Published in final edited form as:
Psychol Aging. 2014 December ; 29(4): 907–912. doi:10.1037/a0037829.

A Bruner-Potter Effect in Audition? Spoken Word Recognition in Adult Aging

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Abstract

Bruner and Potter (1964) demonstrated the surprising finding that incrementally increasing the clarity of images until they were correctly recognized (ascending presentation) was less effective for recognition than presenting images in a single presentation at that same clarity level. This has been attributed to interference from incorrect perceptual hypotheses formed on the initial presentations under ascending conditions. We demonstrate an analogous effect for spoken word recognition in older adults, with the size of the effect predicted by working memory span. This effect did not appear for young adults, whose group spans exceeded that of the older adults.

Keywords

Adult aging; Word recognition; Perceptual interference; Working memory

Imagine someone was giving you instructions, and as they were leaving the room, you realize you were unable to make out the last word the person had said. Assuming you cannot go back and ask, would it be more effective to mentally scan a trace of the acoustic signal and attempt to generate multiple hypotheses as to what the word might have been? Or would it be best to take a single educated guess on the identity of the indistinct word, and on that basis carry on with the presumed instructions? Research examining a similar question in vision has shown that identification of a degraded picture is undermined if one has seen partial information that has led to false hypotheses about what the picture might be (Bruner & Potter, 1964; Luo & Snodgrass, 1994; Snodgrass & Hirshman, 1991).

Bruner and Potter (1964) demonstrated this perceptual interference effect in young adults by presenting blurred pictures in a series of presentations in which the pictures became progressively more focused (an *ascending presentation*). The Bruner-Potter effect refers to their finding that presenting an image coming incrementally into focus requires a clarity level for correct recognition higher than that needed for recognition when the image is shown just once, even at a level with less clarity. Bruner and Potter suggested that the need to inhibit incorrect perceptual hypotheses formed on the initial presentations under ascending presentation conditions out-weighed any advantage of an accumulation of

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information in the ascending exposures (Bruner & Potter, 1964; Snodgrass & Hirshman, 1991).

Although the Bruner-Potter effect has been studied primarily in the recognition of visually presented stimuli, the possibility that recognition of spoken words might be impeded by incorrect perceptual hypotheses was raised by Frederiksen (1967, 1969), who noted the frequent perseverations of incorrect responses, more so in some individuals than others, even as he progressively increased the clarity of spoken words by decreasing the level of a background noise. Frederiksen referred to the ability to reject erroneous hypotheses in terms of "cognitive flexibility", anticipating much later arguments that executive functioning and working memory capacity may underlie cognitive flexibility and the ability to inhibit potential sources of interference to protect task performance (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; see also Engle & Kane, 2004; Miyake & Shah, 1999; Garavan, Ross, & Stein, 1999). If interference from incorrect perceptual hypotheses, or its prevention, generalizes across domains, one might expect a similar Bruner-Potter effect in audition.

In the following experiment, we created an auditory analog to the Bruner-Potter experiment with two major differences. First, we contrasted ease of recognition for fixed versus ascending presentations for spoken words rather than for degraded pictures. For this purpose we employed the technique of *word onset gating*, in which participants hear increasing amounts of word onset information (the onset gate size) until a word can be correctly identified (Grosjean, 1980, 1996). Although hearing the initial sound of a word, such as the "ca" (/kæ/) in "camera" may activate all words known to the listener that share this initial sound (e.g., *camel*, *cactus*, *castle*), this number progressively decreases as more of the word onset is heard, and the words that no longer share this onset become eliminated (Marslen-Wilson & Zwitserlood, 1989; Wayland, Wingfield & Goodglass, 1989). Because the number of possible word candidates that share the same initial sounds declines steeply as a word unfolds in time (Tyler, 1984; Wayland et al., 1989), correct word identification often occurs even before the full word duration of a stimulus word has been heard (Grosjean, 1980; Marslen-Wilson, 1984; Lindfield, Wingfield & Goodglass, 1999).

An extension of the Bruner-Potter effect to spoken word recognition would predict a higher probability of correctly identifying a word from an onset duration of a given size when this onset is presented in the form of a single presentation than when this same onset duration is reached with an ascending presentation condition in which the onset duration is progressively increased to that point. This would follow from the analogous assumption that recognition following a single presentation would be free from the potential interference engendered by incorrect hypotheses formed during an ascending presentation (Bruner & Potter, 1964; Snodgrass & Hirshman, 1991).

A second departure from the earlier visual studies is that we asked our question in the context of adult aging, with special attention to working memory capacity. This focus follows the above-cited suggestions that individual differences in working memory capacity may underlie cognitive flexibility – represented in this case by the need to reduce potential interference from initially activated perceptual hypotheses formed on early gated presentations. Adult aging adds an interesting dimension to this question because older adults are known to show greater susceptibility to interference than young adults across a variety of domains (Hasher & Zacks, 1988). Indeed, Sommers and Danielson (1999), offered an age-related inhibition deficit account for their finding that spoken words that share sounds with many other words are differentially harder to recognize by older adults than by young adults.

Although in general older adults have reduced working memory capacity relative to their young adult counterparts (Salthouse, 1994), it is possible to examine interference effects for sets of young and older adults both of whom range in working memory capacity. To the extent that one can demonstrate an auditory analog to the Bruner-Potter effect, one can thus ask whether the size of the effect, as represented by a difference in recognition accuracy for words at a given gate size with fixed versus ascending presentations, can be accounted for by individual differences in working memory capacity independent of age.

Methods

Participants

Forty healthy community-dwelling older adults, 13 men and 27 women, with ages ranging from 65 to 87 years were included in this study (*M* = 75.2 years, *SD* = 6.0). Because stimuli would be presented aurally, all participants were tested for hearing acuity. Testing for each participant was conducted using a GSI 61 clinical audiometer (Grason-Stadler, Madison, WI) using standard audiometric procedures in a sound-attenuated testing room (Harrell, 2002). The older adults' better-ear pure-tone average (PTA) across 500, 1,000 and 2,000 Hz ranged from 6.7 to 43.3 dB Hearing Level (HL) (*M* = 24.7 dB HL; *SD* = 9.9), representing a range audiometrically defined as normal acuity to a moderate hearing loss. The group's mean better-ear speech reception threshold (SRT) using Central Institute for the Deaf (CID) W-1 spondee words (Auditec, St. Louis, MO) was 22.6 dB HL (SD = 10.4). None of the participants was a regular user of hearing aids (Kochkin, 1999). Also included in this study were 40 younger adults, 14 men and 26 women, with ages ranging from 18 to 26 years (*M* = 20.0 years, *SD* = 1.8). Their PTAs ranged from 3.3 to 25.0 dB HL (*M* = 11.7 dB HL; *SD* = 5.2). Their mean SRT was 8.9 dB HL (*SD* = 5.5).

The older adult group had completed an average of two more years of formal education at time of testing than the younger adults (*M* older = 16.9 years, *SD* = 2.1; *M* younger = 14.6 years, *SD* = 1.4; $t[78] = 5.80$, $p < .001$), and, as is often found for older adults (Verhaeghen, 2003), had higher vocabulary scores than the younger adults (*M* older = 16.1, *SD* = 2.0; *M* younger = 14.5, *SD* = 2.0; $t[78] = 3.51$, $p < .01$) using the Shipley vocabulary test (Zachary, 1986).

Working memory capacity was measured using a complex reading span task modified from Daneman and Carpenter (1980), in which participants read sets of sentences, determined whether each was true or false, and then attempted to recall the last word of each sentence. McCabe and colleagues' (2010) stair-step procedure for scoring was used, in which participants received three trials for any given number of sentences, ranging in succession from one to five sentences per trial. All participants received all three trials for sentence lengths of one to three sentences regardless of accuracy on these trials. After that point the task was stopped when a participant missed two of the three trials at any length, with working memory scores calculated as the total number of trials in which all sentence-final words were recalled correctly in the right order. Using this method, working memory scores ranged from 3 to 13 for the older adults (*M* = 7.9, *SD* = 2.8) and from 5 to 15 for the younger adults (*M* = 9.9, *SD* = 2.9). Although overall the older group showed a significantly lower span score than the younger adults, $t(78) = 3.19$, $p < .01$, there was, as intended, considerable overlap between working memory scores for the two groups.

Participants also received the Stroop task (Stroop, 1935), often used to reflect susceptibility to interference (MacLeod, 1991; Wingfield, Goodglass & Lindfield, 1997). The size of the effect was measured as the difference in response latencies to naming the ink color in which a color name was printed in an incongruent ink color (e.g., BLUE printed in red ink) relative to the speed of naming the ink color when the ink color was printed in a neutral condition (e.g., naming the color in which a row of *X*s was written). The older adults' difference scores (*M* = 693.95 ms, *SD* = 460.96) were significantly larger than those of the younger adults (*M* =134.33 ms, *SD* = 111.30); $t(76) = 7.46$, $p < .001$. (Stroop scores were unavailable for two older adults.) Both the working memory and Stroop tasks were administered in a visual modality to avoid a potential confound with hearing acuity.

Stimulus Materials

The stimuli consisted of 60 words selected from the Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982). The words were two-syllable common nouns with high frequencies of occurrence in English based on published norms (Francis & Kučera, 1982). Sound files for the target words were obtained from the Auditory Toronto Word Pool database and edited using SoundEdit speech editing software (Macromedia, Inc., San Francisco, CA) to produce a sequence of presentations in which the onset duration (gate size) of the target word was increased by 30 ms increments until the full word was included in the gate size. This was accomplished by selecting the desired gate size on a computer-generated visual display of the speech waveform, with the gate size measured from the point of the word onset as determined visually on the waveform and then verified by auditory monitoring. The mean spoken duration of the target words was 556 ms, representing an average of 18.5, 30-ms gates needed to include an entire word.

Procedure

Pretest and Calibration—It has been well established that older adults and those with reduced hearing acuity require a larger amount of word onset information for correct word identification than younger adults and those with better hearing (e.g., Lash, Rogers, Zoller, & Wingfield, 2013). To avoid a potential scaling problem we conducted a pretest calibration session analogous to that used by Luo and Snodgrass (1994) and Snodgrass and Hirshman (1991) in their replication of the original Bruner-Potter effect with fragmented pictures. Our goal was to obtain a critical recognition threshold (gate size) value to allow us to compare accuracy levels for fixed versus ascending presentations from a similar baseline for both older and younger adults.

In this pretest calibration session 20 words were presented using a traditional ascending presentation method in which participants heard the first 30 ms of a word's onset, then the first 60 ms of the word's onset, and so forth, increasing the onset duration by 30 ms increments until the word was correctly identified. A threshold level was calculated individually for each participant as the average gate size that allowed for words to be correctly identified close to 50% of the time, allowing an accuracy range of 40 – 60% correct. None of the words heard in the pretest calibration session was used for the same participant in the main experiment.

Stimuli were presented binaurally over Eartone 3A (E-A-R Auditory Systems; Aero Company, Indianapolis, IN) insert earphones via a Grason-Stadler GS 61 clinical audiometer at 25 dB higher than the individual's SRT for his or her better ear (25 dB Sensation Level [SL]). All testing was conducted individually in a sound-attenuated testing room.

Fixed versus Ascending Presentations—For the main experiment, each participant heard 20 words under fixed presentation conditions and 20 words under ascending presentation conditions. For the ascending condition, words were presented with onset durations progressively increased by 30 ms, with the participant encouraged to attempt to say what the word might be after each presentation. The presentations were stopped, and accuracy scored, at the individual's gate-size threshold (approximately 50% correct) as determined in the pretest session. The word onsets presented in the fixed condition were presented just once at that same pretest determined gate size.

All stimuli were presented binaurally over insert earphones at the same 25 dB SL intensity level as used in the pretest calibration session. The order of presentation (fixed or ascending) and the particular words heard in the pretest, ascending, and fixed presentation conditions were varied across participants.

Results

Figure 1 shows the mean percentage of words correctly recognized by older adults and younger adults when words were heard under fixed and ascending presentation conditions. The relative similarity between older and younger adults' accuracy levels in the ascending condition reflects the individual gate size adjustment based on participants' thresholds in the pretest calibration session. Of interest is the difference value between the fixed accuracy level in which the same gate size was presented without prior presentations and the accuracy level for the ascending condition.

The data shown in Figure 1 were analyzed with a 2 (Presentation condition: fixed, ascending) X 2 (Group: older adults, younger adults) mixed-design analysis of variance (ANOVA), with presentation condition as a within-subjects variable and group as a between-subjects variable. Overall, a greater percentage of words were correctly recognized under the fixed relative to the ascending condition even though the critical gate sizes were the same for both conditions for each participant. This difference, exemplified in the Bruner-Potter effect, was confirmed by a significant main effect of presentation condition, $F(1, 78) = 4.84$, $p < .05$, $\eta_p^2 = 0.06$. It can also be seen, however, that a significant difference between fixed and ascending performance appeared only for the older, $t(39) = 4.03$, $p <.001$, but not for the younger adults, $t(39) = 0.05$, *n.s*. This pattern was reflected in a significant Presentation condition X Group interaction, $F(1, 78) = 5.21$, $p < .05$, $\eta_p^2 = 0.06$. Within the context of this interaction, the main effect of participant group was not significant, $F(1, 78) = 0.47$, *n.s*, $\eta_p^2 = 0.01$.

Individual Differences

Considering that executive functions, to include working memory, tend to decline with age, we questioned whether age differences, *per se*, might not be the defining factor underlying the size of the auditory Bruner-Potter effect. We first examined whether the obtained individual difference factors might relate to the degree of susceptibility to the perceptual interference effect and to each other. Table 1 shows Pearson correlations between the predictor variables: *Chronological Age*, *Hearing acuity*, based on better-ear PTAs for 500, 1,000 and 2,000 Hz, *Vocabulary knowledge*, based on the Shipley vocabulary test (Zachary, 1986), *Reading suppression*, as measure by the Stroop task (MacLeod, 1991), and *Working memory capacity* (*WMC*), as measured by the McCabe et al's (2010) complex span task, and the extent to which each related to the difference between the percentages of words correctly identified in the fixed condition versus the ascending condition. As might be expected, greater differences were associated with older age, longer response latencies to suppressing reading words, and lower working memory capacity. As might also be expected, Table 1 shows that there were significant correlations among several of the variables. (The pretest adjustment to equate individual baselines eliminated a potential correlation between the size of the Bruner-Potter effect and hearing acuity.)

To address whether these individual difference factors may influence the degree of susceptibility to the Bruner-Potter effect, we preformed a hierarchical multiple regression analysis in which we entered, in order, the predictor variables: (1) *Chronological Age*, (2) *Hearing acuity*, (3) *Vocabulary knowledge*, (4) *Reading suppression*, and (5) *Working memory capacity* (*WMC*). Chronological age was entered into the model first because of its significant relationship with the other predicator variables, and our interest in whether after controlling for chronological age, other predictor variables such as hearing, vocabulary, and cognitive factors would add unique variance to the Bruner-Potter effect. Working memory capacity was entered into the model last to test the hypothesis that working memory, over and above age, would predict the differences in performance between fixed and ascending conditions.

Results for the regression analysis are summarized in Table 2. For each predictor variable, we show: (1) the R^2, which represents the cumulative contribution of each variable when it was entered into the model along with the previously entered variables, (2) the change in R^2, which shows the contribution of each variable at each step, and (3) the final β, which shows the unique contribution of each variable to the final model after all of the variables have been entered. (Two older adults' reading suppression [Stroop] data were excluded because of the previously noted missing values.)

As the first predictor variable entered, chronological age, explained about 6% of the variance in the difference between fixed and ascending presentations; $R^2 = 0.06$, $F(1, 76) =$

5.13, $p < .05$. When controlling for chronological age, hearing acuity, vocabulary, and reading suppression were not found to add significant variance to the difference between fixed versus ascending presentations. Working memory capacity, however, accounted for an additional 11% of the variance, even when the effects of age and other predictor variables were controlled; R^2 change = .11, $F(1, 72) = 9.89$, $p < .01$. As a whole, our regression model accounted for 20% of the variance in performance differences between fixed versus ascending presentation conditions, which was statistically significant, $R^2 = 0.20$, $F(5, 72) = 3.54$, $p < .01$. As can be seen in the last column of Table 2, when the overlapping effects of all other predictor variables were removed, chronological age did not add a significant contribution to the size of the effect. Rather, working memory capacity was found to be the single best predictor of the size of the auditory Bruner-Potter effect, (final $\beta = -.37$, $p < .01$). Neither hearing acuity, vocabulary knowledge, nor performance on the Stroop task added a significant unique contribution to the model.

The above pattern was reinforced when the order of entry in the hierarchal regression analysis was reversed (i.e., entering working memory first and chronological age last). This reversed order yielded similar results, with working memory again appearing as the single best predictor of the auditory Bruner-Potter effect. We also performed hierarchal regressions within each age group, which showed similar results. That is, for the older adults, working memory capacity was the only significant predictor of the effect, (final $\beta = -.43$, $p < .05$) and was the strongest, albeit marginal predictor for young adults, (final $\beta = -.32$, $p = .059$

Discussion

It was some five decades ago that Bruner and Potter demonstrated that degraded pictures required a greater level of visual clarity for their correct identification when they were presented in a series of presentations that incrementally increased their clarity, than when pictures were shown at the same level of clarity without any prior exposures (Bruner & Potter, 1964). Subsequent studies have replicated this basic finding, and have supported the notion that correctly identifying a picture with ascending presentations is hindered by interference from residual activation of incorrect perceptual hypotheses carried on across presentations (Luo & Snodgrass, 1994; Snodgrass & Hirshman, 1991).

Past studies in the domain of spoken word recognition have shown that words are more difficult to recognize when they have competition from many phonological neighbors that may be activated when hearing a word (Sommers & Danielson, 1999), or when the linguistic context in which a word is heard potentially activates a large number of words with similar contextual probabilities (Lash et al., 2013). These studies have also shown that the negative effects of competition on the ease of word recognition is greater for older adults who are presumed to be less effective in inhibiting potential interference than their younger counterparts (Lash et al., 2013; Sommers & Danielson, 1999). These findings would thus lead to two inter-related predictions: that the Bruner-Potter effect developed for visual recognition should also appear in the domain of spoken word recognition, and that this effect would be greater for older relative to younger adults.

The main effect of presentation condition we observed in the present experiment confirms the first prediction; that the Bruner-Potter effect also appears in audition. The second prediction, that the effect would be stronger for older adults also received support, in that the Bruner-Potter effect was found for the older adults, but not for the young adults. We suggest the reason for this lies in expectations based on the general finding that older and younger adults, as groups, typically differ in working memory capacity (Salthouse, 1994). In the present case, where both age groups ranged in working memory spans, the effect of chronological age as a variable gave way to differences in working memory capacity.

The importance of working memory capacity as a significant predictor of the size of the Bruner-Potter effect observed in the regression analysis in the present study is consistent with extant arguments that the overlapping constructs of working memory and executive function underlie the effectiveness of inhibitory control (Conway, Cowan & Bunting, 2001; Engle & Kane, 2004; Kane, Bleckley, Conway & Engle, 2001; Kane & Engle, 2003; McCabe et al., 2010) as well as broader cognitive functions (e.g., Daneman & Carpenter, 1980; Kyllonen & Christal, 1990; Süβ, Oberauer, Wittman, Wilhelm, & Schulze, 2002; Janse & Jesse, in press).

It is interesting that the Bruner-Potter effect that has been demonstrated for young adults using pictures did not appear for spoken words as measured by gate size to threshold. The present data do not allow us to say why this is so. In addition to the number of procedural differences between the presentations of gated words versus distorted or fragmented pictures, it is also the case that the average working memory spans for our undergraduate participants was close to a full standard deviation above the mean for similar aged participants given by McCabe et al., (2010). We suggest this as a potentially fruitful line for further enquiry.

There are two final notes of importance. One of these is that one should not underrate the importance of hearing acuity to spoken word recognition. The failure of differences in hearing acuity to contribute to the size of the interference effect in this experiment was a consequence of adjusting the word onset durations to a common baseline as determined in the pretest calibration session. Without such an adjustment individuals with reduced hearing acuity are at a significant disadvantage in spoken word recognition, albeit mitigated when a constraining linguistic context is present (e.g., Lash et al., 2013).

While performance on the Stoop task had a significant relationship with the Bruner-Potter effect, less clear is the reason why the Stroop task, usually seen as a test of the ability to inhibit interference from a prepotent response, did not appear as a predictor of the size of the Bruner-Potter effect when tested in the regression analysis. Our choice to present the Stroop task in a visual (McLeod, 1991) rather than an auditory (Sommers & Danielson, 1999) format, was intended to avoid a potential confound with participants' hearing acuity. It may be that the suppression of an automatic response of reading words (the Stroop effect) operates on a different system than the rejection of erroneous hypotheses generated with ascending presentations. In addition, when considering the overlapping effects of general age-related slowing in Stroop performance, the Stroop task as a predictor variable was not able to add unique variance above and beyond age.

It is clear, however, that the interference effect in picture recognition observed by Bruner and Potter and others has its counterpart in auditory word recognition, and that working memory capacity, rather than age, *per se*, is the driving force behind the magnitude of the effect.

Acknowledgements

This research was supported by NIH grant R01 AG019714 (A.W.) and training grant T32 AG000204 (A.L.) from the National Institute on Aging. We also gratefully acknowledge support from the W.M. Keck Foundation.

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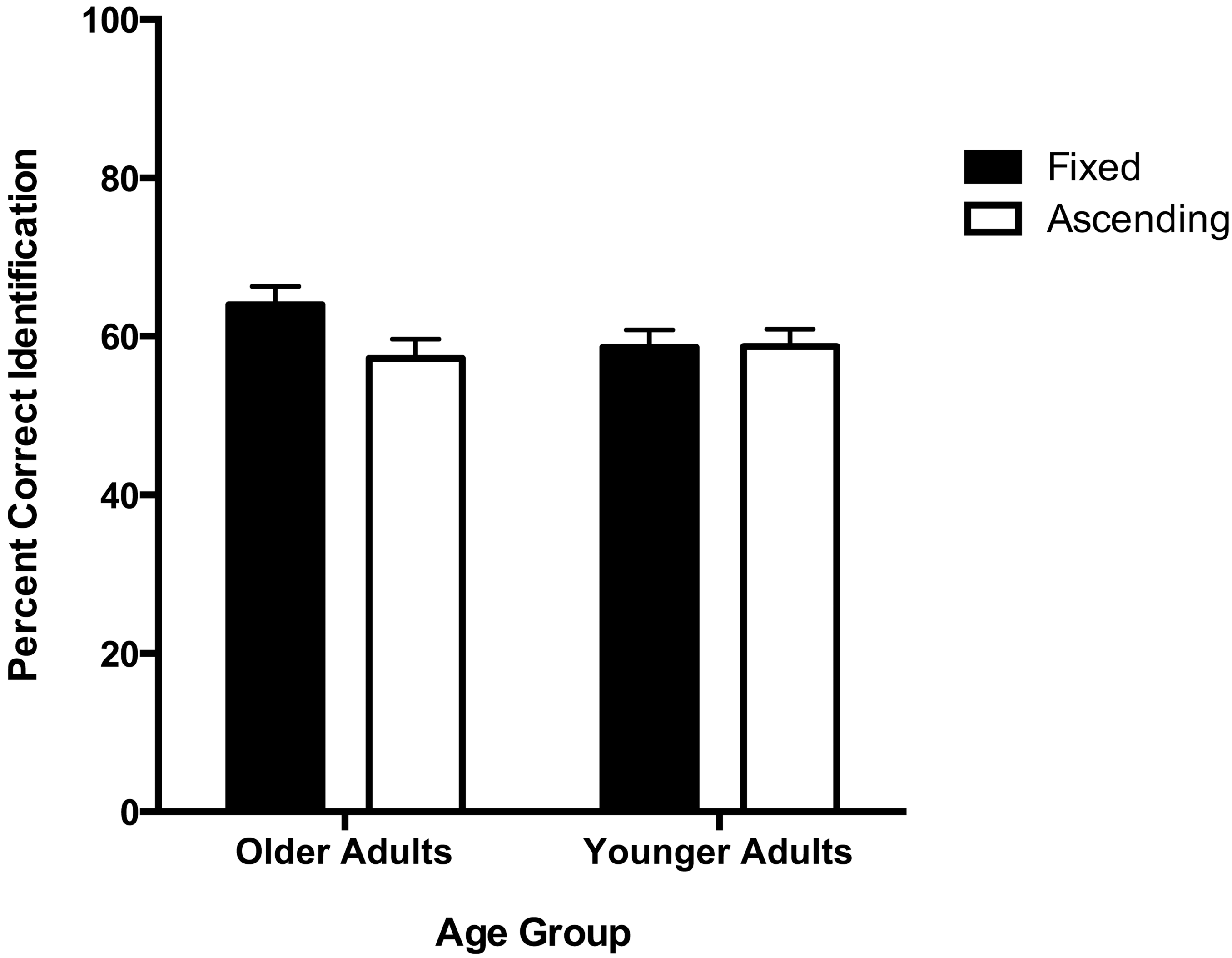

Figure 1.

Percentage of words correctly identified by older and younger adults when the same word-onset durations were presented under fixed or ascending presentation conditions. Error bars represent one standard error.

Table 1

Pearson Correlations Between Predictor Variables and the Difference between Fixed versus Ascending Accuracy

Predictor Variables	*Fixed v. Ascending Difference*	*1*	*2*	*3*	*4*
1. Chronological age	.25*				
2. Hearing acuity (PTA)	.10	.66***			
3. Vocabulary knowledge (Shipley)	.10	.36**	.19		
4. Reading suppression (Stroop task)	.24*	.68***	.58***	.07	
5. WMC (complex span task)	−.42***	−.37***	−.18	−.03	−.37***

Note. PTA = pure-tone average; WMC = working memory capacity;

* $p < .05$.

** $p < .01$.

*** $< .001$

Table 2

Summary of Hierarchical Multiple Regression

Predictor Variables	R^2	Change in R^2	Final β
Chronological age	.06	.06*	.09
Hearing acuity (PTA)	.07	.01	−.09
Vocabulary knowledge (Shipley)	.07	.00	.07
Reading suppression (Stroop task)	.09	.02	.07
WMC (complex span task)	.20	.11**	−.37**

Note. PTA = pure-tone average; WMC = working memory capacity;

* $p < .05$.

** $p < .01$