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Research Article

Age-Related Differences in Speech Rate Perception Do Not Necessarily Entail Age-Related Differences in Speech Rate Use

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Purpose: A new literature has suggested that speech rate can influence the parsing of words quite strongly in speech. The purpose of this study was to investigate differences between younger adults and older adults in the use of context speech rate in word segmentation, given that older adults perceive timing information differently from younger ones.
Method: Younger (18–25 years) and older (55–65 years) adults performed a sentence transcription task for sentences that varied in speech rate context (i.e., distal speech rate) and a syntactic cue to the presence of a word boundary.
Results: There were no differences between younger and older adults in their use of the distal speech rate cue to word segmentation.
Conclusions: The differences previously documented between younger and older adults in their perception of speech rate cues do not necessarily translate to older adults' use of those cues. Older adults' difficulties with compressed speech may arise from problems broader than just speech rate alone.

Timing perception in older adults has been shown to differ from that of younger adults in a wide variety of rate-related phenomena. Older adults seem to gravitate toward more slowly timed intervals when estimating durations, measuring out isochronous beats, or performing other simple time-related tasks (Block, Zakay, & Hancock, 1998; Craik & Hay, 1999; Wearden, 2005). This preference gets stronger across the lifespan, though it is not yet clear whether the transition between fast and slow timing preference is gradual or abrupt (McAuley, Jones, Holub, Johnston, & Miller, 2006; McCormack, Brown, Maylor, Darby, & Green, 1999). Various explanations have been put forward for these phenomena, such as age-related changes in attentional or more general cognitive capacities (Lustig, 2003; Vanneste & Pouthas, 1999; Wearden, Wearden, & Rabbitt, 1997) or more domain-specific properties (Pichora-Fuller, 2003). Regardless, these differences in timing perception cut across many domains.

One focus of timing research has been the influence of aging on language processing. Some research has examined lexical properties of language; for example, the speed of lexical indexing, as illustrated through difficulties with the tip-of-the-tongue phenomenon (Burke, MacKay, Worthley, & Wade, 1991). However, a large and growing literature has focused on the perception of the speech signal itself and, in particular, on listeners' processing of speech rate. Peelle and Wingfield (2005) had undergraduates and older adults recall rate-compressed sentences after a single presentation during an adaptation period, which was followed in some experiments by a transfer period in which listeners had to do the same task for sentences presented at a different (but still compressed) rate. Recall accuracy, as measured by the accuracy of content word transcriptions for the sentences, did not differ between the groups during the initial stages of an adaptation period. Despite this, younger adults, but not older adults, were able to transfer some of the gains from the adaptation period to the transfer period, and continued improving on their recall performance even after the first few trials. Peelle and Wingfield suggested that rate compression may be more problematic in

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speech processing for older adults than younger adults. Older listeners seem to be particularly challenged by compression of consonantal materials, with difficulties perhaps stemming from the brief and acoustically rich acoustic information that characterizes consonants (Gordon-Salant & Fitzgibbons, 2001; Gordon-Salant, Fitzgibbons, & Friedman, 2007). Older adults' difficulties with understanding speech in noise are well correlated with their difficulties in understanding compressed speech (Versfeld & Dreschler, 2002), though speech rate contrasts may provide a convenient way to disentangle an attended speech stream from the acoustic background (Gordon-Salant & Fitzgibbons, 2004). In turn, these challenges with processing of signal-based information may have consequences for cognitive processing (Baltes & Lindenberger, 1997).

Other researchers have focused on the use of syntactic and semantic context in determining percepts: Older adults may compensate for their problems with acoustic information by relying more heavily on knowledge-based information from the syntactic and semantic context (Pichora-Fuller, 2009). For example, Wingfield, Tun, Koh, and Rosen (1999) found that older listeners were aided in making sense of compressed speech when pauses were included specifically at linguistic boundaries, where syntactic information may be particularly salient, rather than at other locations within a sentence. Abada, Baum, and Titone (2008) noted that older listeners used semantic context more than younger listeners when disambiguating the voicing of ambiguous stop consonants. Older adults are much more susceptible than younger adults to showing misplaced confidence in top-down contextual information for both "false seeing" and "false hearing" paradigms. They often allow context cues to guide their use of visually primed information on subsequent recall (Jacoby, Rogers, Bishara, & Shimizu, 2012) or auditorily primed information on lexical discrimination (Rogers, Jacoby, & Sommers, 2012). Although this can be beneficial when the context correctly indicates the correct response, it can be detrimental if the context is misleading.

Understanding the speech signal depends on a wide variety of component processes beyond adjusting for speaking rate and semantic and syntactic integration. For instance, listeners must also parse the speech stream into words, a process known as word segmentation. Numerous studies have found that the perception of word boundaries is not signaled by any single, invariant acoustic cue; instead, cues combine to trigger the perception of word boundaries (Cole, Jakimik, & Cooper, 1980; Lehiste, 1960, 1964; Nakatani & Dukes, 1977). As a result of this weighting of multiple cues, segmentation can be affected both by speaking rate and by semantic and syntactic integration, suggesting that it may likewise be affected by aging.

Word segmentation is a particularly interesting test case concerning the effects of aging on speech perception because of a recently developed, rate-linked literature regarding what have been termed distal prosodic effects on word segmentation. These effects were first investigated by Dilley and McAuley (2008), who used ambiguous syllabic sequences, such as *chocolate lyric down town ship wreck*. The last four syllables of such sequences could either be parsed as *downtown shipwreck* or *down township wreck*, depending on the placement of word boundaries within the sequences. Dilley and McAuley (2008) kept the pitch and rate information of the last three syllables (*town ship wreck*) constant while manipulating the patterns in previous syllables (*chocolate lyric down*), and found that listeners were sensitive to the patterns of rate and pitch information in the first five syllables, using the information found in the first syllables to guide their parsing of the last three syllables.

More recent studies have suggested that these effects can also be found in more naturalistic speech. Dilley and Pitt (2010) investigated distal prosodic effects on word segmentation using sentence fragments, such as *John said he would obey a rebel*. In casual speech, *a* is often pronounced as an unstressed [ə] (i.e., like the first syllable in *about*), and is frequently coarticulated with (produced overlapping in time with) the vowel at the end of the word *obey*. These factors lead to acoustic ambiguity to the presence of a word boundary signaling the presence of *a* (i.e., the fragment above could be heard as *obey a rebel* or *obey rebel*). Dilley and Pitt (2010) exploited this ambiguity by looking for effects of speech rate context on the segmentation of *a* and similar acoustically ambiguous function words. They slowed down the speech rate of earlier syllables (those more than one syllable removed from the ambiguity; i.e., *John said he would o-*) and assessed how often participants transcribed the acoustically ambiguous function word *a* between *obey* and *rebel*. Participants were significantly less likely to report hearing a function word when the distal rate was slowed down (i.e., they were more likely to report *obey rebel* rather than *obey a rebel*).

It is crucial to note that this difference seemed to stem from a contrast between the distal rate and the rate of the sentence closer to the point of ambiguity, rather than the effects of rate manipulation more generally. The presence and strength of these effects has been verified across a variety of experiments. Distal rate effects have been shown variously to be more powerful than acoustic manipulations of nearby acoustic context (Heffner, Dilley, McAuley, & Pitt, 2013) and top-down syntactic cues (Morrill, Baese-Berke, Heffner, & Dilley, in press). Listeners seem to adapt over the course of an experimental session to the speech rates being presented within the session (Baese-Berk et al., 2014).

If older adults' differences in rate perception affect word segmentation, these differences could appear in studies of distal rate effects for older adults. Given the consistency of results finding differences in the perception of rate between older and younger adults, it is perhaps unsurprising that many studies have found that older adults weight the use of bottom-up cues less strongly than younger adults, as noted above (Helfer & Wilber, 1990; Pichora-Fuller, 2009; Versfeld & Dreschler, 2002; Wingfield et al., 1999). Given the differences in the perception of rate between younger and older adults and that segmentation can be strongly influenced by speech rate context, it seems plausible to think that older adults may use speech rate differently from younger adults when dealing with word segmentation.

If older adults find it more challenging to use speech rate context to segment words, what other cues might they use in lieu of speech rate? When possible, older adults use semantic and syntactic cues to a greater extent than younger adults when determining how to process a sentence (Abada et al., 2008; Jacoby et al., 2012; Pichora-Fuller, 2008; Rogers et al., 2012; Sheldon, Pichora-Fuller, & Schneider, 2008; Sommers & Danielson, 1999; Wingfield & Tun, 2007), perhaps taking advantage of their enhanced experience with their native language. Thus, older adults may downweight the signal-based cue of speech rate context, exploiting their knowledge of the language in determining how to parse sentences instead.

In this experiment, we systematically compared younger and older adults' use of both signal-based and knowledge-based information in word segmentation, focusing on the use of distal rate cues in determining the number of word boundaries. As the study of distal rate cues is relatively new, their effectiveness is largely untested in age groups other than young adults. Honing in on word segmentation in particular instead of on broader measures of accuracy could help in determining what aspects of speech recognition are challenged as a result of aging. Further, studying rate as a cue in and of itself to a phonetic contrast could help illustrate whether change in speech rate perception would entail change in the use of speech rate material. We hypothesized that older adults would use signal-based distal speech rate less than younger adults due to the differences in rate-related processing from younger adults.

We also predicted that older listeners would compensate for their decreased reliance on signal-based cues to word segmentation by increasing their use of knowledge-based information to parse the speech stream, in line with previously outlined experiments. As a knowledge-based cue, we manipulated a cue that we dubbed *syntactic obligatoriness*, in line with the cue of *syntactic well-formedness* manipulated in Morrill et al. (in press). All of the materials used in Dilley and Pitt (2010) and many of its follow-ups used lexical contexts that were essentially grammatically neutral to the existence of the critical word boundary. These contexts were frequently constructed by truncating off sentence-final lexical material. For example, *John said he would obey (a) rebel* was constructed from the full sentence *John said he would obey (a) rebel leader.* The first version of the sentence (*obey [a] rebel*) could be considered an optional context fragment, because the lack of sentence-final prosody means that perception of the word boundary signaling *a* is not necessary for the sentence to be perceived as syntactically well-formed; both *John said he would obey a rebel* and *John said he would obey rebel* could lead to the perception of a grammatical sentence. However, *John said he would obey (a) rebel leader*, with the word-final prosody implying that no further lexical material would be made accessible, can be considered an obligatory context sentence, as perception of *a* is required to perceive the sentence as grammatical (i.e., *John said he would obey a rebel leader* is grammatical, and *John said he would obey rebel leader* is not). Here, we predicted that older adults would rely on the cue of syntactic obligatoriness more than younger adults, as shown by higher critical word report rates for older adults than young adults in obligatory context sentence fragments.

Method

Participants

Forty-one participants (30 women, eight men, and three who did not indicate their gender) were recruited to participate in this experiment, including 21 younger participants and 20 older participants. For younger participants, we sought participants between the ages of 18 and 25 years. For older participants, we sought participants between the ages of 55 and 65 years. All but two younger participants (excluded in later analysis) were self-reported native monolingual English speakers. All participants self-reported normal hearing, except for one younger participant, who reported an auditory deficiency and was excluded from further analysis. Participants were also given brief hearing screenings, which were meant to assess whether hearing thresholds at octave frequencies between 250 Hz and 4000 Hz were greater than 20 dB. We excluded two older participants whose thresholds in their better ears were above 20 dB binaurally at frequencies lower than 4000 Hz, and a third who reported tinnitus. The remaining older adults showed evidence for fairly age-typical, or even decreased, rates of high-frequency hearing loss. Only 29% of participants in our study showed evidence of a hearing threshold higher than 20 dB at 4000 Hz, a rate lower than the 53% of adults aged 50–59 years with high-frequency hearing loss reported in one recent comprehensive study (Agrawal, Platz, & Niparko, 2008). One younger participant was also excluded due to problems caused by experimenter error. In total, this left 17 younger participants (ages: M = 19.9 years; range = 18–21 years) and 17 older participants (ages: M = 58.8 years; range = 55–65 years). All participants were recruited for class credit or monetary compensation at the University of Maryland, College Park. The methods used in this experiment were approved by the Institutional Review Board of the University of Maryland, College Park.

Materials and Design

The experiment had a 2 (syntactic obligatoriness: optional or obligatory) × 2 (distal rate: slowed or unmodified) × 2 (age: younger or older) mixed design. The stimuli from the experiment were adapted from materials created for Dilley and Pitt (2010) and were always syntactically obligatory in their full form. The particular sentence fragments selected here were chosen on the basis of the strength of the distal speech rate effect in pilot studies and the accuracy of participant responses in Dilley and Pitt (2010). A full list of stimuli in this experiment can be found in the Appendix.

Syntactic obligatoriness was manipulated using truncation of sentence-final lexical material to transform obligatory syntactic contexts into optional syntactic contexts.[1] The obligatory context fragment *John said he would obey (a) rebel leader* was transformed into the optional context fragment *John said he would obey (a) rebel* through truncation of the sentence final word *leader*. Both obligatory and optional versions of each sentence fragment were also manipulated to create versions with a slowed distal speech rate. The sentence fragments were split into a proximal region (the critical word, e.g., *a*, [ə]; the previous syllable, e.g., *-bey*, [bej]; and the following phoneme, e.g., *r-*, [ɹ]), as well as a distal region (the rest of the sentence, including both earlier and later portions). To create slowed distal rate sentence fragments, the duration of the distal context was increased to 175% of the duration of the original context. Distal rates were slowed using pitch-synchronous overlap and add (PSOLA) in Praat software (Boersma & Weenink, 2009). Figure 1 shows a sample sentence fragment, broken apart into distal and proximal regions, and showing which portion of the fragment would be truncated to create an optional context fragment version of the stimulus.

Procedure

Participants were randomly assigned to one of four lists of stimuli, with roughly equal numbers of younger and older adults across each list (six younger and older adults in one list, four in two of the others, and three participants in the last list). All four lists contained all 26 experimental items and 36 fillers and differed in which of the 26 experimental items were assigned to each combination of distal rate and syntactic obligatoriness. Every participant heard a version of each experimental item once. The fillers were balanced to closely approximate the experimental sentence fragments in syntactic obligatoriness, truncation, and distal speech rate manipulation.

All participants were tested in quiet rooms. Participants were instructed to type the entirety of each sentence fragment after hearing it. They were allowed to repeat sentence fragments as many times as desired before beginning transcription, though transcription could only be attempted once. Participants heard two of the filler fragments as practice trials. The experimental trials began with eight filler items, followed by a mix of experimental items and fillers in a single randomized order, identical across participants. The experiment was self-paced. Most participants took 10–15 min for their hearing screening and 20–25 min to complete the experiment, including a 30-s break administered midway through the trials.

Data Analysis

Participants' transcriptions of each experimental trial were used to compute a *critical word report rate*. The critical word report rate represented how often participants had heard a function word (such as *a*, *or*, *her*, or *the*) in the part of the sentence fragment with ambiguity to the existence of a function word, termed the critical region. For example, *John said he would obey a rebel leader* and *John said he would obey the rebel leader* are both instances of the example sentence fragment transcribed with a critical word. Trials in which the participant's transcription of the sentence fragment was inaccurate within the critical region on aspects of the transcription other than the presence of the function word were ignored. This removed trials in which the participants' transcriptions deviated too far from the originally intended utterance for the presence of a critical word to be determined; for example, it is unclear whether an older participant's transcription of the *rebel leader* sentence as *John said he would obey label* was transcribed as it was solely due to the distal rate manipulation in the context, or whether the participant may have misinterpreted the utterance more radically, given the misperceived segmental information in the critical region. Approximately 7.0% of trials for older participants and 2.8% of trials for younger participants were eliminated using this criterion, which is identical to criteria used in Baese-Berk et al. (2014) and Morrill et al. (in press).

Results

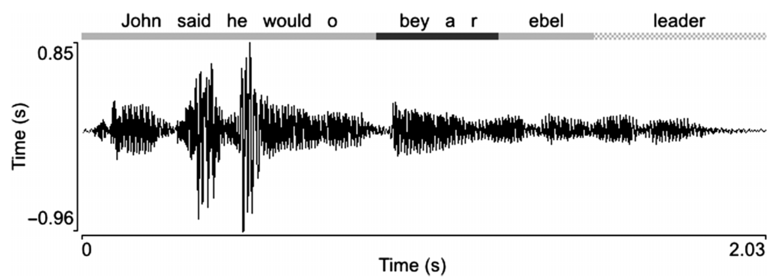
Figure 2 shows critical word report rates (i.e., the proportion of experimental sentences for which participants transcribed using a critical function word) as a function of age, distal rate, and syntactic obligatoriness. The set of data here was analyzed using model comparison of generalized linear mixed-effects models in the lme4 package (Bates, Maechler, Bolker, & Walker, 2013). The approach adopted was subtractive (see e.g., Barr, Levy, Scheepers, & Tily, 2013). In essence, we attempted to create the most fully specified model possible and then compared this fully specified model to models that subtracted some combination of these fixed effects and random slopes for each factor. Finding a significant difference in model fits between the less-specified model and the fully specified model indicated that the effects subtracted from the full model to create the less-specified model explained a significant amount of variation in the critical word report rates.

We first constructed a full model for this set of data, with all three fixed factors (age, distal rate, and syntactic obligatoriness) and their full interactions, random intercepts for participants and items, and random slopes by participant for distal rate and syntactic obligatoriness and by item for age and distal rate.[2] In other words, the full model

[1]Although truncation alone does have a limited effect on the distal rate effects discussed here (Heffner & Dilley, 2011), the effect sizes are smaller than those observed when the truncation changes the syntactic obligatoriness of the context. Further experiments are required to tease these effects apart.

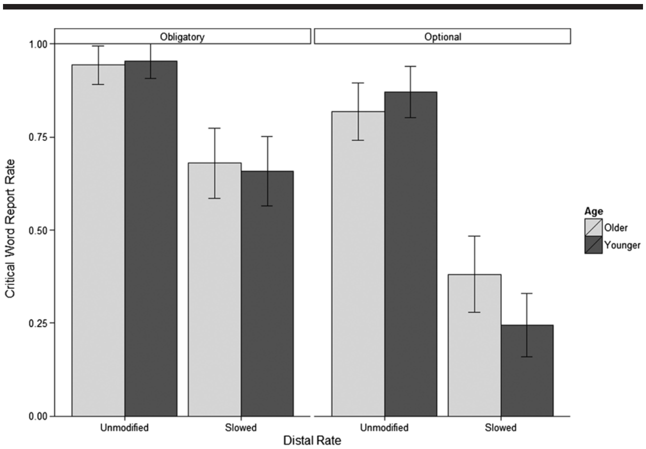
[2]Note that the linear mixed-effects modeling would not converge without eliminating the random slope by item for syntactic obligatoriness.

Figure 1. Waveform representations of a sample stimulus for our experiment. This particular fragment has a normal speech rate and has an obligatory context (i.e., is not truncated). The lines above the waveform indicate the extent of the distal (light gray) and proximal (dark gray) regions within the sentence fragment. The dotted light gray section at the end of the fragment delimits the region in the distal context that is truncated to create the optional context.



allowed for main effects of each of our three factors, interactions between them, and random variation by participant in the strength of the effects of distal rate and syntactic obligatoriness, as well as random variation by item for the effects of age and distal rate. We then constructed models that lacked some of these factors and random slopes. What we will call a "limited" model for each factor includes all random slopes and random intercepts of the full model but lacks the fixed effect for that factor. A significant difference between the full model and the limited model would indicate that there was a main effect of the subtracted fixed factor. What we will call the "null" model for each factor includes all random intercepts of the full model, but does not include the fixed effect for that factor, nor the random slopes for items or participants (as applicable) for that factor. A significantly better fit for the full model over the null model would indicate that one or both of the following would be true: either there was some amount of systematic variation between conditions as a result of the factor or there was noisy variance within items or participants in the strength of the factor. We then used subtractive methods to compare the full model to the limited and null models to see if there was a significant change in model fit between the full model and the less-specified models.

Figure 2. The bars on the left represent the sentences with obligatory sentential contexts; the bars on the right represent those with optional sentential contexts. Within each group of sentences arranged by syntactic obligatoriness, the bars on the left represent the normal-rate sentences, and the bars on the right represent the slowed-rate sentences. The bars are colored according to the age of participants, with lighter bars representing the responses of older participants and darker bars representing the responses of younger participants.



Our first analyses probed main effects of each factor in the model. In the models that involved dropping the distal rate factor, both the limited model, $\chi^2(4) = 44.9$, $p < .001$, and the null model, $\chi^2(10) = 274$, $p < .001$, provided a significantly worse fit to the data than the full model. In models that lacked the syntactic obligatoriness factor, the limited model, $\chi^2(4) = 40.1$, $p < .001$, and the null model, $\chi^2(7) = 90.1$, $p < .001$, similarly fit significantly worse than the full model. As such, there was a significant main effect of both distal rate and syntactic obligatoriness, as dropping only the fixed effects or the fixed effects and random slopes relating to each factor led to a worse model fit than the full model. Sentences with an unmodified distal rate had higher critical word report rates (M = 90%, SD = 8%) than sentences with a slowed distal rate (M = 49%, SD = 16%). In addition, syntactically obligatory sentences had higher critical word report rates (M = 81%, SD = 11%) than syntactically optional sentences (M = 58%, SD = 14%). The limited and null models that lacked the age factor were not significantly different from the full model, which was true both for the limited model for age, $\chi^2(4) = 7.24$, $p = .12$, and the null model for age, $\chi^2(7) = 8.00$, $p = .33$. In other words, dropping age as a main effect, and even the random slope by item for age, did not significantly affect model fit. It did not appear that the average critical word report rates for older adults (M = 71%, SD = 10%) were significantly different from critical word report rates for younger adults (M = 68%, SD = 9%).

Under traditional modeling approaches, it is not advisable to take a lack of a significant difference as positive evidence for the lack of such an underlying difference. However, under certain reasonable assumptions, the ratio of Akaike weights of the models may provide evidence in favor of the model without age over the full model, akin to methods in Bayesian analysis (Burnham & Anderson, 2002).

The ratio of Akaike weights essentially gives a ratio of likelihoods across different models. The more likely one model is compared to another, the larger the value for the ratio of weights. The AICcmodavg package (Mazerolle, 2013) was used to compare corrected Akaike information criterion values between the full model and the model without any effects of age. The ratio of Akaike weights was 15.1 for the comparison between the null model and limited model and 30.3 for the comparison between the null model and the full model. This indicated that the model lacking age effects (both fixed effects and random slopes) was much more likely to accurately represent the underlying data than either of the other models. In other words, we can be fairly confident in the conclusion that age did not seem to be informative in and of itself to participants' critical word report rates, nor did it interact with speech rate or syntactic obligatoriness, nor were any particular items showing evidence of age effects that were washed out across items.

We assessed whether there was a significant interaction between distal rate and syntactic obligatoriness, comparing the null model for age to the same model without an interaction between distal rate and syntactic obligatoriness. We saw no difference between the two models; a model that included the interaction did not explain more variance in the data than a model that did not, $\chi^2(1) = 0.182$, $p = .67$. Here, the ratio of Akaike weights was 2.6, likely too small to indicate that the interaction between distal rate and syntactic obligatoriness should be dismissed outright. Thus, it seems that the most appropriate model fit includes a fixed effect of distal rate ($b = -4.50$, $p < .001$), a fixed effect of syntactic obligatoriness ($b = -1.97$, $p < .001$), and an interaction between the two terms ($b = -0.32$, $p = .62$).

Discussion

We set out to examine differences in the use of speech rate information in word segmentation. To do this, we set up a simple experiment comparing the use of syntactic information to word boundaries with the cue of distal speech rate (Dilley & Pitt, 2010). Our results showed that context speech rate affects older adults' perception of word boundaries in a way similar to how it affects younger adults. This alone is of note, as studies of distal speech rate effects on word segmentation have rarely extended their findings to nonundergraduate populations.

However, the extent to which older and younger adults' perception of acoustically ambiguous function words mirrored each other was somewhat surprising. We predicted older adults would use signal-based speech rate cues less than younger adults. We suggested that instead, older adults might compensate for a decreased use of signal-based cues by increasing their reliance on the knowledge-based cue of syntactic obligatoriness. What we found instead were no differences whatsoever between younger and older adults in their use of distal speech rate (i.e., the rate of speech of words more than one syllable removed from a potential word boundary) for word segmentation. This was corroborated by Akaike weight ratio tests, which suggested that a model explicitly ruling out any age effects provided the most likely fit to the data. One concern might be that our older adults were, in fact, younger than the older adults in other studies of aging; however, this is not necessarily the case. For example, whereas Gordon-Salant and Fitzgibbons (2001, 2004) found poorer performance on rate-compressed sentences in adults aged 65–75 years, follow-up work in our lab (Heffner & Newman, 2013) has shown the same pattern in adults aged 55–65 years, the same age as those tested here. Thus, effects of aging in general do not appear limited to those aged 65+ years; the lack of a difference obtained here is, we believe, a true reflection of a lack of a difference between older and younger adults in their use of distal speech rate cues to word segmentation.

These results imply that older adults' perception of speech rate information need not necessarily translate to their use of speech rate cues to particular speech perception phenomena. This is a particularly interesting finding considering the robust literature indicating differences in rate perception between younger and older adults (Gordon-Salant & Fitzgibbons, 2001, 2004; Gordon-Salant et al., 2007; Lustig, 2003; McAuley et al., 2006; McCormack et al., 1999; Peelle & Wingfield, 2005; Pichora-Fuller, 2003; Vanneste & Pouthas, 1999; Wearden et al., 1997) and concomitant evidence for older adults making use of signal-based cues less than and knowledge-based cues more than younger adults (Abada et al., 2008; Pichora-Fuller, 2008, 2009; Rogers et al., 2012; Sheldon et al., 2008; Sommers & Danielson, 1999; Wingfield & Tun, 2007; Wingfield et al., 1999). Indeed, one intriguing aspect of these studies is that both slowing down rates and speeding up rates might serve as a type of signal degradation (cf. Gordon, Daneman, & Schneider, 2009). Under this perspective, it is unexpected that slowing-down rate and speeding-up rate should have dissimilar effects.

The lack of an age effect on word segmentation occurred despite that some of our older participants showed evidence for an age-appropriate level of high-frequency hearing loss. Further studies will need to examine whether these results can extend to older populations, as well as to populations with a larger incidence of age-related hearing loss, more comparable to previously indicated rates of higher frequency hearing loss (Agrawal et al., 2008; Morrell, Gordon-Salant, Pearson, Brant, & Fozard, 1996). Although the older adults in this study generally had normal hearing, older adults with reduced signal-based processing capabilities may differ in their use of this signal-based acoustic cue to word boundaries. It may also be useful to include a more balanced gender ratio of participants to help yield a more diverse group of participants.

Some methodological differences could be made to make the experiments in the distal speech rate and aging literatures more parallel. For example, our rate manipulation involved a decrease in distal speech rate, as the materials were originally recorded here with an acoustically ambiguous function word, the perception of which could only be eliminated by slowing the distal rate. Perhaps a manipulation that involved speech compression would make the setup more analogous to previous experiments. Our syntactic manipulation was quite subtle; the use of a more salient syntactic modulation may have made it more possible for older adults to make use of knowledge-based cues to parse the speech signal they were hearing. Having some sentences that were incomplete may also have encouraged listeners not to rely heavily on semantic information. Further experiments are necessary to determine whether these methodological differences may provide insight into the results obtained here.

Overall, these results are consistent with the interpretation that older adults do not differ from younger adults in their use of these distal speech cues to word segmentation. Why should this be? One idea would be that older adults are not impaired in their perception of *relative* timing duration, even if their *absolute* perception of timing does differ from younger adults. This would be in line with the idea that differences in timing perception between older and younger adults derive from differences in the internal "clock" of older adults when compared with younger ones (e.g., see Lustig, 2003). If an older listener's clock were, for example, consistently slow across an utterance, it may lead to impairment in the accuracy of the perception of the utterance due to problems correctly analyzing the duration of segments within the utterance. Because it is the *relative* difference in speech rate that drives the distal speech rate effects (see Dilley, Morrill, & Banzina, 2013; Dilley & Pitt, 2010; Heffner et al., 2013, experiment 3), and because the entire sentence would be equally affected by these changes in clock speed, older listeners would still derive the correct ratio between the context speech rate and the speech rate near the critical word. Thus, they would not show a change in distal speech rate effects from younger adults, at least when interpreting the sentence correctly at a global level. Along these lines, it is worth noting that older adults generally misperceived sentences more often than younger adults, but that these sentences could not be evaluated for whether they included the critical determiner or not.

Older adults may not have shown any differences in speech rate cue use because differences in the *perception* of rate cues need not necessarily entail differences in the *use* of rate cues. Many previous studies of speech compression have examined the effects of wholesale speech compression on measures such as accuracy (Pichora-Fuller, 2009). Although such studies have been expanded on to show that, for instance, the compression of consonants is particularly challenging to older adults (Gordon-Salant & Fitzgibbons, 2001), it is seldom the case that experiments to date have looked specifically at a rate-related cue to a lexical-phonetic process such as word segmentation. This has implications for more general theories of speech perception. For example, lexical theories of word segmentation (e.g., the TRACE model of speech perception; McClelland & Elman, 1986) suggest that word segmentation occurs at a stage of processing after individual phonemes are successfully perceived. If, however, aging makes the perception of individual phonemes more challenging, it is unclear how word segmentation would not be affected by degraded performance at earlier stages of processing. Further work will be necessary to illuminate the reasons why older adults find it challenging to understand time-compressed speech without simultaneously occurring challenges in the effects of time-expanded speech on word segmentation.

Theories that allow for the direct influence of acoustic and phonetic information on word segmentation, such as Mattys, White, and Melhorn (2005), seem more capable of accommodating the results here. Such theories would simply predict that the cues affecting word segmentation (such as the speech rate effects used here) may be different from those that affect comprehension of compressed speech in aging. Given the signals affected by rate compression do not appear to be the same as those used for word segmentation, perhaps more domain-general cognitive abilities are affecting comprehension of compressed speech (Lustig, 2003; Vanneste & Pouthas, 1999; Wearden et al., 1997). Constraints on processing speed might explain why older adults would be particularly challenged by compressed speech but would be unaffected by a rate cue to word segmentation implemented through the expansion of parts of a sentence.

In sum, we have compared younger and older adults in their use and perception of rate information in speech. Previous studies led us to believe that older adults would be impaired in their use of distal speech rate in word segmentation. However, contrary to our predictions, and distinctive in the realm of timing-related auditory processing in aging, we find no effects of aging on the use of these rate cues for word segmentation. This may be explained as the result of the differences between older and younger adults in the perception of relative and absolute rate changes, in the use and perception of rate cues, and in processing abilities of those groups. Examining still older participant groups, who may have larger differences from younger adults in these capacities, and using word segmentation changes that may be cued both by slowing down and speeding up distal speech rate, may provoke further insights into these problems.

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Appendix

Experimental Fragments Used in Experiment

Critical words are given in parentheses; material that was truncated to create an optional syntactic context is shown in brackets.

Anne wanted to see (a) very funny [movie].
Bob said that there (are) stocks [to buy].
Chris said his mother and father (are) both [old].
Connor knew that bread and butter (are) both [in the pantry].
Dan took off after (her) young [friend was hired].
Dave asked how long it takes to repay (a) large [debt].
Don said that it’s easy to go to (a) regular [store].
It costs a lot to tattoo (a) pink [flamingo].
It takes a lot of work to review (a) personal [file].
It’s not easy to convey (a) likely [position].
It’s not long before (her) bad [back goes out].
John said he would obey (a) rebel [leader].
Lance said goodbye before (her) large [car got towed].
Rose knew that there (are) lamps, [which are expensive].
Sam knew there (are) apples, [which are sweet].
Sue said there (are) lunches [that are healthy].
Tess thought there (are) loans [that have better rates].
The boy wanted to glue (a) broken [toy].
The leaves fell after (her) green [lawn dried up].
The message was clear after (her) blank [stare said it all].
The sign was replaced after (her) black [car got stolen].
These copy machines are (our) largest [ones].
These houses are (our) best [options for making money].
They were sad after (her) poor [dog was put down].
Todd said there (are) rooms, [which are ugly].
Zach knew that there (are) things [in the closet].