The effects of contextual strength on phonetic identification in younger and older listeners

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Abstract

It has often been reported that older listeners have difficulty discriminating between phonetically similar items, but may rely on contextual cues as a compensatory mechanism. The present study examined the effects of different degrees of semantic bias on speech perception in groups of younger and older listeners. Stimuli from two [g]-[k] VOT continua were presented at the end of biasing and neutral sentences. Results indicated that context strongly influenced phonetic identification in older listeners; this was true for younger listeners only in the case of less-than-ideal stimuli. Findings are discussed in relation to theories concerning age-related changes in speech processing.

INTRODUCTION

The ability to comprehend speech would not be highly remarkable if every production of every phoneme retained the same acoustic properties across all speakers. In reality, phoneme productions vary by speaker (see Ladefoged et al., 1972; Perkell, 1969). Moreover, the speech signal often competes with background noise and is quite fleeting (see Stine-Morrow et al. 1999); the result is a degraded speech signal. Understanding this degraded signal is a complex process. Complaints of difficulty understanding speech by older listeners (Tremblay, Piskosz, & Souza 2002; 2003) provide evidence that this task becomes more difficult with age (see also CHABA, 1988; Humes, 1996).

To acquire empirical data assessing whether there is an effect of aging on speech perception, perceptual identification studies have been conducted with younger and older adult subjects (e.g., Stine-Morrrow et al., 1999; Tremblay et al., 2002; 2003; Sommers & Danielson, 1999). Many of these studies have focused on the ability of subjects to perceive phonemic contrasts, such as the categorical perception of voicing contrasts in stop consonants (e.g., [g] vs. [k]; [d] vs. [t], etc.). Voicing contrasts in word initial stop consonants are reflected largely by differences in voice onset time (VOT), the interval between the release of a stop consonant and the onset of voicing. Strouse, Ashmead, Ohde, and Grantham (1998) investigated the influence of age on perception of stop voicing contrasts. Older listeners with good hearing (equivalent to younger listeners) displayed less accurate VOT discrimination and an overall decrease in temporal processing ability. Tremblay et al. (2002, 2003) presented both behavioral and electrophysiological evidence that older adults present a different neurological response to voicing contrasts than younger adults. Older adults exhibited difficulty discriminating VOT contrasts behaviorally, as in previous studies (e.g. Strouse et al., 1998); moreover, VOT contrasts evoked delayed neural responses from older adults. The latencies of the N100 and P200 response components were prolonged for older adults relative to younger adults (Tremblay et al., 2002; 2003). These studies demonstrate a decreased sensitivity to temporal cues and a decreased ability to interpret certain acoustic cues in older adults (Tremblay et al., 2002; 2003; Stine-Morrow et al., 1999; Wingfield, Aberdeen, & Stine, 1991).

Age-related differences in speech perception have sometimes been attributed to cognitive factors or peripheral hearing loss associated with aging (Roth & Sommers, 1997; for a recent review, see Schneider, Daneman & Pichora-Fuller, 2002). However, cognitive factors and peripheral hearing loss alone have not been found to account for a great deal of speech perception difficulties in aging (Roth & Sommers, 1997; Tremblay et al., 2003; see also Humes & Roberts, 1990; Humes & Christopherson, 1991; Humes & Floyd, 2005). Moreover, most studies that have examined cognitive factors have not focused on abilities specific to speech perception (Roth & Sommers, 1997). Similarly, studies of non-speech auditory perception in aging abound, but few have specifically explored speech perception skills (see e.g., Schneider & Pichora-Fuller, 2001; but cf. Coughlin, Kewley-Port, & Humes, 1998); those that have attempted to relate non-speech auditory processing skills such as gap detection to speech perception skills have met with limited success (e.g., Schneider & Pichora-Fuller, 2001; Schneider et al., 2002). Despite suggestions that older adults exhibit a decline in speech perception abilities associated with some aspects of the aging process, many older adults nevertheless remain remarkably able to communicate, indicating that they may be relying on additional information or strategies in speech comprehension.

For instance, some investigators have suggested that older adults may rely to a great extent on contextual information in language processing (e.g., Cohen & Faulkner, 1983; but cf. Craik, 1968; Stine-Morrow et al., 1991). In particular, it has been suggested that older listeners may rely on context as a means of partially compensating for reduced speech perception abilities (e.g., Boothroyd & Nittrouer, 1988; Pichora-Fuller et al., 1995; Sommers & Danielson, 1999; Wingfield et al., 1996; 1991; Cabeza, 2002; Cabeza et al., 1997; Cabeza et al., 2002). To give but one example, Wingfield et al. (1991) used a gating task to determine the word onset duration needed to identify words with and without sentence and intra-word context. Results indicated that the presence of context shortened the word onset duration needed for identification for both younger and older adults and that, overall, older adults required longer initial 'gates' or segments for accurate word identification. Importantly, the age-related difference in segment length required for word identification with context was smaller than the difference without context, suggesting that older adults are able to use contextual cues to compensate for difficulty processing acoustic input (Wingfield et al., 1991; see also Stine-Morrow et al., 1991).

Within the field of speech perception more generally, a widely-held view holds that the process is an interactive one, with higher-level knowledge influencing phonetic decisions (e.g., Elman & McClelland, 1984; Luce, Pisoni, & Goldinger, 1990; Samuel, 1986; Warren, 1970). Although such interactivity is clearly necessary in situations in which low-level acoustic phonetic input is impoverished or degraded (e.g., in noisy environments), many researchers have argued that such an interactive process is the norm (across the age-span) rather than occurring only in exceptional circumstances (e.g., Fox, 1984; Ganong, 1980; Miller et al., 1984; Pitt & Samuel, 1993; but cf. Burton et al., 1989; McQueen, 1991). For example, numerous investigations have demonstrated an influence of lexical status on phonetic perception; one of the earliest such studies was conducted by Ganong (1980). In this experiment, several continua varying in terms of VOT were created. The continua endpoints were chosen such that one endpoint (either voiced or voiceless) formed a real word in English, whereas the contrastive endpoint formed a non-word (e.g., dash-tash). Identification tasks showed that young adult listeners were more apt to categorize ambiguous stimuli from the mid-range of the continua as belonging to the phonetic category that formed the real word, suggesting a lexical influence on speech perception (Ganong, 1980). This lexical effect has been replicated many times, although as noted above, researchers differ in the degree to which they attribute such effects to normal automatic processing mechanisms or to strategies invoked under conditions of increased uncertainty (e.g., Burton et al., 1989; McQueen, 1991; Pitt & Samuel, 1993).

In addition to lexical influences, sentential semantic context has also been shown to affect phonetic perception (Borsky et al., 1998; Connine & Clifton, 1987; Miller et al., 1984). In an early study, Connine and Clifton (1987) embedded stimuli from seven VOT continua at the end of sentences that biased one or the other possible interpretation of the ambiguous stimulus (i.e., continuum endpoint) of each continuum. For instance, sentence contexts like "She drives the car with the__" were coupled with stimuli from a 'dent-tent' continuum. Normal young adult listeners were influenced by the sentential context, producing more phonetic identification responses consistent with the semantic bias and thus yielding a category boundary shift[1] (Connine & Clifton, 1987; see also Borsky et al., 1998; Baum, 2001; Miller et al., 1984). It is this type of contextual influence that is exploited in the current investigation, with a focus on effects of aging.

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[1] The phonetic category boundary is defined as that point along the continuum at which listeners produce 50% identification responses consistent with each endpoint. As noted, this boundary may shift from that found under neutral conditions.

In previous experiments focused specifically on contextual influences on *phonetic* identification in aging, Boyczuk & Baum (1999) examined lexical status and neighborhood density effects on VOT perception in groups of young adults (20-29 years) and older adults (60-69 years; 70-79 years). Their results revealed lexical effects in all participant groups, with somewhat stronger effects (the difference just failed to reach statistical significance) apparent in the older adult listeners, as reflected in both category boundaries and overall percent voiced responses. In a similar study examining both lexical and prosodic (i.e., metrical stress) influences on phonetic categorization, Baum (2003) found substantially stronger effects of both prosodic and lexical context on phonetic identification in groups of older listeners (mean age=70 years) relative to young adults. The findings were interpreted as reflecting an increased reliance on contextual information on the part of older listeners, perhaps as a compensatory strategy for limited speech processing capacities in the context of increased stimulus uncertainty (Baum, 2003; see also Wingfield et al., 1989; 1992).

In the present investigation, the apparent increased reliance on context in older individuals was probed with regard to sentential semantic context, with differing strengths or nature of semantic biases. That is, contexts that strongly and moderately biased target words were examined (see Titone, 1998), as detailed below, to determine the extent to which older adults depend on higher-level knowledge in rendering phonetic identification decisions.

METHODS

Participants

Two groups of subjects participated in this study: 10 young adult subjects (ages 18 to 25 years, mean age=20;8) and 10 older subjects (ages 59-79 years, mean age=69;5). All subjects were right-handed native speakers of English (from birth) with relatively good hearing (audiometric pure-tone screening at 30dB HL at .5, 1, and 2 kHz); see Schneider & Pichora-Fuller, 2001) and no history of neurological or speech and language deficits. Older adults were screened using the *Mini Mental State Examination* (Folstein, Folstein, & McHugh, 1975) to ensure adequate cognitive functioning[2]. All subjects were selected from a pool of volunteers for language research at the School of Communication Sciences and Disorders, McGill University.

Stimuli

Stimuli consisted of 40 sentences divided into eight categories (described below) and two five-step velar VOT continua (*gash-cash* and *goal-coal*). Unambiguous nouns were chosen for the endpoints such that, for one continuum, the voiced endpoint was of a higher frequency than the voiceless endpoint, whereas for the second continuum, the voiceless endpoint was of higher frequency. In particular, in the gash-cash continuum, the voiceless endpoint was more frequent than the voiced endpoint (cash=32; gash=3, Francis & Kucera, 1982); in the goal-coal continuum, the voiced endpoint was more frequent (coal=40, goal=100, Francis & Kucera, 1982).

Contextual strength was manipulated by creating sentence contexts that biased a central or peripheral semantic feature of an upcoming word (as in Titone, 1998). Central feature context sentences have a high degree of contextual strength, and peripheral feature context sentences have a moderate degree of contextual constraint. Five central semantic-feature biasing and five peripheral-feature biasing sentence contexts were created for each endpoint of each continuum, yielding a total of forty sentences (listed in Appendix). Each stimulus along the continuum appeared as the final word in each 9-word sentence frame (see below). Central and peripheral

[2] While there may be subtle variations in cognitive performance among both participant groups despite normal MMSE scores, we simply wanted to rule out global impairment.

semantic features were determined using the ratings methods of Titone (1998). Words were presented to fourteen American and Canadian adult native speakers of English ranging in age from 16 to 54 years (mean age=25 years). Participants were asked to list semantic features of each word with which they were presented. Those features provided by more than 50% of participants were deemed central features; responses provided by less than 30% of participants were deemed peripheral features. These features served as the basis for the creation of the sentence contexts for each category (central /g/ bias (CG); central /k/ bias (CK); peripheral /g/ bias (PG); peripheral /k/ bias (PK); neutral (N)).

Multiple repetitions of all sentences and final target word stimuli were produced at a normal speaking rate by an adult male native speaker of English and recorded in a sound-attenuated room using a portable digital audio tape recorder (Sony DAT Walkman TCD-D100) and a head-mounted microphone (AKG Acoustics C420). The stimuli were then digitized onto an IBM-compatible computer using the Bliss speech analysis system (Mertus, 1989) at a sampling rate of 20 kHz with a 9.0-kHz low-pass filter and 12 bit quantization.

Continua consisted of five steps each, created following the procedure described by Boyczuk and Baum (1999). VOT and total word duration of each token produced were measured. The means of these values were calculated and the production that most closely approximated the means was selected as the exemplar of each word endpoint. As illustrated in Table 1, for the gash-cash continuum, VOT ranged from 21 ms to 69 ms, with an average step size of 12 ms; for the goal-coal continuum, the VOT ranged from 26 ms to 99 ms, with an average step size of 18 ms.

Insert Table 1.

To create these stimuli, cursors were placed on the voiced exemplar waveform at zero crossings in the vowel closest to the calculated step size intervals. The voiced endpoint of the continuum was the voiced exemplar token; all other stimuli were created by replacing the burst and the original VOT of the /g/ and a portion of the vocalic segment of the voiced token with sections of the burst and aspiration noise of the naturally produced /k/ of the voiceless token. Using this methodology, each item on each continuum had the same total duration (548 ms for gash-cash; 295 ms for goal-coal). Truncating the vowels at zero crossings resulted in progressively shorter vowel segments as VOT increased.

For the experiment, each of the final target word stimuli (VOT continuum steps) for both continua were paired with each sentence. That is, all VOT stimuli steps for the gash-cash continuum were paired with all forty sentences for the first block of the experiment. For the second block of the experiment, all VOT stimuli for the goal-coal continuum were paired with all forty sentences. This resulted in 400 unique sentences, 200 per experimental block. A trial consisted of a sentence frame followed by a 50 ms inter-stimulus interval and ending with a token from the continuum being tested. Subjects were given a 5 second response window. At the end of this response window, the next trial was presented. Sentence frames consisting of gash-cash contexts and goal-coal final target words, and vice versa, served as a neutral (unbiased) comparison context.

Procedure

Testing was completed in a single session of approximately one hour. Participants were seated in a sound-treated (but not sound-proof) room in front of a button box with buttons labeled “G” and “K”. They were instructed to decide as quickly as possible whether the last word of each sentence they heard over closed headphones began with a “G” or a “K” sound.

Further, they were told that some sentences may not make sense and that they might hear repetitions of similar sentences. Participants were permitted to adjust the volume to a comfortable listening level to ensure adequate audibility across listeners.

Each experimental block (continuum) was preceded by a set of practice trials in which all stimuli along the continuum were presented in random order in the context of five different sentence frames. Upon completion of the practice block, participants were asked to identify the two words they heard to ensure that the stimuli were intelligible. Following the practice block, subjects were presented with an experimental block from one continuum presented in random order. This was followed by another practice block for the alternate continuum, and then the experimental block for that same continuum. Block order and button assignments were counter-balanced across subjects within each group.

RESULTS

To examine whether context influenced the phonetic perception of sentence final target words, the category boundaries and the percentage of voiced (/g/) responses were calculated for each subject within each group for each biasing condition. Category boundaries are frequently used in phonetic identification studies to examine whether there has been a shift in the perception of ambiguous, intermediate stimuli along a continuum. Measures of total voiced responses allow for the inclusion of any perceptual changes at other points along a continuum (see Boyczuk & Baum, 1999).

Figure 1 illustrates mean percentages of voiced responses for each group and condition for the gash-cash continuum. Figure 2 illustrates the percent voiced responses for each group and condition for the goal-coal continuum. Examination of the graphs shows an effect of bias on identification of stimuli, with the older group somewhat more influenced by context than the younger group.

Insert Figure 1.

Insert Figure 2.

Following Boyczuk and Baum (1999), category boundaries were calculated for each subject for each condition on each continuum by fitting a linear regression line to the data in the boundary regions of the continua in order to determine the stimulus number (and associated VOT value) corresponding to 50% voiced responses. Table 2 presents average category boundaries (in ms) and standard errors for each group in each condition for both continua. Values in this table demonstrate that for both continua, both groups tended to demonstrate the expected pattern of boundary shifts in the biased conditions, with larger differences for the older adults. As expected, contexts biasing the voiceless endpoint shifted boundaries toward the voiced endpoint (i.e., toward lower VOT values) relative to contexts biasing the voiced endpoint. Contexts biasing the voiced endpoint shifted boundaries toward the voiceless endpoint. As predicted, the differences in boundaries between conditions were larger for the older subjects than for the younger subjects.

Insert Table 2.

In order to verify whether these differences reached statistical significance, separate Group (Young, Older) X Bias (CG, CK, PG, PK, N) repeated measures analyses of variance (ANOVAs) were conducted on category boundary values for each continuum. For the gash-cash continuum, the ANOVA revealed a significant main effect of Bias ($F(4,68) = 9.12$, $p < .001$), indicating a contextual influence on subjects' phonetic identifications. There was also a marginally significant Group x Bias interaction ($F(4,72) = 2.43$, $p = .066$). To explore this interaction further, post-hoc tests were conducted using the Newman-Keuls procedure ($p<.05$). The post hoc tests revealed that within the older group alone, the boundaries computed in the CG and CK conditions differed significantly and the CG boundary differed from that found in the N condition. Further, the PG boundary was significantly higher than the N boundary, which was, in turn, significantly higher than the boundary in the PK condition. For the younger participants, only the CG boundary differed significantly from that found in the N condition.

For the goal-coal continuum, the ANOVA revealed only a significant main effect of Bias ($F(4,64) = 4.97$, $p < .001$). Post-hoc analyses using the Newman-Keuls procedure demonstrated that both the CG and PG boundaries differed from that for the N condition; in addition, the PG and PK boundaries differed significantly.

Overall percentages of voiced responses were calculated for each subject for each continuum by taking the average percent voiced responses across all continuum steps for each condition (see Pitt & Samuel, 1993). This measure permits one to identify changes in identification performance at other points along the continuum (e.g., the endpoints). Table 3 presents average percentages of voiced responses and standard errors for each group in each condition for the gash-cash and goal-coal continua.

A two-way ($Group_2$ X $Bias_5$) repeated measures ANOVA on the percentage of voiced responses for the gash-cash continuum revealed a significant main effect of Bias ($F(4,72) = 8.38$, $p < .001$) and a significant Group X Bias interaction ($F(4,72) = 3.82$, $p < .01$)[3]. Post-hoc analyses of the interaction using the Newman-Keuls procedure demonstrated that within the older subject group alone, paralleling the findings for boundary values, the percent voiced responses for the CG condition was significantly higher than both the N and CK conditions, supporting an influence of biasing context. Within the peripherally-biasing conditions, the

[3] The data were also arcsine-transformed; results of the subsequent ANOVA were identical.

overall percent voiced responses for the PK condition was significantly lower than both the N and PG conditions, again reflecting the influence of the sentence context. No significant differences across conditions were observed for the younger participants.

For the goal-coal continuum, a similar ANOVA revealed only a significant main effect of Bias ($F(4,72) = 4.83$, $p = .002$)[4]. Post-hoc analysis of the Bias effect revealed significant differences between the CG and both N and CK conditions; for the peripheral contexts, only the PG and PK conditions differed significantly.

Insert Table 3.

In examining the patterns of individual results, it is clear that the majority of older adults display response patterns in keeping with the group averages, thus demonstrating an influence of sentential context. In contrast, within the younger adult group, only approximately 50% of the group exhibit some contextual influence, most noticeable in the region of the ambiguous stimuli.

While individual subject responses tend to pattern with the group means, there was one older subject, AC11, whose responses differed somewhat from the rest of the group. As shown in Figure 3, this subject was influenced by the central biasing context in both continua. Most interestingly, this individual seemed to rely completely on semantic context in rendering phonetic decisions, as responses within the neutral condition remained close to chance for all steps along the continua. Findings for the peripheral biasing contexts were less consistent, although a similar trend is evident for the 'gash-cash' continuum. As has been demonstrated elsewhere (e.g., Baum, 2003), this older individual's reliance on contextual information overrode any cues provided by the acoustic input.

Insert Figure 3.

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[4] The data were also arcsine-transformed; results of the subsequent ANOVA were identical.

DISCUSSION

The principal objective of the current investigation was to determine whether age-related differences exist in the degree to which older and younger individuals make use of top-down processing—specifically, semantic context—in phonetic identification. The findings demonstrated that while semantic influences are present to some degree in both age groups of listeners, older individuals seem to rely to a somewhat greater extent on contextual information, in keeping with previous findings (e.g., Boothroyd & Nittrouer, 1988; Pichora-Fuller et al., 1995; Sommers & Danielson, 1999; Wingfield, 1996; Wingfield et al., 1991). Effects of semantic context on phonetic identification in young adult listeners emerged only for one of the two continua; we attribute this context effect in the 'goal-coal' continuum as reflective of a strategy invoked under conditions of increased stimulus uncertainty (but see below for an alternative explanation). That is, although the 'goal-coal' stimuli were constructed in the same manner as the 'gash-cash' stimuli, they were substantially shorter in duration (due in part to their phonological structure) and somewhat less clear due to the final 'dark' /l/ following the diphthongal nucleus. Recall that the two pairs of stimuli were chosen to control for differences in frequency of occurrence across the voiced and voiceless endpoints and thus a limited set of base stimuli were available; the endpoint stimuli were also of the same grammatical category to ensure that they could all be substituted for one another in the biasing sentence context frames. Thus, in keeping with certain claims in the literature, normal-hearing young adult listeners appear to make use of semantic contextual information in phonetic identification mainly when the signal is degraded or less-than-ideal in some way (see Burton et al., 1989; McQueen, 1991). Of direct relevance to the goal of the present investigation, older listeners relied on semantic context more consistently, across both continua and, in some instances, even at continuum endpoints (see Figure 2).

With regard to the magnitude of the category boundary shifts computed, shifts on the order of 3-6 ms emerged for the older participant group in both the central and peripheral biasing conditions, in keeping with previous findings (e.g., Baum, 2001). Interestingly, upon inspection of Table 2, it is apparent that boundary shifts were generally quite small for the young adult listeners (on the order of 1-2 ms) with a single exception in the peripheral biasing contexts for the 'goal-coal' continuum (~5 ms). In fact, it is this somewhat surprisingly large boundary shift that accounts in large part for the emergence of a semantic bias effect for the young listeners for the 'goal-coal' continuum. One possible explanation for this unexpected finding may relate to the details of the specific biasing contexts, provided in the Appendix. Although great efforts were made to ensure that the contexts avoided syntactic cues that might bias the identification of the final word, this was not feasible in all cases. Upon close inspection of the stimuli, it may be noted that the sentence frames for the PK condition contained somewhat more such syntactic cues (in this instance, the preposition 'of') than the other biasing conditions. Whereas the differences in the presence of such cues across conditions were not substantial, they may have influenced the listeners and resulted in the anomalously large context effect for the peripherally-biased 'goal-coal' stimuli. Although one might expect older adults to also be influenced by these syntactic cues, it is possible that the limited nature of the cues (i.e., simply the preposition 'of') was too subtle or provided insufficient preceding context to have influenced the older participants. Another possibility, due to age-related changes in processing speed, is that the older adults had insufficient time for the subtle syntactic contextual cue to influence their phonetic decisions (Wingfield, 1996).

If one examines for a moment the average boundary values across the two continua, particularly in the N condition, it is apparent that lexical frequency is exerting an effect for both participant groups. That is, in the 'gash-cash' continuum, 'cash' is the more frequent endpoint, attracting more (/k/) responses and thus shifting the boundary to lower VOT values for both groups. Similarly, the 'goal' endpoint, as the more frequent of the pair, attracts more (/g/) responses, shifting the boundary to higher VOT values (see Table 2). One might, of course, argue that the N condition is not truly neutral in that when the target continuum stimuli are embedded in the sentence context frames, an anomalous string results. Nonetheless, it is clear that the contexts cannot provide any appropriate semantic bias and all are equally anomalous; therefore, the stimuli in this condition are neutral with respect to the potential influence of the context on phonetic identification.

It is also noteworthy that, with the exception of the results for the young adults on the 'goal-coal' continuum (discussed elsewhere), the degree of bias (i.e., central vs. peripheral) had little influence on the extent of the boundary shift that resulted. This finding was somewhat surprising, but suggests that older adults, in particular, make use of any contextual information available to them to compensate for reduced speech processing abilities associated with aging (Tremblay et al., 2002; 2003).

In sum, the results add to the body of work that claims that older individuals demonstrate an increased reliance on contextual information in language processing (Cohen & Faulkner, 1983; Boothroyd & Nittrouer, 1988; Pichora-Fuller et al., 1995; Sommers & Danielson, 1999; Wingfield et al., 1996; 1991). Notably, the data gathered in the present experiment extend previous findings regarding lexical (Baum, 2003; Boyczuk & Baum, 1999) and metrical (Baum, 2003) effects on phonetic identification to the domain of sentential semantics (Connine, 1987), indicating that under conditions of increased stimulus uncertainty, older listeners rely on higher-level context to assist in phonetic identification decisions. As claimed elsewhere, this ability to make use of contextual cues when needed may provide older listeners with a very useful compensatory strategy to retain adequate language comprehension in the face of limitations in (temporal) perceptual acuity (Baum, 2003; Wingfield, 1996; Wingfield et al., 1989; 1992). It remains to be seen whether the kind of compensatory comprehension behaviors identified here are related to age-related changes in brain activity (e.g., Cabeza, 2002; Cabeza et al., 2002).

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APPENDIX: Sentence Stimuli

Central CASH [CK]

1. He left no record while shopping because he used CASH.
2. Alice went to the local bank to withdraw some CASH.
3. Joe took out his heavy wallet to count the CASH.
4. Sara examined the presidential faces on the newly issued CASH.
5. The woman usually paid for her new clothes with CASH.

Peripheral CASH [PK]

1. Mike always washed his hands thoroughly after touching the CASH.
2. Steve yelled when the scary man reached for the CASH.
3. Jen started an art project that involved designing fake CASH.
4. Jane's mood changed when she saw the bag of CASH.
5. Gary felt important when he had a lot of CASH.

Central GASH [CG]

1. Greg fainted when he saw blood oozing from the GASH.
2. The doctor told Jon he needed stitches for the GASH.
3. The most painful injury Sue had involved a nasty GASH.
4. After the nasty fist-fight, Tom's face had an ugly GASH.

5. The nurse had to clean and dress the infected GASH.

Peripheral GASH [PG]

1. Sally was very upset after she noticed her son's GASH.
2. The designer closely examined the wall that had a GASH.
3. George needed to find a way to repair the GASH.
4. Whenever Dan uses heavy power-tools, his hand gets a GASH.
5. Ana could not bear to look at the unfortunate GASH.

Central COAL [CK]

1. Ray's hands were very black after he touched the COAL.
2. For energy, many poor countries routinely extract and burn COAL.
3. To prepare for the barbeque, Ali bought a bag of COAL.
4. Nate developed a terrible cough after years of mining COAL.
5. Kate hated the black soot produced by the dirty COAL.

Peripheral COAL [PK]

1. Linda was always cautious when lifting the large box of COAL.
2. Marty examined the external structure of the piece of COAL.
3. Jeff collected many interesting objects including small bits of COAL.

4. The artist had an intriguing way of graphically depicting COAL.

5. The last parcel remaining was the bag of loose COAL.

Central GOAL [CG]

1. Everyone cheered when the young player scored the winning GOAL.

2. The soccer player skillfully aimed the ball at the GOAL.

3. The player with the most protective gear guards the GOAL.

4. Last year’s losing hockey team almost never scored a GOAL.

5. Andy was angry when the puck deflected off the GOAL.

Peripheral GOAL [PG]

1. After the long tiring class, Jan leaned against the GOAL.

2. Tina found it very hard to see the metal GOAL.

3. After weeks of waiting, Stan finally made his first GOAL.

4. After school, the young students mowed grass around the GOAL.

5. When Tim fell, his shoes got caught in the GOAL.

ACKNOWLEDGEMENTS

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Table 1

VOT Values and Step Sizes For All Continuum Stimuli

Stimulus Number	Voice onset time (ms)	Step size (ms)
gash-cash		
1	21	
2	33	12
3	45	12
4	57	12
5	69	12
goal-coal		
1	26	
2	44	18
3	62	18
4	80	18
5	99	19

Table 2

Average Category Boundaries in ms For Each Group in Each Condition for Both Continua (standard errors appear in parentheses)

	CATEGORY BOUNDARY IN MS (GASH-CASH)				
GROUP	Central G	Central K	Peripheral G	Peripheral K	Neutral
Young adults	41.96 (0.86)	40.15 (0.85)	40.02 (1.09)	38.73 (2.09)	39.26 (1.09)
Older adults	46.79 (2.45)	41.63 (2.58)	45.28 (2.08)	39.09 (2.49)	41.81 (2.09)

	CATEGORY BOUNDARY IN MS (GOAL-COAL)				
GROUP	Central G	Central K	Peripheral G	Peripheral K	Neutral
Young adults	46.52 (2.18)	46.36 (2.05)	46.07 (2.16)	41.21 (1.26)	43.55 (1.70)
Older adults	48.79 (2.20)	45.66 (2.88)	46.59 (2.39)	42.63 (3.05)	44.27 (2.74)

Table 3

Percent of Voiced Responses for Each Group, Condition, and Continuum (standard errors appear in parentheses)

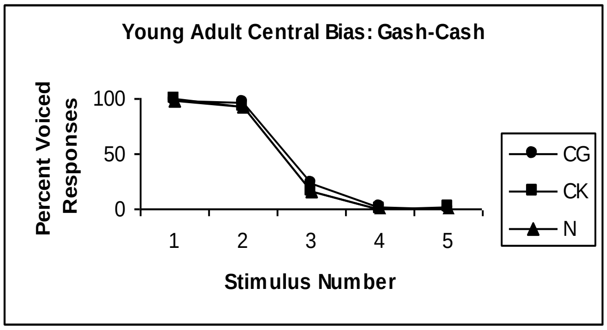
% voiced responses (gash-cash)					
GROUP	CG	CK	PG	PK	N
Young adults	44 (1.5)	42 (1.2)	42 (1.7)	40 (1.8)	42 (1.6)
Older adults	56 (4.2)	42 (4.1)	50 (2.8)	38 (4.3)	46 (2.8)
% voiced responses (goal-coal)					
GROUP	CG	CK	PG	PK	N
Young adults	33 (2.3)	30 (2.6)	32 (2.3)	26 (1.6)	30 (1.8)
Older adults	40 (6.3)	27 (4.1)	32 (2.6)	28 (4.3)	30 (3.3)

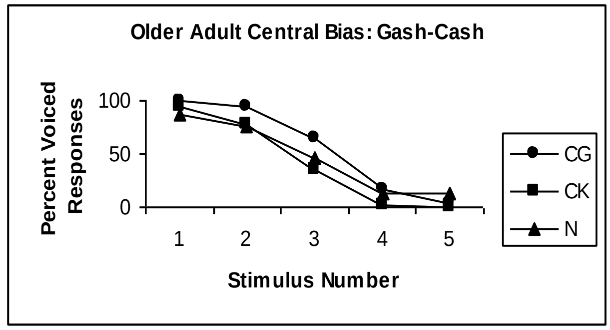
Figure Captions

Figure 1. Mean percent voiced responses for central (Central Gash (CG); Central Cash (CK)) and peripheral (Peripheral Gash (PG); Peripheral Cash (PK)) biasing and neutral (N) contexts for younger and older groups for the ‘gash-cash’ continuum.

Figure 2. Mean percent voiced responses for central (Central Goal (CG); Central Coal (CK)) and peripheral (Peripheral Goal (PG); Peripheral Coal (PK)) biasing and neutral (N) contexts for younger and older groups the ‘goal-coal’ continuum.

Figure 3. Percent voiced responses for central and peripheral biasing contexts for older adult subject AC11 for the ‘gash-cash’ and ‘goal-coal’ continua.


Young Adult Central Bias: Gash-Cash
Percent Voiced Responses
100
50
0
1
2
3
4
5
Stimulus Number
CG
CK
N


Older Adult Central Bias: Gash-Cash
Percent Voiced Responses
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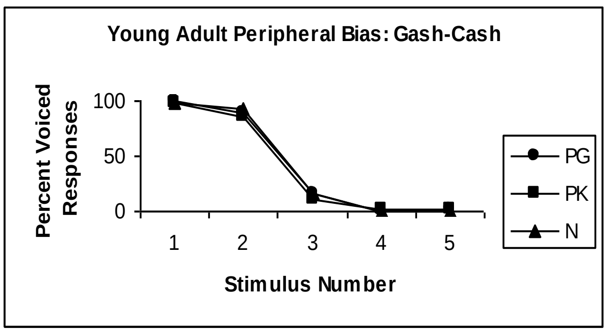
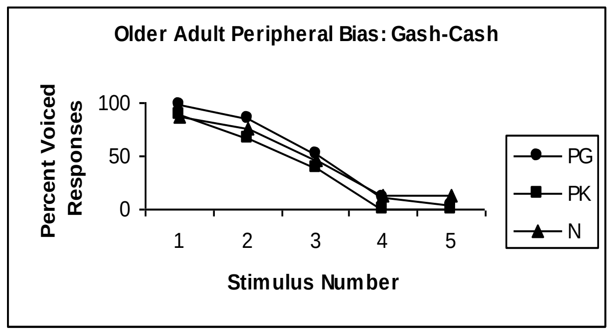
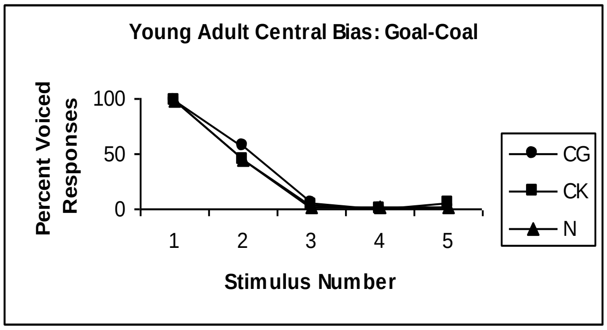
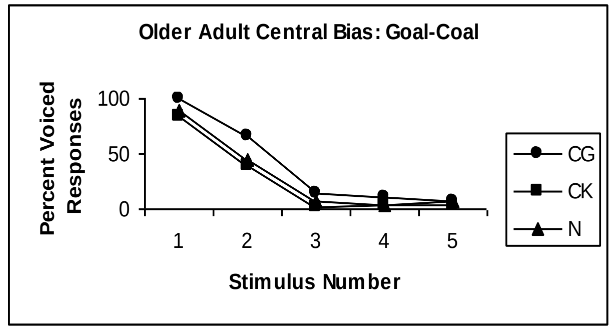
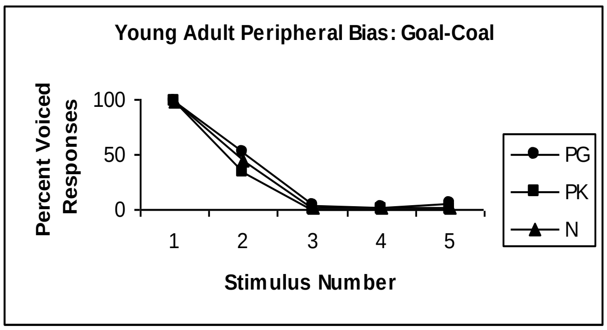
1
2
3
4
5
Stimulus Number
CG
CK
N

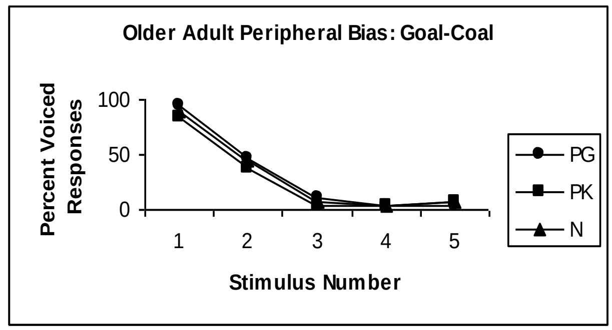

Young Adult Peripheral Bias: Gash-Cash
Percent Voiced Responses
100
50
0
1
2
3
4
5
Stimulus Number
PG
PK
N

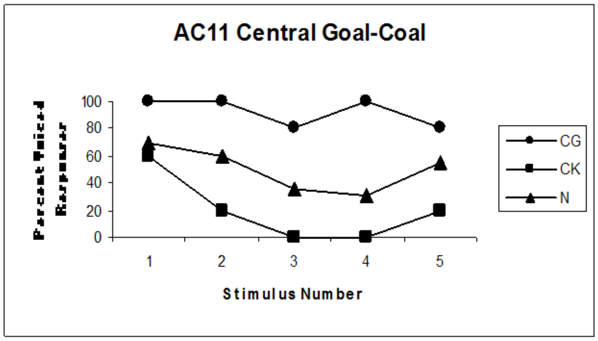

Older Adult Peripheral Bias: Gash-Cash
Percent Voiced Responses
100
50
0
1
2
3
4
5
Stimulus Number
PG
PK
N

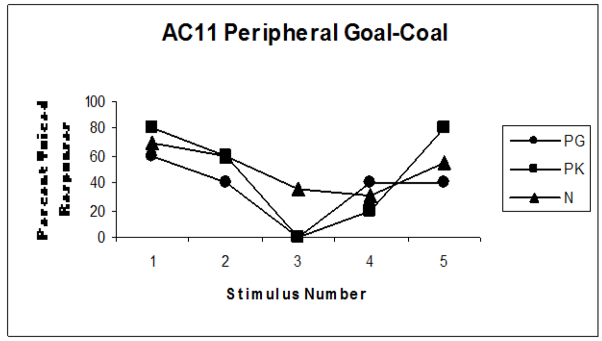

Young Adult Central Bias: Goal-Coal
Percent Voiced Responses
100
50
0
1
2
3
4
5
Stimulus Number
CG
CK
N


Older Adult Central Bias: Goal-Coal
Percent Voiced Responses
100
50
0
1
2
3
4
5
Stimulus Number
CG
CK
N


Young Adult Peripheral Bias: Goal-Coal
Percent Voiced Responses
100
50
0
1
2
3
4
5
Stimulus Number
PG
PK
N


Older Adult Peripheral Bias: Goal-Coal
Percent Voiced Responses
100
50
0
1
2
3
4
5
Stimulus Number
PG
PK
N


AC11 Central Goal-Coal
100
80
60
40
20
0
1
2
3
4
5
Stimulus Number
CG
CK
N


AC11 Peripheral Goal-Coal
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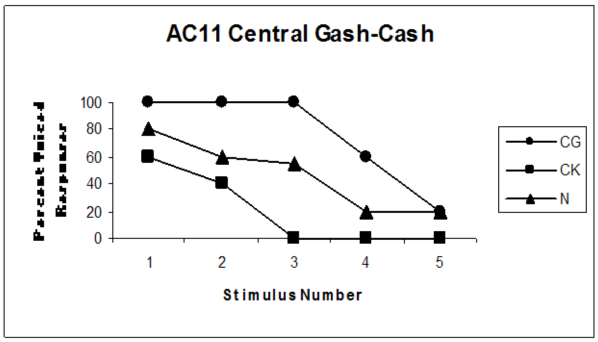
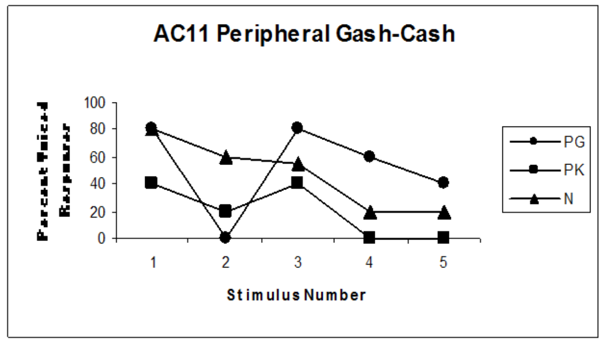
80
60
40
20
0
1
2
3
4
5
Stimulus Number
PG
PK
N


AC11 Central Gash-Cash
100
80
60
40
20
0
1
2
3
4
5
Stimulus Number
CG
CK
N


AC11 Peripheral Gash-Cash
100
80
60
40
20
0
1
2
3
4
5
Stimulus Number
PG
PK
N