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Prosody–syntax interactions in aging: Event-related potentials reveal dissociations between on-line and off-line measures

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ABSTRACT

This study used ERPs to determine whether older adults use prosody in resolving early and late closure ambiguities comparably to young adults. Participants made off-line acceptability judgments on well-formed sentences or those containing prosody–syntax mismatches. Behaviorally, both groups identified mismatches, but older subjects accepted mismatches significantly more often than younger participants. ERP results demonstrate CPS components and garden-path effects (P600s) in both groups, however, older adults displayed no N400 and more anterior P600 components. The data provide the first electrophysiological evidence suggesting that older adults process and integrate prosodic information in real-time, despite off-line behavioral differences. Age-related differences in neurocognitive processing mechanisms likely contribute to this dissociation.

There has been a great deal of interest in the potential deterioration in spoken language processing abilities associated with aging [8,14,16,17,19–21,23–25]. Investigators have suggested that elderly listeners modulate how they weight aspects of the input to compensate for reduced speech processing abilities [1,13,14,22,23]. One input parameter that has received substantial attention is prosody, due to its key role in sentence interpretation [2,11,24,25].

Most studies of prosodic processing in aging have demonstrated that older adults are not only sensitive to prosody, but exploit it to a greater extent than do young adults [11,18,25]. For instance, Wingfield and colleagues [25] found that prosody influenced recall abilities of both younger and older listeners, although younger adults were better at ignoring conflicting prosody in the stimuli. Importantly, the behavioral paradigms used thus far have been unable to conclusively determine whether older adults process and integrate prosody differently from young adults in real-time.

Event-related potentials (ERPs) provide a useful means of addressing precisely these questions. Previous investigations of the integration of prosody and syntactic parsing using ERPs have focused on garden-path sentences (with temporary syntactic ambiguities). For example, a sentence that begins with the fragment in (1) below can be followed by either of the two endings (A) or (B):

(1) *When a bear is approaching the people.*
 A) . . .*the dogs come running* [Late Closure, LC].
 B) . . .*come running* [Early Closure, EC].

With no cues to phrase boundaries, young adults typically rely on a default parsing strategy known as Late Closure [4], yielding the preferred reading in (A), where the ambiguous noun phrase (underlined) is the object of the first verb rather than the subject of the second verb. However, studies have shown this parse can be modified by prosodic boundary cues that can either induce or reduce the garden-path effect [10,12,15]. In a recent ERP study in which such sentences were edited to include either co-operating or conflicting prosodic boundary cues, Pauker and colleagues [12] demonstrated P600 and biphasic N400-P600 garden-path effects in response to two types of sentences containing prosody–syntax mismatches. Importantly, both missing and superfluous prosodic boundaries showed an immediate influence on parsing and overrode typical preferences, inducing garden-path effects. This study also replicated the closure positive shift (CPS), an ERP correlate of prosodic phrasing [15].

The present investigation examines whether older individuals demonstrate a comparable pattern of ERP responses. In general, endogenous ERPs including language-related components in older adults tend to be somewhat lower in amplitude [3], emerge at longer latencies [9], and may have different scalp distributions [3,9] when compared to those in young adults.

There are no published CPS data in older subjects; if they are sensitive to prosody, we would expect a similar response as in young subjects, perhaps with different scalp distribution, amplitude and/or latency. A crucial question is whether older adults demonstrate on-line garden-path effects at all. If they do, we predict a more frontal P600, in keeping with previous findings [3]. N400 effects may be reduced, extending previous reports of aging effects on N400 amplitudes from semantic incongruity to verb-argument structure/theta roles [3,5,7].

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Table 1
Sample stimuli. Conditions C and D are derived from A and B by cross-splicing (vertical line marks splicing point). #: Prosodic boundary; EC: Early Closure; LC: Late Closure; A1–B2: start of A + end of B (no prosodic boundary); B1–A2: start of B, end of A (two boundaries).

Condition	Sentence Example – Part 1	Sentence Example – Part 2
A (LC)	*When a bear is approaching t*	*he people # the dogs come running*
B (EC)	When a bear is approaching # t	he people come running
C* (A1-B2)	*When a bear is approaching t*	he people come running
D* (B1-A2)	When a bear is approaching # t	*he people # the dogs come running*

Thirteen elderly participants (65–80 years, 7 females) were recruited. All were right-handed native English speakers with no history of brain injury or hearing impairment (PTA < 35 dB HL). One female subject was subsequently excluded due to excessive movement artifacts.

Forty EC and LC sentence pairs were recorded with normal prosody (A and B in Table 1). Forty additional (garden path) sentences without any boundaries (Condition C) were derived from the original A/B stimuli by cross-splicing the initial portion of the A-items with the final portion of the B-items. The second, more severe garden path with two boundaries (condition D, $n = 40$) was generated by cross-splicing the initial portion of B and the final portion of A (see [12]). Cue points marking words in each speech file allowed us to time-lock ERP analyses to the splicing point at the unvoiced fricative of the ambiguous NP and other critical positions.

Unrelated filler sentences were included, consisting of 80 phrase-structure violations (e.g., *He hoped to *meal the enjoy*...) and matched correct controls. All sentence types were evenly distributed across four blocks of 80 trials in a pseudo-randomized order. Eight experimental lists were created and evenly assigned across male/female participants.

After ten practice trials, participants listened to the sentences in a shielded, sound attenuating chamber, and provided sentence-final acceptability judgments (i.e., does the sentence sound natural?) via mouse button press.

EEG was continuously recorded (500 Hz sampling rate; Neuroscan Synamps2 amplifier) from 19 Ag/AgCl electrodes of the 10–20 System (Electro-Cap International), referenced to the right mastoid (impedance <5 kΩ). EOG was recorded from bipolar electrode arrays.

Acceptability judgment data and response times were subjected to repeated-measures ANOVAs with factors (i) Prosody (i.e., the presence/absence of a prosodic boundary, which yields comparisons of A/C vs. B/D prior to the splicing point, and A/D vs. B/C thereafter [see [12]) and (ii) *Violation* (A/B vs. C/D). For response times, we also included the factor *Acceptance* (accepted vs. rejected trials; [12]).

EEG data were analyzed using EEProbe (ANT, The Netherlands). Single subject averages were computed separately for the four conditions (i.e., A/B/C/D) following data pre-processing (filtering (0.16–30 Hz bandpass), eye-blink correction, artifact rejection, and detrending). Averages were based on all trials independent of the behavioral response, as ERPs did not differ between accepted and rejected trials. Following our previous analyses [12], averages were computed for 2200 ms epochs beginning 500 ms prior to the splicing point (baseline: −450 to −250 ms; [12] for details). Within this epoch, CPS and garden-path ERP components in condition D were quantified in three time windows: (a) from −150 to +150 ms (CPS), (b) 250–400 ms (N400 in D), and (c) 750–950 ms (P600 in D). As the disambiguating element in condition C occurred later, we analyzed the P600 of that condition in a 1400 ms epoch time-locked to the onset of the final verb phrase, comparing C versus its matched control B between 650 and 850 ms (baseline: −200 to +200 ms).

As all ERP effects in both the old and young subjects were found near the midline, we report repeated-measures ANOVAs (Greenhouse-Geisser corrected) for midline electrodes with the factors Prosody, Violation, and Electrode (Fz/Cz/Pz). Analyses at lateral electrodes (F3,F4,F7,F8/C3,C4/P3,P4/T3,T4,T5,T6) are only reported if they revealed additional effects. Effects within older subjects are reported first and then compared to the pattern previously observed in young subjects (via analyses including the factor *Age Group*).

Acceptability rates and response times for the behavioral task are displayed in Table 2. Correct EC and LC control conditions A and B received high and equal acceptability ratings (78.1% and 78.0%, respectively; $F < 1$), while the two violation conditions C and D were accepted to a somewhat lesser degree, as reflected by the single significant effect of Violation: $F(1,11) = 6.15$; $p < .04$. Surprisingly, older adults accepted violation conditions C and D in a large proportion of the trials and, unlike young subjects, did not show any effect of garden-path severity (68.3% in both conditions; $F < 1$). As illustrated in Table 2, this pattern differed from that of young subjects who accepted condition C only 53.4% of the time and condition D significantly less often (28.0%; $p < .005$). In fact, Age Group interacted significantly with Violation ($p < .0005$), with Prosody ($p < .006$), and with Violation × Prosody ($p < .008$), all of which always reflected stronger effects in the young subjects. (As confirmation that the older adults did not simply have difficulty making acceptability judgments in general, we computed acceptability ratings for the filler (grammatical/ungrammatical) stimuli as well. Grammatical sentences were accepted by the older adults approximately 89% of the time and ungrammatical

Table 2
Acceptability judgment (%) and response times per age group per condition.

Measure	Condition	Old		Young	
		Mean	Std Dev	Mean	Std Dev
Percent accepted (%)	A	78.1	14.7	87.5	12.4
	B	78.0	16.3	87.2	12.7
	C	68.3	17.3	53.4	29.1
	D	68.3	27.2	28.0	33.4
Acceptance time (s)	A	.775	.310	.683	.334
	B	.821	.268	.702	.324
	C	1.024	.440	.929	.440
	D	.841	.346	.944	.422
Rejection time (s)	A	1.459	.975	1.144	.674
	B	1.412	1.119	.900	.601
	C	1.422	.841	.936	.538
	D	1.556	1.109	.748	.438

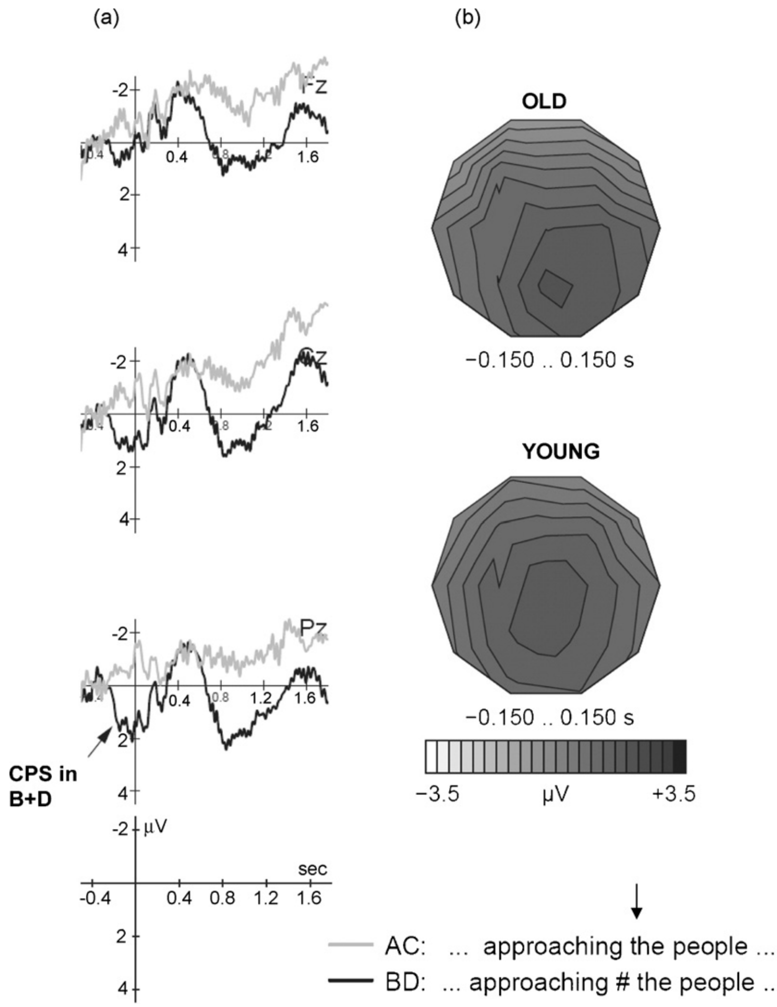

Fig. 1. (a) ERPs in older adults collapsed across A + C (grey) and B + D (black) at midline, time-locked to splicing point (arrow in legend). The prosodic boundary in B + D elicited a posterior CPS. (b) Voltage maps illustrate young participants showed a more broadly distributed CPS.

approximately 2.5% of the time.) For response times, the only significant effect in older subjects was a main effect of Acceptability ($F(1,11) = 7.49$; $p < .02$), indicating that responses for rejected trials were delayed by more than 500 ms compared to accepted trials, especially in the D condition (841 vs. 1556 ms). Again, this contrasts with the young subjects who were *faster* at rejecting (748 ms) than at accepting (955 ms) sentences in violation condition D, but *slower* at rejecting than accepting trials in control conditions A and B. These group differences were reflected by a significant Group × Acceptance interaction ($F(2,60) = 4.31$; $p < .05$) and by a marginal Group × Violation × Acceptance interaction ($p = .077$). Together, these behavioral data suggest stronger prosody effects in younger than older participants.

Following [12], Figs. 1 and 2 illustrate ERPs (N400, P600 CPS) time-locked to the splicing point in the older subjects.

In Fig. 1, ERPs collapsed across conditions B and D (with a boundary preceding NP2) and conditions A and C (without such a boundary) are superimposed. Between −150 and +150 ms, we see a large posterior positive shift in B/D that is absent in A/C: the CPS. This component is statistically reflected by a main effect of Prosody ($F(1,11) = 10.78$; $p < .01$) and a Prosody × Electrode interaction ($F(2,22) = 14.47$; $p < .0005$), pointing to a posterior maximum (Prosody: FZ: ns; CZ: $p < .01$; PZ: $p < .0002$). An ANOVA contrasting age groups revealed a shared highly significant Prosody × Electrode interaction ($F(2,60) = 15.36$; $p < .0001$) in absence of any violation effects (all F's < 1), as expected prior to the splicing point, supporting the overall centro-parietal distribution of the CPS across groups. No interaction with Group reached significance.

In Fig. 2, mismatch condition D is compared to condition A, its matched control after the splicing point. Near the splicing point, we again see the CPS in D but not A. Unlike in the young subjects, there is no indication of an N400 difference between 250 and 400 ms, however a large P600 emerges in D between 650 and 1200 ms (the same time window as in young subjects). The ANOVA for the N400 (250–400 ms) revealed no significant effect in the old subjects, whereas the group contrast showed a significant Group × Violation × Prosody interaction ($F(1,30) = 5.54$; $p < .03$), due to a significant N400 for condition D in the young group only [12]. In contrast, the P600 component in old subjects was statistically confirmed. To avoid overlap with the P600 in the C condition, the data were analyzed between 750 and 950 ms. We found a significant Prosody × Violation interaction ($F(1,11) = 11.75$; $p < .01$) and a highly significant Violation main effect when following up with a contrast between A and D ($F(1,11) = 20.67$; $p < .0001$). Interestingly, at lateral electrodes, we found an additional marginally significant Violation × Antpost × Hemisphere interaction ($F(2,22) = 3.88$; $p < .06$). The ANOVA contrasting age groups revealed not only a highly significant shared main effect of Violation at both midline ($F(1,30) = 36.94$; $p < .0001$) and lateral electrodes ($F(1,30) = 19.35$; $p < .0001$), but also a significant Group × Violation × Antpost × Hemisphere interaction ($F(2,60) = 4.13$; $p < .04$) pointing to a broader, less posterior distribu-

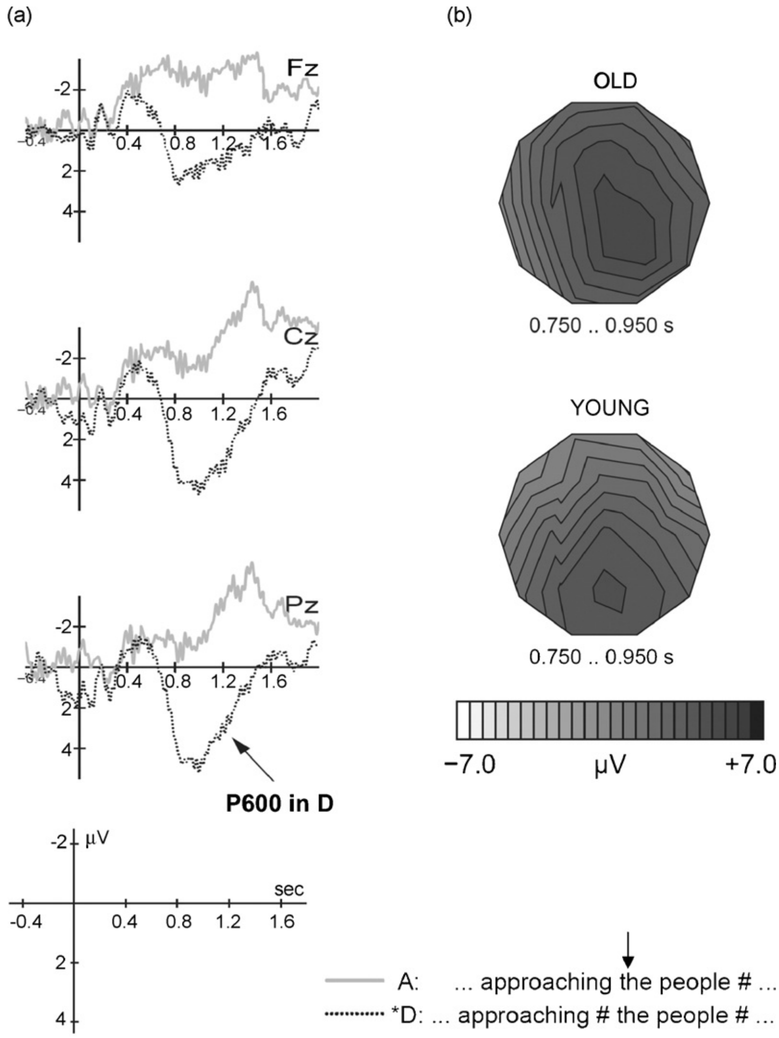

Fig. 2. (a) ERPs in older adults contrasting matched conditions A (grey) and D (dotted) at midline, time-locked to splicing point (arrow in legend). The superfluous second prosodic boundary in D elicited a centro-parietal P600 but no prior N400. (b) Voltage maps illustrate young participants showed a more posterior P600.

tion of the P600 in older compared to younger subjects, especially over the right hemisphere (see [3,9]).

The effects in condition C were analyzed time-locked to the onset of the disambiguating second verb phrase. As illustrated in Fig. 3, condition C elicited a small parietal P600 compared to its matched control condition B, reminiscent of that found for young subjects. Comparisons of ERPs between 650 and 850 ms revealed a marginally significant Violation × Electrode interaction ($F(1,11) = 3.07$; $p < .09$), pointing to a marginal Violation effect at PZ ($F(1,11) = 3.49$; $p < .09$) in absence of more frontal effects. The ANOVA including both age groups showed only a shared Violation × Electrode interaction ($F(1,30) = 11.54$; $p < .0004$), again reflecting a significant Violation effect at PZ ($F(1,30) = 7.83$; $p < .01$), but not at FZ or CZ (F's < 1). No indication of group differences was found.

The present investigation compared the on-line processing of garden-path sentences with either co-operating or conflicting prosody in older and younger adults. For the older adults, a CPS at prosodic boundaries was reliably elicited, indicating that they were clearly processing the prosodic patterns; however, the prosody–syntax mismatches did not yield the same pattern as in the young adults. For the behavioral judgments, it is striking that the older adults accepted the prosodically anomalous stimuli at a very high – and equivalent – rate (∼68%), in stark contrast to the very low – and significantly different – rates of acceptance by the young adults for conditions C (53%) and D (28%). On the basis of these findings alone, one might conclude that the older adults were less sensitive to prosody than were the young adults. However, our ERP data demonstrate clear on-line prosody effects (CPS and P600) in the *absence* of similar effects in the off-line judgments, suggesting that in initial stages of processing, young and older adults' treatment of prosodic phrasing information does not differ substantially. The differences arise primarily at a later stage at which prosodically driven garden-path effects are integrated or (re)analyzed; older adults appear to manipulate the lexical and syntactic structure of the sentence to fit the prosody [25]. Such a strategy may involve relatively complex operations which yield longer response times, which are increased even further when such an approach fails—precisely the pattern found in the present data. For older adults, rejections of stimuli in conditions C and D always took longer than acceptances, in contrast to the pattern in young subjects. Viewed together, the ERP and behavioral analyses suggest that older adults weight prosodic information more heavily than do young adults in sentence interpretation [11,18,25], as prosody appears to drive the structural reanalysis (i.e., lexical and syntactic information is altered to match the prosody).

Another interesting finding also relates to the dichotomy between on-line and off-line performance in the older adults. As noted, based on the judgment results, the older adults did not appear to perceive the D stimuli as more severe violations than

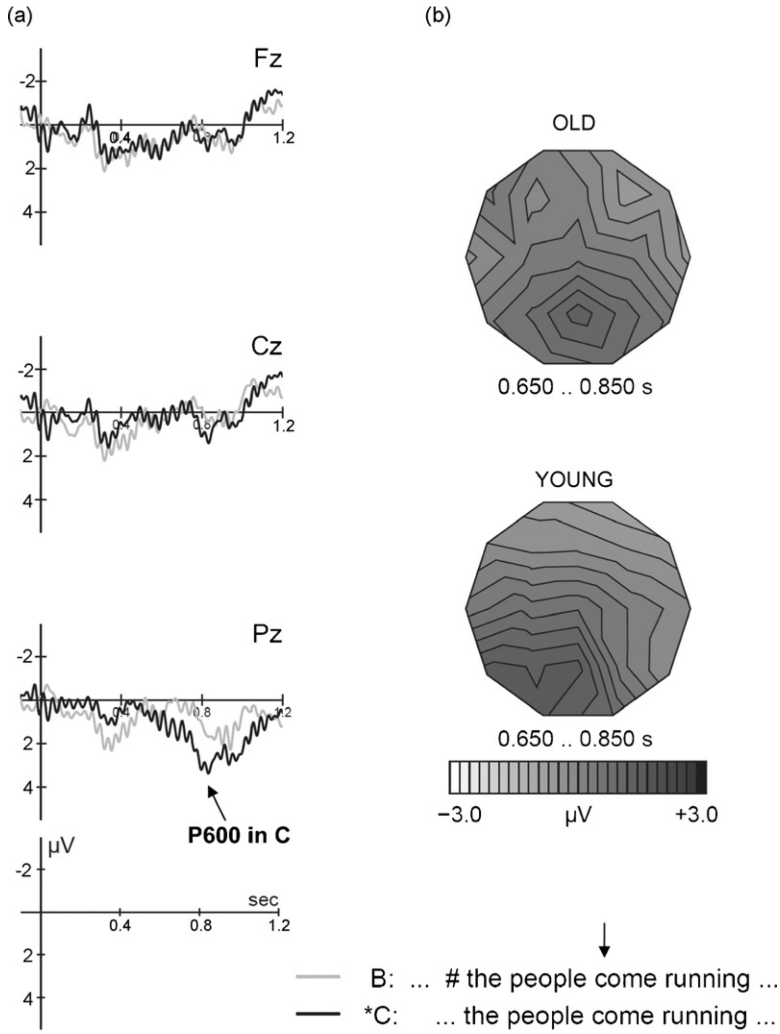

Fig. 3. (a) ERPs in older adults contrasting matched conditions B (grey) and C (black) at midline, time-locked to disambiguating second verb phrase (arrow in legend). The garden-path effect in C was reflected by a posterior P600. (b) The somewhat more posterior and left-lateralized P600 scalp distribution in young vs. older participants was not statistically significant.

those in C. Nonetheless, the on-line ERP data clearly demonstrate a larger P600 in D than C, suggesting that in initial on-line processing, condition D yielded a stronger garden-path effect in the older adults as well. In an earlier study, we hypothesized that young subjects had more difficulty accepting D than C stimuli because it is more difficult to delete a boundary than to create a new one [12]. This is true only if the listener attempts to reanalyze the sentence via a prosodic manipulation. For the older adults, in line with [25], we have suggested instead a lexical/morpho-syntactic revision; thus, we would not expect a difference in these behavioral judgments.

An additional finding merits brief discussion. Somewhat surprisingly, for the older adults, no N400 was elicited in condition D. For young adults, we attributed the N400 to difficulties with theta role assignment and verb-argument structure violations [12]. The absent N400 in the older adults may be parallel to the reduced semantic N400 effects reported in this group [3,6,9] and extend those findings to verb-argument structure violations, suggesting that such a reduction is not due to constraints on spreading activation [3], but rather to differences in the integration of conceptual knowledge (see [5–7]).

Importantly, while this is the first study to show that the CPS is elicited in older subjects, its latency in the older adults was comparable to that found for young adults, indicating that the older adults process the prosodic phrasing information immediately, initially in a similar manner to young adults. Moreover, the presence of the CPS in both older and young subjects accurately predicted whether they would encounter parsing difficulties downstream. Age group differences only appear to arise in how the participants cope with the mismatch, as detailed above. The present data clearly demonstrate the need for sensitive on-line assessments of the role of prosody in sentence parsing to truly untangle the nature of processing changes associated with advancing age.

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