When criminals blow up... balloons. Associative and combinatorial information in older and younger listeners' generation of on-line predictions

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Abstract

In the course of sentence processing, comprehenders must identify relationships between sentence elements in accordance with the sentence's syntactic structure. However, low-level associative processes, which may yield interpretations incompatible with global sentence context, have also been suggested to be at play in the early moments of processing. In two experiments, we examine the influence of low-level associative cues alongside combinatorial information in sentences of varying complexity. Verb-driven predictions are used as means to explore the use of these information sources in the earliest moments of processing. In addition, we explore effects of listener age on processing, given past claims that older adults' predictions are more shallow. However, results showed similar patterns across age groups, although we did find clear ways in which associative cues overshadowed combinatorial computations when these cues occurred very close to the verb.

Keywords: verb-driven predictions; associative cues; combinatorial semantics; visual world paradigm; aging; spoken language processing

Introduction

"The clown grumbled at the criminal and blew up the balloon". At first glance, there seems to be nothing extraordinary about this sentence (if you accept clowns can be bad-tempered) and it is relatively straightforward to understand: a clown complains to an individual and inflates a balloon. However, the string "the criminal and blew up the" is itself almost a plausible agent-verb pairing if one ignores the conjunction. Does the presence of this substring have any effect on how comprehenders link the verb with the intended agent (the clown) during incremental processing?

Although all theories of sentence processing assume that the syntax of the sentence is ultimately used to constrain the interpretation of incoming information, real-time incremental processing has been thought to also reflect the operation of low-level associative processes, which may yield interpretations incompatible with the global sentence context. For example, Townsend and Bever (2001) propose initial interpretations of partial input are computed in part from associative information (see also Kuperberg, 2007). Similarly, "merely local" links between sentence elements can be momentarily computed despite inconsistency with global syntactic information (e.g., Duffy, Henderson, & Morris, 1989; Tabor, Galantucci, & Richardson, 2004; Levy, Bicknell, Slattery, & Rayner, 2009). In this study, we describe two eye-tracking experiments using the 'visual-world' paradigm that examine how (associative) lexical cues compete with combinatorial information, and how this guides eye movements in the context of *predictive processing*. One focus is the manner in which listeners identify upcoming patients upon hearing the verb in a sentence where there is indeterminacy about the identity of the agent. In addition, we explore how anticipatory processing in this context might vary as a function of listener age. This comparison is motivated by past claims that older adults are less efficient at using combinatorial information in predictive processing (Federmeier & Kutas, 2005).

Theoretical background

Associative and combinatorial processes During sentence comprehension, syntactic and semantic processes are normally understood to operate in parallel (Townsend & Bever, 2001; Kuperberg, 2007). However, whereas syntactic processes seek to achieve a 'compositional' analysis of a sentence by identifying links among constituents using syntactic and morpho-syntactic constraints (e.g., subject - verb agreement, case marking, etc.), semantic processes can in some cases proceed by means of simple processing heuristics that use surface cues to derive a rapid and shallow preliminary conceptual representation. Although semantic and syntactic processes are intended to act in concert to yield a coherent sentence representation, the more impulsive and unconstrained nature of semantic processing can create links between sentence elements that are incompatible with syntactically legitimate interpretations, resulting in temporarily competing representations (Kuperberg, 2007). One source of evidence involves sentences like "The coach smiled at *the player tossed a frisbee*" which is read more slowly than a control sentence like "The coach smiled at *the player who was tossed a frisbee*". This is because the words in italics in the former sentence can form a locally coherent clause that is nonetheless incompatible with the global syntactic structure (Tabor et al., 2004; see also Konieczny, 2005; Bicknell, Demberg, & Levy, 2008). Similarly, Duffy et al. (1989) found that the activation level of sentence-final words does not always respect the full syntactic structure, but can reflect the influence of earlier words that do not have an appropriate syntactic connection with them. For example, reading times are speeded for the final word in a sentence such as "While she talked to him the barber trimmed the ... mustache", reflecting the legitimate combinatorial connections between barber + trim + mustache. However, the same amount of facilitation is observed in "While talking to the barber she trimmed the ... mustache", where these connections are absent or indeterminate. The association-driven effects can, however, be modulated to some degree by the syntactic relationships in the preceding context (Morris, 1994). For example:

(1) The gardener talked as the barber trimmed the ...

(2) The gardener talked to the barber and trimmed the ...

Because barbers typically trim hair and gardeners typically trim plants, the information preceding the sentence-final word *mustache* in (1) is fully consistent with this word and speeds its reading in real time. In (2), however, this word is incompatible with the "legitimate" analysis of the sentence and fixation times on the final word are longer.

To date, most evidence for associative and combinatorial factors has been based on reading paradigms, which are best suited to detect *integrative processing*, namely the process of integrating a new element into the existing hypothesis space for the sentence's representation. In this study, we instead explore *predictive processes* in spoken language as a way to understand how associative and combinatorial factors operate in earliest moments of language processing. As background, linguistic prediction is understood to occur when information about upcoming structure or meaning is activated in advance of downstream language. A substantial body of research has shown that predictive processing reflects combinatorial processes. For example, in a context containing a motorcycle and a carousel, listeners anticipate reference to the motorcycle when hearing the verb *ride* in "The man will ride the ...", but to the carousel when given the sentence "The girl will ride the ..." (Kamide, Altmann, & Haywood, 2003). In this case anticipatory eye movements reflect a combination of three elements: the verb, the nature of the agent and a compatible object referent. Additional studies have shown ways in which predictive eye movements can also be triggered by a combination of broader information types (case–marking, gender cues, probability distributions for syntactic structures, past events, and affordances, e.g., Kako & Trueswell, 2000; Chambers & San Juan, 2008; Kamide, Scheepers, & Altmann, 2003; Demberg, Keller, & Koller, 2013). However, in addition to this "sophisticated" combinatorial processing, there is also evidence suggesting predictions sometimes reflect the influence of low-level lexical associations (e.g., Kuperberg, 2007; Bicknell, Elman, Hare, McRae, & Kutas, 2010; Kukona, Fang, Aicher, Chen, & Magnuson, 2011). For example, Kukona et al. (2011) presented listeners with sentences of the type "Toby arrests the crook" where, upon hearing "arrests", anticipatory eye movements should in principle be directed toward an individual who could serve as the patient for the verb (e.g., a crook). However, listeners were also likely to consider a candidate that was implausible as a patient but was nonetheless highly associated with the verb (e.g., a policeman). This associative effect was reduced when listeners were provided with additional syntactic cues, as in passive sentences like "Toby was arrested by the policeman". Although the salient syntactic cue in the passive sentence may account for this difference, the authors also speculated that the additional time that elapsed between the verb and the object noun slot may help in overcoming associative effects. Links between sentence elements that are triggered by associative cues might rapidly diminish as the sentence continues to unfold. The current study provides a means to directly explore effects of this type.

Prediction and aging In addition, we test the claim made in past work that older adults are less efficient at aspects of predictive language processing (e.g., Federmeier & Kutas, 2005). On this account, seniors may show smaller and delayed effects of anticipation with more complex sentence types, reflecting Federmeier and Kutas' assertion that combinatorial cues in particular are not used efficiently by this age group in generating predictions. There is, however, research suggesting that age doesn't have a strong negative impact of predictive processing, and might have a small and positive effect (Huettig & Janse, 2016). There are, however, a number of important differences between these studies. For example, whereas Huettig and Janse's spoken language eyetracking study focused on the anticipation of nouns on the basis of a gender-marked article within the noun phrase, Federmeier and Kutas's ERP study focused on combinatorial aspects of meaning, which build up over the course of the sentence. These differences motivate our strategy of exploring older and younger listeners' performance on a range of sentence types within a single experiment.

The current study

In this study, we examined how older and younger listeners use lexical and combinatorial information to generate predictions in sentences of varying complexity. We take as a baseline an analogue of the sentence materials in Kamide, Altmann, and Haywood (2003)'s Experiment 2. In view of Kamide, Scheepers, and Altmann (2003)'s findings, we expect eye movements to reflect the anticipation of a correct patient (e.g., balloons) using a combination of information conveyed by the agent and the verb in the unfolding sentence ("*The clown blew up the ...*"). We compare this to a situation in which another mentioned character serves as a 'lexical lure', occurring either just before the target verb (local lure, "*The clown grumbled at* **the criminal** *and blew up* the balloons") or earlier in the sentence (distal lure, "**The criminal** *grumbled as the clown blew up* the balloons"). On the assumption that early semantic-associative processes operate independently of syntactic constraints, the addition of this character creates another potential agent that could be linked with the verb. Thus, we predict that upon hearing the verb ("*blew up*"), the lures might reduce anticipatory looks to the intended patient image in the display (balloons, see Figure 1) and increase looks to a competitor image (bank). This is because the competitor's relevance as a patient would be boosted if the lure character were misconstrued as the agent for the verb. This misconstrual is possible given the independent association between CRIMINAL and BLOW UP (albeit with a different verb meaning). Moreover, this effect might be influenced by the lure's position in the sentence. For example, when occurring just before the verb, the lure might be more likely to be temporarily misconstrued as the agent. This may be because it is closer to providing an uninterrupted sub-

string or because there is less time for the effect of low level association to fade before the verb is encountered.

Finally, as noted above, older adults have been argued to be less efficient at generating predictions using combinatorial cues (Federmeier & Kutas, 2005). The variety of sentences in the current study can provide a fine-grained approach for exploring these ideas in greater detail. For example, older adults might show the same anticipatory patterns as younger adults in the more simple baseline condition, but may be slower in the lure conditions, where the chance to misconstrue the lure character as the agent is higher (especially in the local lure condition). Another possibility is that older adults will show a uniform delay across conditions (including the baseline), given that all of these cases involve some degree of combinatorial processing.

Experiment 1 - Younger Adults

Method

Participants Twenty-four participants took part in the study in exchange for course credit (mean age: 18 years and 6 months). Participants were English native or near-native speakers who acquired English before the age of five. All participants gave written informed consent and were debriefed upon completion of the experiment.

Materials Forty critical displays were created, each containing four clipart objects (see Saryazdi, Bannon, Rodrigues, Klammer, & Chambers, 2018). Figure 1 provides an example containing the target patient (e.g., balloons), a competitor (e.g., bank) and two unrelated objects (e.g., a lipstick and nail polish). The position of each object type was counterbalanced across trials. Out of the 32 critical displays, 24 were accompanied by three sentence versions as follows:

- Baseline: **The clown** *blew up the* balloons.
- Local Lure: The clown grumbled at **the criminal** and *blew up the* balloons.
- Distal Lure: The criminal grumbled as **the clown** *blew up the* balloons.

Figure 1: Example of an experimental display.

These were recorded at a normal speaking rate and were then slightly adjusted using speech processing software so that the duration of the verb and the following determiner was equal across the four versions. The other eight experimental displays were accompanied by sentences in a separate control condition in which the verb information could not be used to predict the target object (e.g., Control: "The man touched the kettle", display objects: kettle, umbrella, sofa, table; display not shown due to space limitations). The materials were pretested by having a different group ($N = 25$ Mechanical Turk) click on one of the four clipart objects that best completed sentences with missing patient information. The sentences were created by pairing each character mentioned in the lure conditions with the main verb e.g., "the clown blew up ..." and "the criminal blew up ...". We chose only those agent-patient pairs on which raters agreed over 95% of the time.
In addition to the critical displays, the materials contained 32 filler displays accompanied by sentences with a range of syntactic structures, different emotional intonations (sad and happy), and in which the verb information was compatible with two, three or four objects in the display.

Procedure Participants were tested individually. They were first seated in front of a 27" computer monitor that displayed the images at a resolution of 2560 x 1440 pixels. After a short calibration phase (EyeLink 1000 operating at a sampling rate of 500Hz), participants were told that they would have to click on the last object mentioned in each sentence. No instructions were provided regarding the speed with which they should respond. The pairing of displays to conditions was cycled across lists so that each participant saw a given display once, yet across participants the display occurred with all sentence types. Participants were given time to preview the visual objects before the onset of the spoken instruction. The preview time was adjusted such that there was an equal amount of time across conditions before the onset of the verb in the accompanying sentence. Between each trial, participants were shown a centrally located fixation point for drift correction, and an extra recalibration procedure was carried out halfway through the experiment. Two practice trials preceded the 80 experimental trials. The entire session lasted approximately 40 min.

Results

This study manipulated Sentence Type across three levels (Baseline, Local Lure, Distal Lure) with the Control condition providing an additional point of comparison. Figure 2 shows the mean likelihood of generating an anticipatory fixation to the target object in the critical time window, an interval that extended from the mean offset of the verb to 200 ms following the onset of the noun (total duration = 1000 ms). The onset of the patient noun, centred across critical trials, is marked with a horizontal dashed line.

To evaluate the observed patterns statistically, we calculated the probability of fixating the target (target fixations divided by the sum of all fixations to the four objects) in the

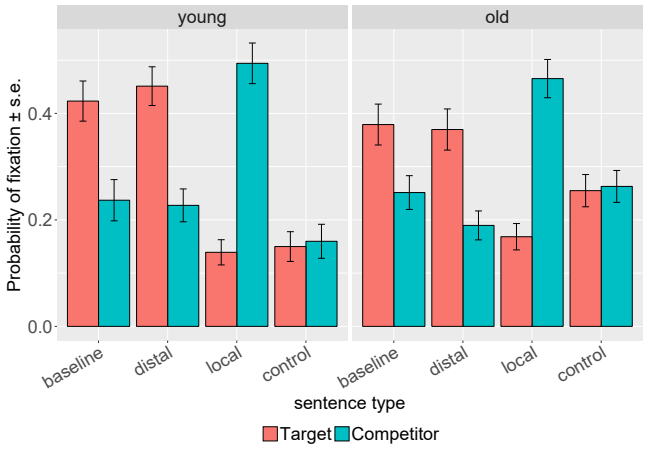

Figure 2: Average probability of anticipatory target fixations.

critical time window. This score was evaluated using linear mixed effect models with Sentence Type as a fixed effect. The random effects structure of the converging model had intercepts for participants and displays, and corresponding slope terms for Sentence Type by participants.

The results showed a significant main effect of Sentence Type. Post–hoc tests revealed a reliably stronger preference to anticipate the target object in the Baseline ($M = .42$, $SD = .28$) and the Distal Lure conditions ($M = 0.45$, $SD = .30$) relative to the Local Lure ($M = .14$, $SD = .22$) and Control conditions ($M = .15$, $SD = .22$), where anticipation was minimal. There were no significant differences between Local Lure vs. Control ($p > .05$) and Baseline vs. Distal Lure ($p > .05$). Further analysis showed a stronger preference to anticipate the competitor only in the Local Lure condition ($M = .49$, $SD = .35$) relative to all other conditions, as seen in Figure 2, left panel (Baseline, $M = .24$, $SD = .28$, $\beta = -0.128$, $SE = 0.03$, $p < .001$; Distal $M = .23$, $SD = .26$, $\beta = -0.269$, $SE = 0.05$, $p < .001$; Control $M = .15$, $SD = .25$, $\beta = -0.339$, $SE = 0.08$, $p < .001$.

Discussion

These results reflect an influence of combinatorial factors, which led to increased anticipatory target patient fixations in the Baseline condition compared to the Control condition. Associative factors also influenced incremental interpretation such that mention of the 'lure' character reduced anticipatory eye movements to target patients. These associative effects seem to depend strongly on the proximity of the verb and the lure: the likelihood of anticipatory fixations in the Baseline condition was significantly greater than in the Local Lure condition, but not from the Distal Lure condition.

Experiment 2 - Older Adults

Method

Participants Twenty-four participants took part in this experiment and received payment for participation (mean age 72 years and 3 months). Participants were English native or near-native speakers who acquired English before the age of five. Upon completion of the experiment, vision and hearing sensitivity were assessed; all participants had normal hearing and normal or corrected-to-normal vision.

Materials and Procedure As in Experiment 1.

Results

As before, the design included the Sentence Type manipulation 3 levels and the accompanying Control condition. The results showed a significant effect of Sentence Type. Post-hoc tests revealed multiple significant differences between Baseline ($M = 0.38$, $SD = .30$) and Distal Lure ($M = 0.37$, $SD = 0.28$)relative to the Control condition ($M = 0.26$, $SD = .25$) and Local Lure ($M = 0.17$, $SD = .22$) (see Table 2). There were no significant differences between Local Lure vs. Control ($p > .05$) and Baseline vs. Distal Lure conditions ($p > .05$). Further analysis showed a stronger preference to anticipate the competitor only in the Local Lure condition ($M = .47$, $SD = .32$) relative to all other conditions (see Figure 2, right panel; Baseline, $M = .25$, $SD = .25$, $\beta = -0.107$, $SE = .03$, $p < .001$; Distal $M = .18$, $SD = .19$, $\beta = -0.279$, $SE = .05$, $p < .001$; Control $M = .26$, $SD = .25$, $\beta = -0.206$, $SE = .06$, $p < .001$.

Age Comparison

For a more fine-grained analysis of the effect of sentence type on predictive behaviour across lifespan (see Figure 3), the data from the two experiments were analyzed together using growth curve analysis (Mirman, Dixon, & Magnuson, 2008). The models tested for intercept, linear and quadratic effects of time on the probability of anticipatory fixations to the target. The baseline condition was systematically compared against each of the other conditions of interest; and Age (2 levels: younger adults, older adults) and Time (2 levels: linear, quadratic) were included as fixed effects. The random effects structure of the converging models had intercepts for

Table 1: Significant contrasts for young adult data.

Contrasts	β	SE	*p*-value
Baseline – Control	−0.137	0.02	<0.001
Baseline – Local Lure	−0.284	0.04	<0.001
Distal Lure – Control	−0.300	0.05	<0.001
Distal Lure – Local Lure	0.311	0.04	<0.001

Table 2: Significant contrasts for older adult data.

Contrasts	β	SE	*p*-value
Baseline – Control	−0.063	0.02	<0.050
Baseline – Local Lure	−0.211	0.04	<0.001
Distal Lure – Control	−0.115	0.05	0.050
Distal Lure – Local Lure	1.995	0.04	<0.001

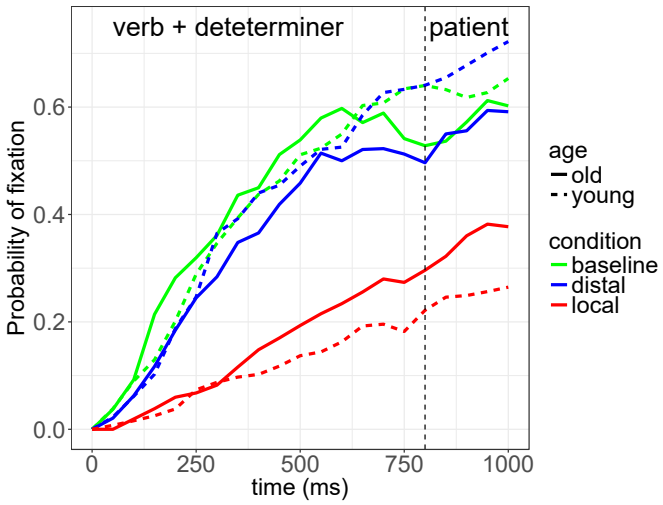

Figure 3: Average probability of fixating the target object across time and split by age groups.

participants and displays, and corresponding slope terms for Time by participants and by displays.

Model 1: Baseline vs. Distal Lure. There were no main effects of Sentence Type or Age ($p < .05$). A main effect of the two time terms indicates an increased consideration of the target over time as well as a "plateauing" of the anticipatory effect (Linear $\beta = 0.721$, $SE = .08$, $t(46) = -9.295$, $p < .001$; Quadratic $\beta = -0.310$, $SE = .06$, $t(35) = -5.268$, $p < .001$). There were no interactions between the factors.

Model 2: Baseline vs. Local Lure. There was a main effect for the Linear Term, reflecting increasing fixations to the target across time ($\beta = 0.460$, $SE = .07$, $t(53) = 7.122$, $p < .001$); a main effect of Sentence Type, suggesting stronger target anticipation in the Baseline vs. the Local Lure condition ($\beta = -0.265$, $SE = .008$, $t(8221) = -30.858$, $p < .001$) and a main effect of Age ($\beta = -0.0348$, $SE = .01$, $t(52) = -2.561$, $p < .05$). The main effects were qualified by a three-way interaction involving the Linear Term, suggesting that older adults (surprisingly) showed stronger target anticipation in the Local Lure condition in the later part of the analysis window (e.g., less influence of the misleading local lure, $\beta = -0.150$, $SE = .038$, $t(7773) = -3.947$, $p < .001$). Older adults also showed some advantage in the baseline condition, which diminished over time.

Discussion and Conclusions

Under some circumstances the human language processing system may intitially build interpretations that are not consistent with the global sentence context. The purpose of the present study was to further explore the interplay between associative and combinatorial influences on processing by measuring verb-driven predictions across two age groups. Listeners were presented with sentences that in some cases included an associative 'lure' character, which occurred just before the target verb, or at an earlier point. We predicted that lexical associations could influence anticipatory eye movements by driving eye movements away from the correct patient object and instead towards the competitor objects, with stronger effects occuring with a more 'nearby' lure. We also conducted a comparison across age groups (older vs. younger adults) to evaluate possible differences in anticipatory processing across adult lifespan.

The results clarified how associative and combinatorial factors jointly influence incremental interpretation. An effect of combinatorial processing was apparent in the finding that listeners combined the agent and verb information in the Baseline condition to correctly anticipate the target referent (an effect that was absent in the Control condition, where no information could not be used to generate predictions). An associative effect was also observed, but interestingly this was only the case in the local lure condition, ("The clown grumbled at *the criminal and blew up* ..."), where listeners were notably less likely to anticipate the target object upon hearing the verb. We conducted a follow-up analysis confirming this result occurred largely because listeners were instead fixating the competitor in this condition, consistent with temporary misconstrual of the correct agent-verb pairing. One possible explanation for the proximity effect is that, by placing the lure farther from the verb, its influence decayed over time, enabling the parsing mechanism to establish the correct syntactic relations. Alternatively, it is possible that the weak prosodic nature of the conjunction allows the "criminal and blew up" substring to be temporarily encoded as a legitimate syntactic parse. Regardless, this pattern is in line with modelling work suggesting that temporal proximity is an important factor in attempting syntactic links between sentence constituents (e.g., Stevenson, 1994). In a similar vein, Levy et al. (2009) proposed that comprehenders maintain uncertainty beliefs about previously read words, thus processing multiple similar variants of the sentence read thus far. On this account, the Local Lure condition presents a higher level of uncertainty, and alternative interpretations (e.g., "[...] the criminal *that* blew up the balloons") might be held active for a longer period of time.

One especially notable result was the absence of a combinatorial "deficit" for older adults. As noted earlier, previous research using ERP methodologies had argued that older adults show greater difficulty in coordinating combinataorial cues during anticipatory processing. The current results, however, show no evidence of this, with both groups showing similar performance across conditions. In fact, older adults seemed to be less affected by the local lure. Future research is clearly necessary to resolve these discrepancies. One explanation for older adults' reasonably impressive performance may involve older adults' greater linguistic knowledge. In relation to this, more skilled language users have been shown to better inhibit eye movements to implausible referents (e.g., Kukona et al., 2016; Borovsky, Elman, & Fernald, 2012) and modelling work suggests that competition effects diminish over time with training (Kukona, Cho, Magnuson, & Tabor, 2014). Moreover, if susceptibility to the local lure can be understood a type of "shallow processing", it is relevant to note

that the solid performance of older adults in the current case is similar to results from reading studies. Daneman, Hannon, and Burton (2006) showed that older and younger readers misinterpreted misleading elements of text at the same rate, yet an analysis of eye movements showed that the older readers detected these anomalies sooner than younger readers.

To conclude, the current study investigated associative and combinatorial information that could influence the predictive processing of sentence information. In addition, age differenceswere tested. Results suggest that associative effects are subject to factors of proximity, and that aging is not itself a strong determinant of predictive processing ability.

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