = -10.51$, $p < 0.001$) conditions (**Table 2**), with other variables fixed. Analysis of the group effect revealed that the odds of correctly identifying a target word is decreased by a multiplicative factor of 0.39 for the mild dementia group ($\beta = -0.93$, $SE = 0.19$, $z = -4.83$, $p < 0.001$) when referenced to the control group (**Table 2**) and other variables fixed.

The significant SNR $\times$ group interaction (**Table 1**), indicated that the effect of noise varied by group status. Specifically, and counter to our expectations, the change from quiet to noise resulted in a lesser detriment to task performance for the dementia

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group compared to the control group for both the +6 dB SNR ($\beta = 1.10$, $SE = 0.18$, $z = 6.11$, $p < 0.001$) and +3 dB SNR conditions ($\beta = 0.79$, $SE = 0.18$, $z = 4.42$, $p < 0.001$).

Discussion

In this study we examined how mild dementia affects spoken word recognition. Our results indicate that listeners with mild dementia symptoms had more difficulty with word identification than did cognitively normal controls both in quiet and at all noise levels. Counter to our predictions, however, we did not find an effect of phonological neighborhood density on word identification accuracy, and listeners with mild dementia were less affected by increases in background noise than were controls. We discuss these findings in detail below.

Prior studies have shown that listeners with dementia have more difficulty with spoken word recognition than controls (Sommers, 1998), typically suggested to be because of the cognitive problems associated with dementia (e.g., executive function deficits). For example, Marshall and colleagues (1996) used a gating paradigm (Grosjean, 1980) to investigate lexical competition in a group of listeners with AD dementia. Participants with AD dementia performed significantly worse on the word identification task than did controls, including taking longer (i.e., a greater number of gates) to identify a cohort once the first phoneme had been identified. Our own results are consistent with this prior work, with listeners with mild dementia showing substantially poorer word recognition accuracy in quiet (~81% correct) than controls (~96% correct). Because we controlled for hearing loss in groups through a comprehensive audiological assessment and inclusion in our model, we attribute these group differences to cognitive deficits in the listeners with mild dementia.

1 While we anticipated performance for both groups to be significantly affected by
2 noise, and for the control group to outperform the group with mild dementia, we
3 hypothesized that noise would have a larger negative effect on performance for the mild
4 dementia group due to the greater cognitive demands of listening to speech in noise,
5 coupled with the reduced cognitive ability in this group. Instead, we found that word
6 recognition accuracy was more affected by noise in our control sample. To some
7 degree, this effect can be explained by the listeners with mild dementia performing
8 significantly worse in quiet, thus having less “room” to reflect the challenge of noise,
9 compared to the control group. However, the explanation is not fully satisfying, because
10 even in the hardest condition, identification accuracy is still around 50%, which is
11 significantly above chance for open-set identification (that is, there is no “chance”
12 performance). In that sense, the listeners with mild dementia are performing better-than-
13 expected in the most difficult SNR condition. We do not have a ready explanation for
14 this provocative finding and further investigation is warranted.

15 Prior studies examining the added impact of noise on speech understanding in
16 listeners with mild dementia are mixed. Mamo and Helfer (2021) examined auditory
17 sentence processing in listeners with diagnosed or suspected mild cognitive impairment
18 (MCI) or AD dementia in quiet and background noise. They found poorer performance
19 for listeners with MCI and AD compared to neurologically healthy age- and hearing-
20 matched controls, consistent with our results. Other studies, however, have reported
21 decrements in speech perception for adults with cognitive difficulties emerging only after
22 the introduction of background noise (Jalaei et al., 2019; Lee, Park, Kim, & Kim, 2018).
23 Differences across studies are likely due to various methodologies used to assess word

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1 recognition, different ways of determining cognitive status, and whether audibility of task
2 stimuli and participant hearing status were taken into account. The emerging
3 consensus, however, is that people with AD have difficulty with speech perception, even
4 when no background noise is present.

5 In our study, hearing sensitivity played a significant role in spoken word
6 identification accuracy: listeners with poorer hearing performed worse on spoken word
7 identification. This is not surprising, given the known effects of hearing loss on speech
8 perception accuracy (see recent review: Slade, Plack, & Nuttall, 2020). It is important to
9 note that once better ear hearing sensitivity was accounted for, the group differences in
10 performance persisted: listeners with mild dementia had worse word identification
11 scores than listeners in the control group. Furthermore, the effect of hearing sensitivity
12 was smaller than that of noise and group membership. Thus, for our sample of older
13 adults, group differences in accuracy were influenced, but not primarily driven, by the
14 greater hearing loss in the listeners with mild dementia.

15 Interestingly, we did not find a significant effect of neighborhood density on
16 spoken word identification, for either group. The lack of a density effect does not
17 necessarily mean words from dense neighborhoods were not more difficult: even when
18 identification accuracy is high, pupillometry shows greater cognitive effort associated
19 with recognizing words from dense neighborhoods compared to sparse neighborhoods
20 (McLaughlin et al., 2021). It may be that accuracy effects on spoken word recognition
21 would emerge under more difficult SNR conditions. However, given our current results,
22 it seems that neighborhood density plays, at most, a small role in word recognition

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1 accuracy, compared to the relatively large effects of cognitive status, hearing ability, and
2 background noise.

3 From a practical perspective, we find it noteworthy that listeners with mild
4 dementia were unable to recognize ~20% of the words they heard in quiet. Single words
5 recorded in isolation do not benefit from acoustic or linguistic context, but they are also
6 typically more clearly produced than when in the context of sentences and do not suffer
7 from the co-articulation effects present in connected speech. We envision an awareness
8 of the speech perception challenges in adults with dementia—which cannot be
9 explained by peripheral hearing difficulty—to be useful in coaching conversation
10 partners, such as family members and clinicians, in effective communication strategies
11 For example, being mindful to speak clearly, slowly, and distinctly, face the listener to
12 provide eye-contact and facial cues, and schedule important conversations when the
13 listener is at their best (i.e., not at the end of a long day) will improve speech
14 understanding for all listeners, but may be particularly important for listeners with
15 dementia.

16 The difficulty individuals with dementia symptoms have with spoken word
17 recognition is also critical to consider in the context of assessment. Difficulties with
18 sensory processing have long been appreciated to affect estimates of cognitive function
19 (Dupuis et al., 2015; Füllgrabe, 2020; Parada, Hillyer, & Parbery-Clark, 2020; Toner et
20 al., 2012; Whitson et al., 2018). For example, if a patient mis-hears instructions, they
21 may fail to complete a test properly; or, on a verbal memory test, mishearing one of the
22 presented items will prevent it from being accurately recalled when later tested.
23 Ensuring audibility of assessment items is critical but does not fully address the issue: in

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1 our data, word recognition deficits persisted in people with mild dementia symptoms,
2 even after controlling for hearing. Thus, cognitive deficits that hinder speech recognition
3 may lead to inaccurate estimates of cognitive function.

4 In conclusion, our results support the fact that listeners with mild dementia
5 symptoms are likely to have difficulties understanding spoken words, even in quiet.
6 Paradoxically, noise may not have a differential effect, though this may be due to poorer
7 performance in quiet. A clearer understanding of individual differences in specific
8 auditory and cognitive abilities may help further clarify reasons for the significant
9 individual variability observed in all listeners.

10

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Conflict of Interest

The authors have no conflict of interest to report.

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Figure 3. Correlations of age and better ear pure tone average (PTA) with word identification accuracy for controls and participants with mild dementia symptoms. Correlation values are listed for bivariate correlations, but we interpret the significance of these effects in the context of our full model.

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Tables

Table 1. Final Model. Effects of Age, Hearing, and Dementia on Word Identification

Fixed Effects	Estimate (<i>odds</i>)	Standard Error	Z-Value	Pr(> z)
Intercept	11.40	1.15	9.93	< .001 ***
Age	-0.06 (0.94)	0.01	-4.01	< .001 ***
Hearing Threshold	-0.08 (0.92)	0.01	-9.78	< .001 ***
Neighborhood Density – Dense	-0.23 (0.79)	0.20	-1.19	0.23
+3 SNR	-3.07 (0.05)	0.27	-11.40	< .001 ***
+6 SNR	-2.72 (0.07)	0.27	-10.05	< .001 ***
Dementia Group	-1.72 (0.18)	0.24	-7.17	< .001 ***
+3 SNR: Dementia Group	0.79 (2.21)	0.18	4.42	< .001 ***
+6 SNR: Dementia Group	1.10 (3.01)	0.18	6.11	< .001 ***

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Table 2. Lower Order Model. Effects of Age, Hearing, and Dementia on Word Identification

Fixed Effects	Estimate (<i>odds</i>)	Standard Error	Z-Value	Pr(> z)
Intercept	10.88	1.14	9.58	< .001 ***
Age	-0.06 (<i>0.94</i>)	0.01	-4.01	< .001 ***
Hearing Threshold	-0.08 (<i>0.92</i>)	0.01	-9.86	< .001 ***
Neighborhood Density – Dense	-0.24 (<i>0.79</i>)	0.20	-1.20	0.23
+3 SNR	-2.57 (<i>0.08</i>)	0.24	-10.51	< .001 ***
+6 SNR	-2.09 (<i>0.12</i>)	0.25	-8.52	< .001 ***
Dementia Group	-0.93 (<i>0.39</i>)	0.19	-4.83	< .001 ***