

# Age differences in electrophysiological correlates of cross-modal phrasal interpretation

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## Abstract

Research shows that older adults may be more sensitive than young adults to prosody, although performance varies depending on task requirements. Here we used electroencephalography to examine responses to simple phrases produced with an Early or Late boundary, presented with matching or mismatching visual displays. While some older adults successfully detected prosodic mismatches, many failed to do so. Nonetheless, mismatches elicited a P600-like positivity in all participants. Those individuals who accurately judged prosody also displayed a second negative-going prosodic mismatch response. Findings show that older adults vary in their reliance on prosody, as reflected both in behavioral and ERP responses.

**Index Terms:** ERP, Aging, Cross-modal, Prosody

## 1. Introduction

Much behavioral research has shown that young adults are sensitive to prosodic cues and that they exploit them to interpret phrase boundaries in both simple phrases (e.g., '(A + E) x O' versus 'A + (E x O)') and complex sentences containing transient syntactic ambiguities (TSAs, e.g., early/late closure: '*Because her grandmother knitted pullovers # Kathy kept warm in the wintertime*' versus '*Because her grandmother knitted # pullovers kept Kathy warm in the wintertime*') (see [1] for a review). Electrophysiological investigations of prosodic processing for phrasal interpretation reveal that phrase boundaries marked by fundamental frequency ( $f_0$ ) and duration, or  $f_0$  alone, elicit a Closure Positive Shift (CPS) and that boundaries violating syntactic structure elicit P600 effects [2].

A growing body of research has documented sensitivity to prosodic information in older adults. In simple phrases, such as the arithmetic phrases above, older adults perform similarly to young adults and are able to exploit prosodic cues to assign phrase structure [3]. Examinations of complex sentences containing TSAs show that older adults exploit prosody in self-paced listening [4], recall [5], and sentence completion [6].

However, there are also indications of age-related differences in prosodic processing. For example, in a self-paced Auditory Moving Window task, conflicting prosody hindered understanding to a greater extent in older adults than in younger adults, suggesting that older adults may in fact be more reliant on prosody than are young adults [7]. When asked comprehension questions about utterances that differed in prosodic boundary only (e.g., 'Madam, Flower is the name of my cat.' versus 'Madam Flower is the name of my cat. '), older adults performed significantly worse than did their younger counterparts [3]. Wingfield and colleagues [5] found that in recall production, older adults were more likely to change conflicting syntax to conform with prosody, whereas younger adults were more

likely to change conflicting prosody to conform with syntax. Kjelgaard and colleagues [6] found that when participants completed sentence fragments that had been presented with incorrect prosody, younger adults' responses were slower than those of older adults, suggesting that either young adults had greater difficulty resolving prosodic anomalies than did older adults, or that older adults weigh prosodic cues differently, and may be able to either override or disregard prosody in some cases. Steinhauer and colleagues [8] illuminated significant differences between behavioral and electrophysiological responses to prosody in older adults. They found that while many older adults accepted prosodically-anomalous stimuli more often than did young adults in an off-line behavioral response, prosodic violations elicited similar event-related potentials (ERPs) in older adults as they did in young adults.

In order to investigate prosodic processing in the absence of syntactic violations that accompany the examination of complex sentences, in the present investigation behavioral and ERP responses were collected from young and older adults to simple auditory phrases (e.g., 'bag and bed and cup') containing either an early or late boundary marked by a 450 ms pause. These phrases were presented simultaneously with visual stimuli consisting of a horizontal array of three pictures corresponding to the three words in the phrase. The three objects were visually grouped in ways that were either congruent or not with the corresponding prosodic grouping (see §2.1 and Figure 1). Phrases and pictures either shared the same semantic and prosodic/grouping content, or differed in one or both of these domains. This design allowed us to explore whether visual context influences prosodic perception to the same degree in younger and older adults, and whether the same electrophysiological correlates to prosody are elicited in aging adults. This design also allows for many possible comparisons bearing on the interactions between semantics and prosody. The present report concentrates only on findings relevant to older adults' performance in this task as compared to a subgroup of young adults.

## 2. Methods

### 2.1. Participants

Data from fifteen older adults (ages 65 to 80 years, mean = 70, sd = 3.5 years; 9 female) tested in the School of Communication Sciences and Disorders at McGill University were compared to data from thirteen young adults (ages 18 to 25 years, mean = 21 years, sd = 1.5 years; 8 female). All subjects were right-handed native speakers of English with no history of neurological or hearing impairments (confirmed by audiometric screening) and with normal or corrected-to-normal vision.

	EARLY BOUNDARY		LATE BOUNDARY	
	HEAR	SEE	HEAR	SEE
<b>Match</b> Phrase and picture match	'bag # and bed and cup'		'bag and bed # and cup'	
<b>Prosodic Mismatch</b> Phrasal boundary differs from visual boundary	'bag # and bed and cup'		'bag and bed # and cup'	
<b>Semantic Mismatch</b> Middle noun in phrase does not match middle item in picture	'bag # and bed and cup'		'bag and bed # and cup'	
<b>Double Mismatch</b> Phrasal boundary differs from visual boundary AND Middle noun in phrase does not match middle item in picture	'bag # and bed and cup'		'bag and bed # and cup'	

Figure 1. Examples of conditions and stimuli

## 2.2. Materials and Procedure

Subjects were presented with auditory phrases created from 16 easily picturable monosyllabic CVC nouns modified to be equivalent in duration such as 'bag and bed and cup', with 450 ms pauses inserted so as to create a phrasal grouping with either an Early boundary ('bag # and bed and cup') or a Late boundary ('bag and bed # and cup') (see figure 1 for examples). Pictures of the items, taken from the Snodgrass and Vanderwart Picture Inventory [9], were presented simultaneous with the auditory phrases.

These pictures corresponded to the phrases both prosodically and semantically (control; C), differed in the phrase grouping depicted (prosodic mismatch; PM), differed semantically at the middle item (semantic mismatch; SM), or differed in both phrase grouping and the middle item (double mismatch; DM). There was an equal probability of being presented with an Early vs Late boundary, control vs mismatch, and prosodic vs semantic mismatch. Semantic mismatches were included to ensure the task could successfully access the processes under investigation, but will not be discussed further here (see Abada et al., in prep). Participants were asked to attend to both auditory and visual stimuli and determine whether or not they matched. ERPs were recorded reflecting sensitivity to prosodic cues and the influence of visual context on prosodic processing.

## 2.3. ERP recording

EEG was continuously recorded in DC mode with a 500 Hz sampling rate using Neuroscan Synamps2 amplifier from 32 pin-type active Ag/AgCl cap-mounted electrodes referenced to the right mastoid and arranged according to the extended 10-20 system [10]. All impedances were kept below 5 k $\Omega$ . Vertical electrooculogram (VEOG; from electrodes placed above and below the right eye) and Horizontal EOG (HEOG; from electrodes placed at the outer canthus of each eye) were recorded to measure blinks and eye movements.

## 2.4. Data analysis

Upon examining behavioral responses, two distinct patterns of behavior emerged for older adults. While all older adults correctly identified semantic mismatches and control matches, many older adults ( $n = 6$ ) did not correctly reject prosodic mismatches, though the remaining participants in this group were successful at identifying these mismatches ( $n = 9$ ). To further explore these differences, the older adult group was divided into two groups: those who perceived prosodic mismatches (+pros older) and those who did not (-pros older). Participants in the -pros group correctly identified prosodic mismatches in less than 19% of trials (mean = 4.69% correct,  $sd = 7.33\%$ ). All other participants correctly identified prosodic mismatches in at least 61% of trials (mean = 85.16%,  $sd = 15.24\%$ ). Behavioral data were analyzed for accuracy using a repeated measures

analysis of variance (ANOVA) with factors Group (3: young, +pros older, -pros older) x Boundary (2: Early, Late) x Prosody (2: match, mismatch) x Semantics (2: match, mismatch).

EEG data were analyzed using EEProbe (ANT, The Netherlands). Data pre-processing consisted of filtering (0.16-30 Hz bandpass) and artifact rejection at electrodes Fp1, Fp2 and VEOG. Single subject averages were computed separately for the four conditions (i.e., PM/SM/DM/C) in each of the two boundary condition (Early/Late) and were computed for 2200 ms epochs beginning at the onset of word 1 of each phrase and ending roughly 100 ms after the offset of word 3 (baseline: 0 to 200 ms). Within this epoch, ERP effects for prosodic processing were quantified by means of amplitude averages in two time windows (a) 1000–1200 ms (prosodic positivity in both Early and Late boundaries) and (b) 1400–1650 ms (prosodic negativity in Early boundary only).

ERP effects were examined at midline electrodes. Separate repeated measures ANOVAs were conducted for each boundary condition for midline electrodes with the factors Prosody (Early or Late visual boundary), Semantics, AntPost (Fz/FCz/Cz/CPz/Pz/Oz) and Group. Greenhouse-Geisser corrections were employed where applicable. All follow-up analyses of Group or distribution effects were examined via additional follow-up ANOVAs for each group or electrode position.

## 3. Results

### 3.1. Behavioral

Behavioral analyses of accuracy revealed significant main effects of Group ( $F(2,25) = 93.18, p < .0001$ ), Boundary ( $F(1,25) = 10.84, p = .0030$ ), and Prosody ( $F(1,25) = 1791.34, p < .0001$ ). Analyses further revealed significant Group x Boundary ( $F(2,25) = 3.55, p = .0441$ ), Group x Prosody ( $F(2,25) = 794.09, p < .0001$ ), Boundary x Prosody ( $F(1,25) = 5.96, p = 0.0221$ ) and Group x Boundary x Prosody ( $F(2,25) = 5.04, p = .0145$ ) interactions. Follow-up analyses showed that the effect of Boundary and the interaction of Boundary x Prosody were significant in the +pros older adults only (Boundary  $F(1,8) = 25.55, p = .0010$ ; Boundary x Prosody ( $F(1,8) = 21.74, p = .0016$ ), and not the other two groups (Boundary: -pros ( $F(1,5) = .82, p = .4062$ , young ( $F(1,12) = .59, p = .4589$ ); Boundary x Prosody: - pros ( $F(1,5) = .66, p = .4541$ , young ( $F(1,12) = .17, p = .6875$ )). The main effect of Prosody, however, was significant in all three groups, and very highly significant in the -pros older adult group ( $F(1,5) = 2515.21, p < .0001$ ) since these adults achieved much lower accuracy rates for the prosodic mismatch conditions overall. As can be seen in Figure 2, these statistics correspond to increased accuracy in the match/control conditions compared to the mismatch conditions in all groups. There was also an overall increased accuracy in the Late boundary compared to the Early boundary condition. Additionally, in prosodic mismatch conditions, accuracy increased in the Late boundary condition in all groups. Figure 2 also shows that +pros older adults were more accurate than both the -pros older and younger groups in all conditions, suggesting that this group is

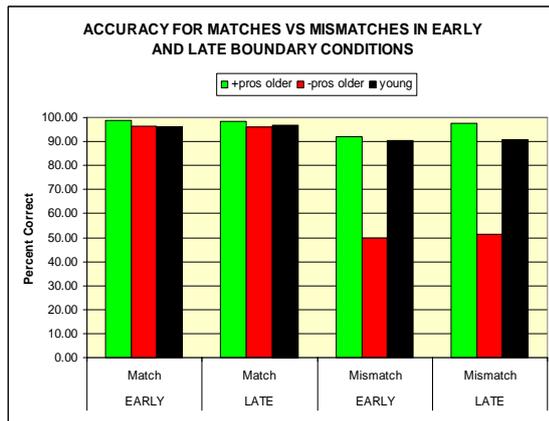


Figure 2. Behavioral data

indeed more sensitive to prosodic cues than are young adults. On the other hand, the  $-$ pros older adults did not differ from the young adults in responses to match items. The differences between the  $-$ pros older and young groups were limited to the prosodic mismatch conditions.

### 3.2. Event-related brain potentials

Analyses of ERPs for prosodic effects revealed an increased positivity for prosodic mismatch conditions that appeared roughly 600 ms after the prosodic anomaly in both boundary conditions (i.e., the onset of an unexpected pause in the Early boundary condition or the absence of an expected pause in the Late boundary condition). This effect was observed in all groups and was confirmed statistically in the 1000 – 1200 ms time window by a main effect of Prosody in both boundary conditions (Early  $F(1,25) = 12.57, p = .0016$ ; Late  $F(1,25) = 15.73, p = .0005$ ) and a Prosody  $\times$  AntPost interaction, again in both boundary conditions (Early  $F(5,125) = 7.66, p = .0018$ ; Late  $F(5,125) = 4.83, p = .0207$ ). These effects were significant at all recording sites, but strongest over fronto-central electrodes. It should be noted, however, that while this effect is statistically significant, in Figures 3 and 4 the effect does not appear robust for the  $-$ pros older adults.

As can be seen in Figure 3, in the Early boundary condition, the prosodic mismatch elicited an additional negativity for prosody, similar in latency and morphology to an N400. This negativity peaked roughly 300 ms after the second noun, or the point at which the pause that correlated with the visual input (late boundary) would have begun if the auditory and visual input matched. This negativity occurs in the same time window as a positivity to semantic information, which will not be discussed here, and therefore results in an interaction between the negative and positive components. This is confirmed statistically in the 1400 – 1650 ms time window by a trend towards a Prosody  $\times$  Group interaction ( $F(2,25) = 2.68, p = .0885$ ) and a Prosody  $\times$  Semantics  $\times$  AntPost interaction ( $F(5,125) = 4.93, p = .0107$ ). Follow up ANOVAs at each electrode position revealed that the Prosody  $\times$  Semantics interaction was significant over the occipital electrode ( $F(1,25) = 5.70, p = .0249$ ). Though the Prosody  $\times$  Group interaction did not reach significance, in order to gain further insight into how these groups process prosody, the main effect of Prosody was examined in ANOVAs for each group. These analyses revealed that the  $-$ pros older adults did not show a significant main effect of Prosody, while the older adults who perceived the prosodic mismatches and the young

adults did show a main effect of Prosody ( $-$ pros ( $F(1,5) = 1.19, p = .3245$ ; +pros ( $F(1,8) = 14.96, p = .0048$ ; young ( $F(1,12) = 4.88, p = .0473$ ).

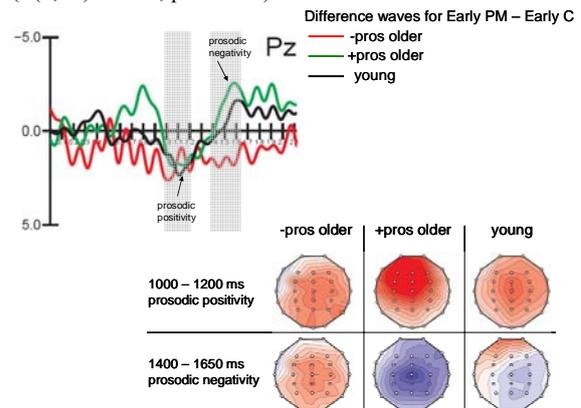


Figure 3. Early boundary difference waves and voltage maps

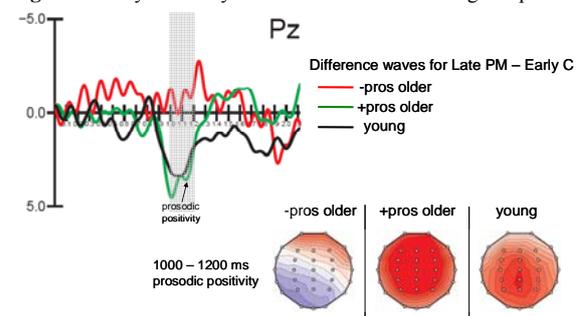


Figure 4. Late boundary difference waves and voltage maps

## 4. Discussion

Our findings show visual context influences prosodic processing in both younger and older adults, which was not previously known. Older adults who are sensitive to prosody are more accurate at detecting both prosodic matches and mismatches than are young adults. This supports previous research showing that older adults have an increased sensitivity to prosody and exploit prosodic cues to a greater extent than do younger adults. On the other hand, many older adults were not successful at detecting prosodic mismatches. This supports previous research showing that prosodic sensitivities are highly task-specific in the aging population and that these differences can be observed on an individual level. It should be noted, however, that it may be the case that there was simply more variance in the older adults and further analyses must be conducted to determine the differences in performance in older adults.

Regardless of behavioral responses, the electrophysiological response to a prosodic mismatch between auditory and visual context in simple phrases that was observed here was a positivity that occurred 600 ms after the point at which the prosodic violation became evident. This response is likely part of the P600 family, suggesting participants integrated visual and auditory stimuli, rather than simply observing these differences [e.g., 13]. Further, both groups of older adults were able to detect the prosodic boundary, even those unable to detect whether the boundary matched or mismatched the visual context. Since this effect occurs at the same time in both boundary conditions and across all groups of participants, it appears to be a robust response to the presence of a mismatch in auditory and visual prosodic input. This shows that the

presence of a pause is indeed sufficient to create phrasal groupings for older adults and that perceivers of this information do use both auditory and visual cues to boundaries to coordinate and interpret this information across content domains.

A second electrophysiological correlate to prosody was observed in those groups who showed a behavioral sensitivity to prosody (i.e., young adults and +pros older) in the form of a negativity that peaked 300 ms after a visually expected, yet absent, boundary. Interestingly, these participants showed an earlier response to prosodic violation when an unexpected boundary was heard. It is likely that this second response was elicited because of the nature of the stimuli themselves. That is, the only auditory cue to prosody was a pause. This pause could only be perceived relative to other elements in the sentence. Therefore, the presence of the early pause did not preclude a second, longer pause. While one could argue that after gaining some experience with the stimuli participants would expect a pause of a certain duration, it appears that the visual stimuli influenced auditory perception and expectations sufficiently to elicit this second mismatch response. Behavioral findings showing increased accuracy in the Late boundary condition further supports this claim. Intriguingly, the electrophysiological response itself is similar in morphology and latency to a conceptual-semantic N400 component (see Figure 3) and thus may index the conceptual mismatch resulting from these stimuli. This is further supported by the absence of this response in those individuals who did not reliably detect prosodic violations, indicating that they perhaps did not form the same conceptual expectations as those individuals who were sensitive to prosody.

Importantly, these findings do not suggest that prosodic sensitivities simply deteriorate after a certain age. Not only were there no differences in age between the subgroups of older adults, but a number of these individuals participated in other studies investigating prosody (e.g., [8]) and were unsuccessful at correctly rejecting prosodic violations in that study, but successfully perceived prosody in the present task.

These findings replicate previous research showing that prosodic processing in older adults is highly task-specific. It appears that not all older adults process prosody in precisely the same manner in all tasks. Further, these findings indicate that ERPs provide crucial insight into prosodic processing that is difficult to obtain via behavioral tasks alone.

## 5. Conclusions

In this study, we investigated prosodic processing in aging populations using cross-modal stimuli. We found that visual “prosodic” (grouping) context is used by many older adults when perceiving prosody, and perhaps to a greater extent than is seen in their younger counterparts. However, not all older adults showed this same response and many had difficulty perceiving the prosodic mismatch between auditory and visual information. Electrophysiological findings show that all participants, regardless of behavioral response, show a P600-like component elicited by prosodic mismatches. This is in keeping with previous results showing a dissociation between online and offline measurements of prosodic processing [8]. Finally, an N400-like conceptual mismatch response to prosody was observed only in those individuals who showed an overt sensitivity to prosody.

Future research is needed to determine whether the differences observed in the older group were caused by the task employed or overall sensitivity to prosody.

## 6. Acknowledgements

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