The role of recent versus future events in children's comprehension of referentially ambiguous sentences: Evidence from eye tracking

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Abstract

Findings from recent eye-tracking studies suggest that adults prefer to rely more on recently seen events than possible future events during sentence comprehension: When the verb in an NP1-VERB-ADV-NP2 sentence was referentially ambiguous between a recent action and an equally possible future action, adults fixated the target of the recent action more often than the not-yet-acted upon object (Knoeferle & Crocker, 2007; Knoeferle, Carminati, Abashidze, & Essig, 2011). We examined whether this preference for the recent event generalizes to five-year-old children. In an eye-tracking study, five-year-olds were presented a display with an animal and two other objects. On the next picture frame, the animal was depicted as performing an action (e.g., a horse galloped to a blue barn). Next, a spoken sentence referred either to an event involving the acted upon target object (the blue barn) or to an equally plausible future action event (e.g. galloping to the red barn). At the adverb in NP1-VERB-ADV-PP sentences, children fixated more often the recent (vs. future) event target. This result replicates the findings from the adult studies and suggests that, just like adults, children rely more on the recent event than expectations of an event that could happen next. At the same time, visual context effects of the recent events were subtly delayed for children (vs. adults). For adults, the recent-event preference emerged during the verb; for children, by contrast, it emerged post-verbally during the adverb. Thus, similar attentional mechanisms underlie visual context effects in both 5-year old children and adults but their time course differs.

Keywords: eye tracking; child language comprehension; visual context; depicted events.

Introduction

Adults have been shown to rapidly and efficiently integrate all sorts of contextual cues during real-time spoken language comprehension. Referential contrast between objects can incrementally influence syntactic disambiguation (e.g., Tanenhaus, Spivey, Eberhard, & Sedivy, 1995), as well as semantic interpretation (Sedivy et al., 1999). Object affordances (Chambers et al., 2004) and depicted events (Knoeferle et al., 2005; Knoeferle et al., 2008) can also rapidly affect structural disambiguation.

Sometimes contextual information can even permit adult comprehenders to actively derive expectations about upcoming information. One source of evidence for predictive processes has been "anticipatory" eye movements to target objects (i.e., eye movements to objects just before they are mentioned). Verb selectional restrictions (Altmann & Kamide, 1999), compositional noun and verb meaning and associated world knowledge (Kamide et al., 2003a,b), prosody (Weber et al., 2006), and information structure (Kaiser & Trueswell, 2005) can each restrict the range of target objects that can be mentioned next, as evidenced by participants inspecting a target object before its mention relative to a control condition.

Like adults, children have also been shown to derive expectations about upcoming information. When children (aged 10-11) listened to a sentence in which the verb *eat* restricted the domain of reference to edible objects, they fixated the only edible object in context shortly after hearing *eat* and before that object was actually mentioned (Nation, Marshall, & Altmann, 2003). This was true for both (verbally and visually) less-skilled children as well as for normally developing children although the former (vs. the latter) made more and shorter fixations to the edible object.

At first glance this might give the impression that child and adult language comprehension and expectation formation are governed by similar mechanisms. Results from another study with younger children (mean age of 4.7), by contrast, suggest marked differences between child and adult language comprehension. In a study by Trueswell et al. (1999), children either heard a locally structurally ambiguous sentence such as *Put the frog on the napkin in the box* or an unambiguous sentence such as *Put the frog that's on the napkin in the box*. For the ambiguous sentence, the prepositional phrase *on the napkin* can either modify the noun indicating the location of the frog, or attach into the verb phrase and specify the destination of the action. Children saw either only one possible referent for *frog* in the 1-referent condition (e.g. a frog on the napkin, an empty napkin, a distractor object and a box) or two referents in the 2-referent condition (e.g. a frog on the napkin, another frog, an empty napkin and a box). A 2-referent context should bias comprehenders to look at the frog on the napkin upon hearing *on the napkin* rather than to the empty napkin.

However, five-year old children frequently looked at the *incorrect* destination (the empty napkin) in both one-referent and two-referent contexts. Adults, by contrast, looked first at the correct target (the frog on the napkin) when hearing *Put the frog on the napkin* and then to the correct destination (the box) rather than the empty napkin in a context with two frogs. These findings were taken as support for the claim that children – unlike adults – incorrectly interpreted the prepositional phrase *on the napkin* as the destination for *put*, and that they were unable

to use the referential contrast (between two frogs) for structural disambiguation. Moreover, children's actions indicated that they never revised this initial misanalysis: On 60% of the trials they performed an action that involved the incorrect destination (e.g., moving a frog to the empty napkin before putting it in the box).

Accordingly, at least some aspects of 5-year-old children's and adults' real-time language comprehension appear to differ. What is not clear, however, is to what extent children's (vs. adults') use of (visual) context for spoken language comprehension is indeed limited, and, more broadly, what demarcates child-adult comprehension differences. Perhaps 5-year-old children and adults are not that dissimilar in their comprehension mechanisms and only employ different (attention) mechanisms in a few isolated instances. Alternatively, children at that age still differ fundamentally from adults in how they use (visual) contextual cues for language comprehension. This is an interesting research question since processing accounts of situated language comprehension (e.g., Knoeferle & Crocker, 2006, 2007) will ultimately want to accommodate language processing from infancy to young-adulthood to older age.

Existing findings suggest similarities in how children versus adults process language in (visual) context, but there are also some differences. Just like adults, infants as young as six months of age can track moving objects with their gaze (Richardson & Kirkham, 2004). 36-month-olds also exhibit adult attention behavior in that they shift their visual attention more quickly to a target picture when they hear *blue car* in a context with a blue and a red car than when the context shows a blue car and a blue house (Fernald, Thorpe, & Marchman, 2010). This suggests that they can rapidly use linguistic input to fixate relevant referents. In younger children, by contrast, this behavior is not yet apparent. Furthermore, when 19-months-old infants listened to nouns as they saw matching (vs. mismatching) objects, their event-related brain potentials to the noun exhibited an N400 (a negativity approximately 400 ms after stimulus onset, see Kutas & Hillyard, 1984) that was larger for mismatches than matches. That negativity was also found in adults, but the scalp distribution and latency of that effect differed in children relative to adults (Friedrich & Friederici, 2004). In summary, it is unclear to what extent children throughout language development and adults share the same mechanisms in language comprehension, language-mediated visual attention, and visual context effects on comprehension.

The present research contributes to this emerging evidence about real-time situated language processing in children by examining how recently-depicted action events guide children's visual attention and spoken language comprehension. We know that adults can rapidly draw on recent action events in informing language comprehension and in interrogating visual context (Knoeferle & Crocker, 2007). Participants saw a character (a waiter) move toward an object, interact with it (e.g., polish candelabra), and move away from it. They then listened to an utterance that referred either to the recent action (polishing the candelabra: simple past tense: *Der Kellner polierte kürzlich die Kerzenleuchter*, "The waiter recently polished the candelabra") or to an equally plausible action that hadn't yet been performed (e.g., polishing crystal glasses; present tense with future meaning: *Der Kellner poliert sogleich die Kristallgläser*, 'The waiter will soon polish the crystal glasses'). At the verb *poliert* . . . ('polish…') the comprehension system and visual attention had a choice between anticipating the recent action target versus anticipating (and thus inspecting) the target of the as-yet-unseen future action. Adult participants preferentially anticipated the target of the recent (vs. the other, future) action, a gaze pattern that continued even as future tense information became available through the adverb (e.g., *sogleich*, 'soon'). Verb meaning and future tense information did not elicit expectations of future events, and adults relied on the recently inspected events. Recent research has replicated these results with real-world stimuli. In addition, the recent-event preference replicated even when both 'recent' and 'future' events were equally frequent but tense effects were then more pronounced (i.e., participants always saw one action before and another action after sentence comprehension, Knoeferle, Carminati, Abashidze, & Essig, 2011).

The present experiment used eye tracking to see to what extent 5-year-olds can also rely on recent events in directing their visual attention and language comprehension. To this end, 5-year-olds saw clipart depictions such as a horse and two stables, one red and one blue (see Fig. 1). The horse moved to the blue stable (Fig. 1b). Subsequently the child would hear *Das Pferd galoppierte gestern zu der blauen Scheune*, (literal translation: 'The horse galloped yesterday to the blue barn', "Yesterday, the horse galloped to the blue barn") or *Das Pferd galoppiert morgen zu der roten Scheune* (literal translation: 'The horse gallops tomorrow to the red barn', "Tomorrow, the horse will gallop to the red barn"). If 5-year-olds rely on recent events with the same time course as adults, then we should see them inspect the target of the recent event (the blue barn) more often than the target of the future event (the red barn) during the verb and post-verbal adverb. While tense information is available post-verbally, there was only a (non-reliable) tendency for tense effects post-verbally in the adults (Knoeferle & Crocker, 2007, Experiment 3; Knoeferle et al., 2011, Experiment 1). Inspections to the target of the future event (the red barn) in children should thus only increase as that target is mentioned.

Experiment

Participants

24 kindergarten children (10 4-year-olds and 14 5-year-olds, range: 4-5;9) took part in the Experiment and received a small toy for their participation. All participants had German as their only mother tongue and normal or

corrected-to-normal vision. All were unaware of the experiment purpose. Children and one of their parents gave informed consent.

Materials and Design

There were sixteen items, and two sentence conditions (Figure 1 and Table 1). Each item consisted of a series of three clipart scenes and four sentences. We created the pictures by using commercially available clipart and graphics programs. The first frame of the scene displayed a central animal agent (a horse) and two objects (e.g., a blue barn and a red barn, Figure 1a). The objects on either side of the animal were identical mirror images that only differed in their color or size (e.g., red barn, blue barn). The verb of the sentence (e.g., *galoppieren* 'gallop', see example in Table 1) was always a motion verb. Both of the two objects (e.g. the blue barn and the red barn) were equally plausible targets of the event (e.g. horse-galloping). However, the agent approached only one of the two objects (e.g. galloping to the blue barn, Figure 1b) and then moved back to another center position (Figure 1c). Each frame was presented for 1500 ms. The sentence could either refer to a past event (Table 1a, *Das Pferd galoppierte gestern zu der blauen Scheune.* 'The horse galloped yesterday to the blue barn.') or a future event (Table 1b, *Das Pferd galoppiert morgen zu der roten Scheune.* 'The horse gallops tomorrow to the red barn.') Figure 1a'-c' and Table 1a'-b' were the counterbalanced version in which the red barn was the target of the recent action. Therefore, each object was the target of a past and a future action once. This ensured that visual characteristics of the post-verbally referenced target object contributed equally to each critical condition.

We also counterbalanced the presentation side of each object. As shown in Figure 1, the blue barn was on the left side and the red barn was on the right side. In the counterbalancing version (not shown), the red barn was on the left side and the blue barn was on the right side.

In addition to the 16 experimental items, we created 8 filler items to ensure that children were exposed to a range of other sentence structures and actions. The two conditions of the sentence (past vs. future tense), the counterbalancing of the target object, and the counterbalancing of the target object presentation side led to eight basic lists. Lists were pseudo-randomized and each participant saw an individually randomized version of one of the eight experimental lists.

Procedure

An EyeLink1000 remote eye-tracker with a sampling rate of 500 Hz monitored participants' eye movements. Images were presented on a 22" LCD color monitor at a resolution of 1680×1050 pixels concurrently with a spoken sentence. We only tracked the right eye, but viewing was binocular. At the beginning of the experiment, each child was instructed to play a game. In this game, children were asked to inspect the images and to listen to the sentences. After each trial, they heard a question about the previous sentence and were asked to try to answer it correctly.

Each trial started with the display of a series of three frames which depicted an action (e.g., Fig. 1a-c). Each of the three frames in Fig. 1 was presented for 1500 ms (totaling 4500 ms). After that, the third image remained on the screen and the sentence was played via speakers. Five hundred milliseconds after the offset of the sentence, a spoken question asked for the target object of the verb in the previous sentence (for example, *Wohin galoppierte das Pferd?/Wohin galoppiert das Pferd?* 'Where did the horse gallop?/Where does the horse gallop?'). Participants' task was to answer the question by naming the correct destination.

At the start of the experiment, each participant was shown two example image sequences and sentences. Next, participants were set up and calibrated manually using a five-point fixation stimulus. The black dot that is used to calibrate adults was replaced by a smiley face to attract children's attention. The EyeLink software validated calibration; if validation was poor, the calibration procedure was repeated until validation was good. Between the individual trials, participants saw a centrally-located smiley on the screen which they were asked to fixate. This allowed the eye-tracking software to perform a drift correction if necessary. The entire experiment lasted approximately 25 minutes.

Table 1: Example item sentences

Picture	Condition	Sentence
Figure 1a-c	Past tense	(a) *Das Pferd galoppierte gestern zu der blauen Scheune..* The horse galloped yesterday to the blue barn.
	Future tense	(b) *Das Pferd galoppiert morgen zu der roten Scheune.* The horse gallops tomorrow to the red barn.
Figure 1a'-c'	Past tense	(a') *Das Pferd galoppierte gestern zu der Roten Scheune..* The horse galloped yesterday to the red barn.
	Future tense	(b') *Das Pferd galoppiert morgen zu der blasuen Scheune.* The horse gallops tomorrow to the blue barn.

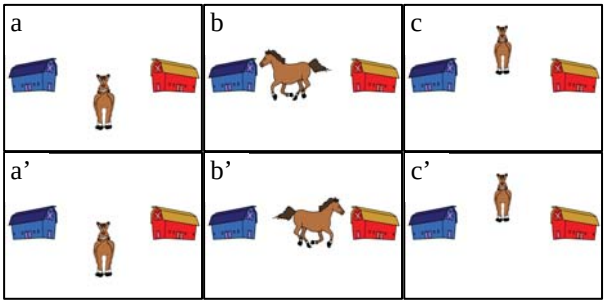

Figure 1: Example item pictures. In Figure 1 a-c, the horse gallops to the blue barn. To counterbalance visual characteristics of the target (e.g., its color), the horse gallops to the red barn in Figure 1 a'-c'.

Analysis

For the purpose of inferential analyses, we defined three time windows: an exact verb region (from verb onset until its offset); the extended adverb region (from verb offset until adverb offset) and the PP region (from preposition onset until sentence end). We coded participants' fixations to four areas of interest in the scene: the agent (e.g., the horse in Figure 1); the recently acted upon object (e.g., the red barn in Figure 1a-c); the future object (e.g. the blue barn in Figure 1a-c); and the background. Of those, the recent and future objects were our target areas of interest.

The proportions of fixation on the target areas of interest (the recent and the future targets) were entered into log-ratio analyses (c.f., Arai, van Gompel & Scheepers, 2007; Carminati, van Gompel, Scheepers, & Arai, 2008; Knoeferle et al., 2011). We computed mean log gaze probability ratios for the recent object relative to the future object *ln* (*P* (future target)/*P* (recent target)) for each condition and for each time window. Then we entered the log probability ratios into a one-factor (*tense*) ANOVA. Separate models were fitted for log-ratios averaged over participants and items respectively. We report the *p*-values for these analyses. To test whether the log probability ratios of each condition differs significantly from zero, we conducted simple *t*-tests. We adujusted the significance level of the *p*-values using the Bonferroni correction.

For the descriptive overview of the time course of the eye-movement data, we divided the utterance from sentence onset into time slots of 250 ms each. For each time slot and target object, we computed the number of fixations that fell within a given time slot. Then we plotted the mean proportion of fixation counts per time slot separately for each sentence condition and each target object.

Results

Figures 2a) and 2b) plot the mean proportion of fixations to the two objects in the future and past tense conditions using time slots of 250ms. Figure 3 zooms in on one region of interest and presents the mean log gaze probability ratios *(ln(P(*future target*)/P(*recent target*))* per condition for the adverb region.

Figures 2a) and 2b) illustrate an overall preference for fixating the acted-upon object rather than the not-acted-upon object from the offset of the verb until well into the NP2, irrespective of tense condition. As illustrated in Figure 2, the preference for looking at the acted-upon object is much reduced and reverses as children hear the second noun phrase in the future compared to the past tense condition.

In agreement with the descriptive pattern, the inferential analysis revealed no significant main effect of tense at both the verb and the adverb region. To test whether children had a preference to inspect one of the two targets, we examined whether the intercept was significantly different from zero. At the verb region this was not the case. By contrast, simple *t*-tests confirmed that log probability ratios of both the future tense condition and the past tense condition by subjects (*ps* < 0.05) and of the past tense condition by items ($p < 0.005$) were significantly different from zero for the adverb region (see Figure 3). This corroborates the findings from the descriptive analysis and indicates that children looked more often at the recently-acted-upon object than at the not-yet-acted-upon object in both the past and future tense conditions. For the PP region, by contrast, analyses confirmed that the children inspected the target objects as they were named (both *ps* < 0.002).

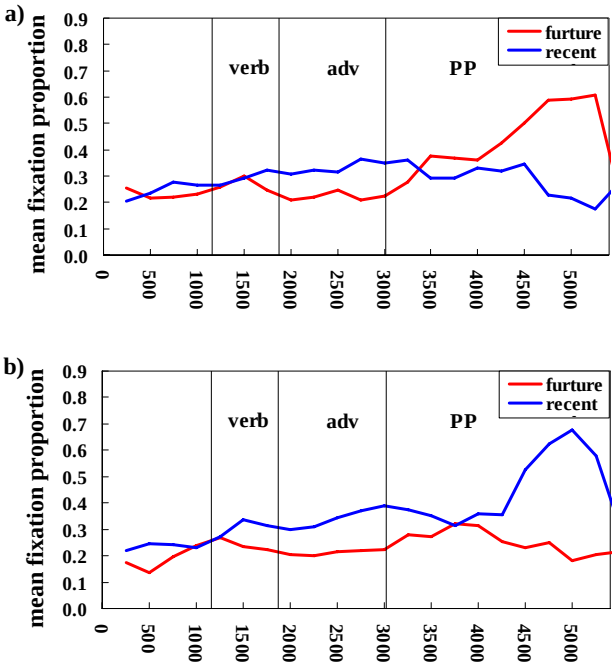

Figure 2: Eye movements to the target of the recent event (recent target: blue lines) and the target of the future event (future target: red lines) from sentence onset to sentence end for a) future tense condition and b) past tense condition

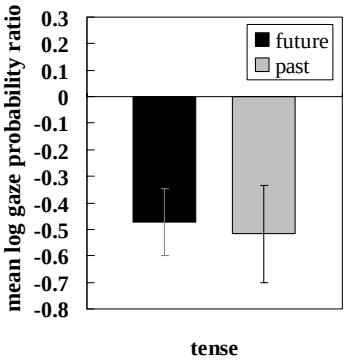

Figure 3: Children's mean log gaze probability ratios *(ln(P(*future target*)/P(*recent target*))* per condition for the adverb region (Error bars represent the standard error of the mean log gaze probability ratios)

Discussion

The present research assessed whether 5-year-old children resemble adults in how and when they make use of recently-inspected clipart events during spoken language comprehension. We conducted an eye-tracking experiment in which we monitored 5-year-olds' eye movements to target objects in a clipart picture as they listened to related sentences. The children saw an animal move towards one of two equally plausible objects (e.g., the horse would gallop to the blue barn when a blue and a red barn were depicted). When the motion verb in an ensuing spoken sentence referred either to that recent action or to another action that hadn't yet happened, children preferred to inspect the target of the recent event (e.g., the blue barn) over the target of the as-yet-unseen but plausible other event (e.g., the red barn).

This finding confirmed clear similarities in how children and adults (Experiment 3 in Knoeferle & Crocker, 2007) direct their visual attention during spoken language comprehension: both of these participant groups preferred to inspect the recent-event (vs. future-event) target. The time course of visual attention, however, was delayed for children relative to adults. While adults in Experiment 3 by Knoeferle and Crocker (2007) began to inspect the recent-event target more often during the verb, the recent-event inspection preference only emerged post-verbally for children.

One open question is what underlies the recent-event preference in both children and adults. The experiment procedure introduced a frequency bias for the recent events. While participants in Experiment 3 by Knoeferle and Crocker (2007) and in the present study saw an event before each experimental trial, they never saw a post-sentence future event acted out. The procedure of never depicting the future event may have created a within-experiment frequency bias toward relying more on recently depicted than on equally plausible future events for comprehension. It is possible that this bias led participants to preferentially inspect the recent (vs. future) event target.

Indeed, statistical regularities play an influential role in a range of cognitive processes for both children and adults. At 8 months of age, children can already use statistical regularities in linguistic input to segment words in fluent speech (Saffran, Aslin, & Newport, 1996). Statistical factors also play a role in children's visual attention to novel (vs. known) object patterns. When circles appeared in a pattern, infants at 11 months inspected novel (vs. known) circle sequences longer; by contrast, that behavior was not yet present at 8 months of age (Kirkham, Slemmer, Richardson, & Johnson, 2007, Experiment 1). For adults, statistical regularities play a role in language processing and other cognitive and motor processes. Adults' short-term linguistic experience can modulate their language production (Kaschak, Loney, & Borreggine, 2006; Haskell, Thornton, & MacDonald, 2010) and sentence reading (Wells, Christiansen, Race, Acheson, & MacDonald, 2009). It also affects adults' action execution (e.g., Chapman, Gallivan, Wood, & Milne, 2010) and visual perception (e.g., Chun & Jiang, 1999).

For the recent-event inspection bias in adults, however, frequency biases appear to play no causal role. When recent and future events were performed equally frequently within the experiment, effects of tense appeared somewhat earlier than in Knoeferle and Crocker (2007, Experiment 3), during the post-verbal adverb. By contrast, adults' recent-event inspection bias during the verb remained largely unchanged (Knoeferle et al., 2011, Experiment 2).

To what extent this preference generalizes to 5-year-olds when both recent and future events are equally frequent is unclear. What is clear, however, is that children, like adults, rapidly used recently inspected clipart events during comprehension, but that the time course of these event effects was delayed in children. For accounts of situated language comprehension (e.g., Coordinated Interplay Account, Knoeferle & Crocker, 2006, 2007), the present findings together with the other results that we discussed suggest that the closely temporally coordinated interplay of language comprehension, visual attention, and visual context effects on comprehension has a developmental basis.

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