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The Processing of Non-canonically Ordered Constituents in Long Distance Dependencies by Pre-school Children: a Real-time Investigation

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Abstract Four experiments were performed which had the goal of determining how and when young children acquire the ability to understand long distance dependencies. These studies examined the operations underlying the auditory processing of non-canonically ordered constituents in object-relative sentences. Children 4–6 years of age and an adult population participated in the study, which employed a cross modal picture priming methodology to determine when constituents in a non-canonical position are reactivated during ongoing sentence comprehension. The results support the view that even very young children have the same structural processing reflex seen in adults. Namely, children re-activate a non-canonically positioned (fronted) direct object NP immediately at the post-verb gap site during sentence processing.

Keywords Sentence processing · Psycholinguistics · Syntax · Developmental

Introduction

A fundamental issue in child language concerns how and when structural processes are acquired. Whether the structural processes in question are the simple concatenation of constituents, the adherence to putative structural constraints (e.g., binding), the processing of long-distance dependencies, or any other structural process, the field of language acquisition is widely split on issues concerning both the automaticity and nature of acquisition of such structural processing reflexes. The various views on

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this issue range from the stand that such processes are highly automatic and largely acquired with minimal learning to the view that structural processes are fully learned phenomena and largely non-reflexive at onset (see, among others, Fodor, 1995; Pinker, 1994 supporting the former view and Bates, & MacWhinney, 1989; Hurewitz, Brown-Schmidt, Thorpe, Gleitman, & Trueswell, 2000; Trueswell, Sekerina, Hill, & ogrip, 1999 supporting the latter view). The exact details of acquisition of such structural processes have obvious and important implications for both processing models of language as well as for linguistic accounts of language (and for models that envelop both perspectives).

Determination of fine-grained developmental details of structural reflexes in comprehension has proved somewhat difficult to come by over the years, largely due to methodological impediments. While many clever approaches to language comprehension in children have led to a base of knowledge concerning what children ultimately understand about utterances, the on-line processing details concerning *how* children come to understand what they do is rather sparse. It is only the on-line, fine-grained processing details that can fully reflect when and how children come to utilize the same structural reflexes as an accomplished adult listener. That is, a child may figure out utterance meanings via any number of mechanisms (e.g., reflexive structural processing, pragmatic analysis of the situation, etc.) and it is only by knowing the precise details of the mechanisms they actually use that we can determine how and when they come to acquire adult-level reflexes and knowledge use. Thus, there is need for detailed moment-by-moment evidence about structural processing in children to constrain theories that attempt to account for the nature of child language acquisition.

There have been a small number of relevant on-line experimental methodologies applied to the examination of children's sentence processes in recent years, including cross-modal priming (McKee, Nicol, & McDaniel, 1993; Roberts, Marinis, Felser, & Clahsen, 2006, in press; Swinney, & Prather, 1989), event-related potentials (Friederici, & Hahne, 2001; Hahne, & Friederici, 1999), self-paced reading/listening (Booth, MacWhinney, & Harasaki, 2000; Felser, Marinis, & Clahsen, 2003), and eye-tracking (Sekerina, Stromswold, & Hestvik, 2004; Trueswell et al., 1999). Our work here will focus on the use of the cross-modal priming paradigm because it can provide specific evidence concerning which words in a sentence are active for a listener at any particular time during the comprehension of that sentence.

The focus of the present studies is on the processing of long distance dependencies in children. In particular, we are concerned with how the parser recovers the canonical Subject–Verb–Object information order in a highly structured, non-scrambled language (English) during the on-going comprehension of (non-canonically ordered) object-relative constructions.

The choice of examining object-relative processing in English has been guided by the wealth of real-time evidence concerning adult processing of such structures. These studies have repeatedly demonstrated that when object-relative sentences are processed by adult listeners, non-canonically placed elements (e.g., the fronted object NP) are automatically re-activated in their post-verb canonical object position during ongoing comprehension. Consider, for example, the object-relative construction:

The policeman stopped the <u>*boy*</u> $_i$ *who the crowd at the party accused* __$_i$ *of the crime.*

This sentence is classically described as containing two underlying concepts, which, when described in underlying canonical (S–V–O) order can be represented as:

(a) The policeman stopped the boy &
(b) The crowd at the party accused the boy of the crime.

The linguistic concept of canonical order of underlying constituents (see, e.g., Kayne, 1994; Chomsky, 1981), and the accompanying processing hypothesis, (namely that comprehension requires interpretation of constituents in their canonical order) has been fully supported by on-line processing evidence. For ease of description we will adopt relatively neutral terminology to capture the linguistic and processing concepts of underlying canonical order. Thus we use the term 'filler' to refer to the 'moved' (fronted) direct object in an object-relative construction and 'gap' to refer to the canonical post-verb position from which the direct object has been putatively moved. We tacitly assume something like 'chaining' that links these putatively moved elements to the underlying structural position from which they were moved (e.g., Chomsky, 1981).

On-line studies of adult comprehension of object-relative sentences have demonstrated automatic & immediate *re*activation of the filler (*boy*) at the site of structural 'gap'. Such reactivation is not found for any other earlier-occurring NP but, just for the non-canonically positioned, object NP, and occurs immediately upon processing the verb for which it is an argument. In particular, this long-distance dependency (LDD) processing effect has been demonstrated with cross-modal priming methodologies (Hickok, Canseco-Gonzalez, Zurif, & Grimshaw, 1992; Love & Swinney, 1996, 1998; Nagel, Shapiro, & Nawy, 1994; Nicol, & Pickering, 1993; Nicol, & Swinney, 1989; Swinney, Ford, Frauenfelder, & Bresnan, 1987; Swinney, Zurif, Prather, & Love, 1996, among others), with end-of-sentence-probe verification tasks (Boland, Tanenhaus, Garnsey, & Carlson, 1995; Clahsen, & Featherston, 1999, Clifton, & Frazier, 1988; Crain, & Fodor, 1985; Garnsey, Tanenhaus, & Chapman, 1989; Pickering & Barry, 1991; Stowe, 1986), and with event-related potentials (Garnsey et al., 1989; Stowe, 1986). In addition, this phenomenon has been replicated with a variety of populations (Swinney et al., 1996; Zurif, Swinney, Prather, Solomon, 1993), all of which implicates the active use of structural knowledge in the ongoing processing of sentences with long-distance dependencies by adult listeners.

While there is dearth of published work detailing how and when children process the dependency relations found in object-relative constructions, the literature does present some limited on-line evidence concerning how children deal with the type of LDD found in explicit co-referential relationships (overt pronouns and reflexives). (We note that Fodor, 1995 has made a cogent argument as to the existence of a similar set of principles governing such overt (explicit) co-reference and the more implicit co-reference conditions as found in WH constructions (e.g., object relative sentences)). McKee et al., 1993 used the Cross Modal Picture Priming (CMPP) procedure (Swinney, & Prather, 1989) to examine the on-line processing of overt anaphors (pronouns and reflexives) in young children. The CMPP procedure is based on the Cross Modal Lexical Priming technique (Swinney, Onifer, Prather, & Hirshkowitz, 1979), but uses priming to pictures rather than words to reflect on-line activation of information in sentences during ongoing comprehension. In the CMPP task, participants listen to auditorily presented sentences and simultaneously make simple classification decisions to pictures (e.g., 'things you can eat' versus. 'things you can't eat') which are presented at a theoretically critical point in the sentence. The time to make these classification decisions to pictures has been demonstrated to be speeded (primed) if the picture has a semantic relationship to a word just previously heard in a sentence. This priming effect is a temporally delimited one, and has been shown to reliably reflect momentary activations in sentences in both adults and children (Swinney, & Prather, 1989).

McKee et al. (1993) employed the CMPP method to investigate how young children process overt anaphors in real-time, in light of existing evidence demonstrating that young children typically demonstrate more difficulties in consciously understanding pronouns than in understanding reflexives (e.g., Grodzinsky et al., 1993, among others).

They presented children ranging in age from 4 to 6 years of age with experimental sentences such as:

(a) The alligator knows that the leopard $_i$ with green eyes is patting *himself* $_i$ on the head with a soft pillow.
(b) The alligator $_j$ knows that the leopard $_i$ with green eyes is patting *him* $_j$ on the head with a soft pillow.
(c) The alligator knows that the leopard with green eyes is patting *the nurse* on the head with a soft pillow.

Children were asked to comprehend the sentences and to make an independent binary classification decision to pictures which were presented at the offset of the (a) overt reflexive, (b) pronoun or (c) an *R*-expression (baseline condition). Overall, the results revealed that these children exhibited the same automatic processing capacities found in adults, reactivating the appropriate antecedent to the overt anaphor immediately after occurrence of the pronoun or reflexive, thus demonstrating that, independent of final conscious interpretation, children demonstrate on-line sensitivity to syntactic binding constraints as young as 4 years of age.[1]

The current studies are aimed at elucidating the processing of the far less visible LDD co-referential relationships found in filler-gap (object- relative) constructions. (Lack of 'visibility' refers to the lack of an overt surface marker licensing the LDD relationship, unlike the more visible marker provided by a pronoun, e.g.; see, Fodor,1995 for a detailed hypothesis about relative visibility and processing of LDDs). We wish to determine whether in these conditions, as in those of overt anaphors, young children establish processing routines that reflect implicit knowledge of, and adult reflexive parsing responses to, the recovery of canonical order during ongoing comprehension. By employing the CMPP technique we can assess fine-grained processing details concerning how (and when) children process these LDDs. To this end, we present four experiments that investigate both young children's (two studies) and adult's processing (two studies) of object relative constructions, such as

"The zebra that the hippo had kissed$_1$ *on the nose ran far away".*

Experiments 1 (with children) and 3 (with adults) examine evidence concerning the reactivation of potential direct object NPs (e.g., 'zebra' (NP1) and 'hippo' (NP2) in the above example) at the canonical direct-object position (immediately after the verb) in object-relative constructions (subscript$_1$) . These studies will allow us to determine whether children aged 4–6 have the same structural reflex as employed by adults.

[1] It is noted in McKee et al (1993) that a group of 7 of 17 children tested were classified separately as they performed differently than the other children or adults. This group did not display the same developed grammatical system as the other children did and the authors discuss a number of possibilities surrounding this finding.

Studies 2 (with children) and 4 (adults) examine for evidence of activation of the NPs at a point prior to the verb (a baseline condition) , allowing us to determine if any activation for these fronted direct objects found after the verb is due to re-activation versus continued activation of the fronted object NP.

Experiment 1– examination for filler (re)activation at the post-verb 'gap' site with children

This experiment studied the activation patterns for pictures related to NP1 and NP2 at the gap site in object-relative constructions.

Subjects

A group of 28 children took part in this study. They were drawn from a child subject pool which included individuals recruited from throughout the San Diego, California, Parents brought the children to our laboratory for four separate, one-half hour sessions (again, with a minimum of 3 weeks separating each visit). Each child received a toy of his or her choice upon completion of each experimental visit. The children ranged in age from 4 to 6 years at the time of testing (Mean age = 5.6, SD = 0.5).

Method

Using the CMPP method, children listened to sentences and were instructed to understand them. They were instructed that they would be questioned about the sentences from time to time. They were also required to make a 'COULD be eaten / COULD NOT be eaten' binary classification decision about a picture that was presented on a computer screen at some point while they were comprehending the auditory sentence. The children made their decisions by pressing one of two large red buttons on a button box that they could rest their arms and hands on. The right button was used for a YES response (*it could be eaten*) whereas the left button was used for a NO response (*it could not be eaten*). The children were pre-trained to a 100% reliability criterion on these button press decisions (see Procedure section below). Participant's reaction times were recorded from the moment the picture was presented until a button-press decision was made (up to a maximum time of 4 s).

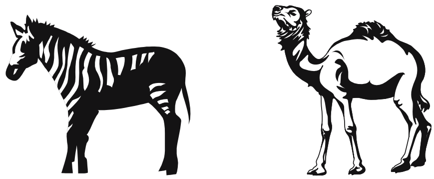
Materials and design

All experimental sentences had the following structure (in which the indexical ($_i$) reflects the co-referential relationship between NP1 (the fronted direct object) and its canonical post-verb 'gap' site):

NP1$_i$	*that*	NP2	*had*	*VERBed* (__$_i$)	*PP*	VP
The zebra $_i$	*that*	*the hippo*	*had*	*kissed* (__$_i$)	*on the nose*	*ran far away.*

The experiment employed a matched-sentence design, in which a particular target probe picture appeared in one sentence as a 'related' probe (e.g., a picture of a zebra paired with the above sentence) and in another sentence as a 'control' probe (picture of a zebra in a sentence which has no 'zebra' or related animal mentioned). Thus, the same picture serves as related probe and a control probe in the overall experimental design. Participants never saw any one picture more than one time in any one of the

Sentence (a) The <u>zebra</u>$_i$ that the hippo had kissed ___$_i$ on the nose ran far away.
Sentence (b) The <u>camel</u>$_i$ that the rhino had kissed ___$_i$ on the nose ran far away.



Example of NP1 Pictures probes appearing during each matched sentence pair

	Related		Control
Sentence(a)	Zebra		Camel
Sentence(b)	Camel		Zebra

Example of NP2 Picture probes appearing during each matched sentence pair

	Related		Control
Sentence(a)	Hippo		Rhino
Sentence(b)	Rhino		Hippo

Fig. 1 Example of counterbalanced design and materials. Depiction of counterbalancing in a match-sentence design used in both studies via a sample matched-sentence pair. Note that each factor (sentence (a) or (b) from matched sentence pair and picture (NP1 and NP1, related and control) were counterbalanced evenly across tape and list factors (e.g., all four visits))

four sessions in which they participated (i.e., any particular picture appeared as either a related or a control probe, but not both, in any one of four experimental sessions). Participants did experience each picture at some point in each of their four visits as an experimental or as a control probe. Because activation was examined for both NP1 and NP2, there were four such counterbalanced conditions. These constituted the four experimental sessions in which the children participated (again, at a minimum of three weeks between sessions, to minimize repetition effects). In each session, children experienced equal numbers of non-repeated exemplars of each experimental condition. Each participant experienced these sessions in a randomly assigned (fully counterbalanced) order to eliminate repetition effects across the overall experiment. See Fig. 1 for overview of this design.

A total of 69 sentences were presented to each participant in each of the four sessions (visits) (See Appendix A for full list of sentential materials). Thirty-two of these sentences constituted 'experimental' sentences, 32 constituted 'filler' sentences and five were practice sentences. All sentences contained two animal NPs (as in the example above). No animal was repeated throughout the experimental sentences. The filler and practice sentences were constructed such that 22 sentences contained a relative clause similar to that structure in the experimental sentences. The other 15 fillers and practice sentences were not object relative constructions, but were matched for overall length with the experimental sentences The purpose of using these latter constructions was to eliminate expectancy strategies based on sentence form.

The 32 experimental sentences were paired with pictures of animals. As described in the Procedures section below, all children were trained to judge that animals were NOT edible.[2] In addition, the 32 filler sentences were paired with both pictures of common edible items (hamburgers, carrots, etc.) to which participants were trained to make a YES response (22 items) and with inedible inanimate objects to which we participants were trained to make a NO response (ten items). The latter were included so that NO responses could not be made on the basis of animacy alone. Finally, five items were initially presented to participants as practice items in conjunction with the CMPP training. These were designed to generate both YES and NO responses from participants. There were two edible pictures and three non-edible pictures paired with these practice sentences (which consisted of four relative clause constructions and one right-branching construction). During these CMPP practice trials, the experimenter was able to check that the participant understood which items were edible and which were not.

In order to counterbalance the materials so that no child heard or saw any item more than once in any one visit, two recordings of sentences (tapes) and two lists (picture probes) were created. The tapes counterbalanced the sentence in which a particular picture was assigned as either experimental or control. Thus, in any such counterbalanced pair, the same sentence form (including the identical verb) was employed, but the animals named in the sentence differed (See Fig. 1). The two lists counterbalanced whether it was NP1 or NP2 which was tested for in any sentence.

The sentences were recorded onto the two tapes at a normal speaking rate (4.3 syllables per s) by a female speaker. Each tape contained the sentences in balanced orders. The sentences were then processed in a digital wave editing program which allowed a 1 kHz tone to be placed in an isolated channel of the tape (inaudible to participants) at the point at which the picture would be presented. In Experiment 1 this trigger tone was synchronized with the offset of the critical verb the filler sentences had tones placed randomly from between the third word of the sentence up to the next to the last word of the sentence. Once the trigger tone was added, these sentences plus non-audible trigger tone were then recorded out to a DAT tape. Sentences were presented to the participants binaurally over a set of headphones. The computer program that controlled all timing, presentation and reaction time recording for this experiment was a version of RT lab. This program allowed for pictures to be presented on a computer monitor simultaneously with onset of the inaudible 1 kH trigger tone. A msec-accurate computer timer was initiated with onset of the trigger tone (which itself initiated the picture presentation). This timer terminated with the participant's button press, recording both the time to respond and the type of response. The pictures remained on the computer screen for 2 s, and an additional 2 s was allowed for response. Any reaction times beyond the total of 4 s from the picture onset was recorded as a NO RESPONSE and counted as an error.

[2] Note that there are numerable other published findings that have validly used a NO response as the main measure for reaction time studies. Note that all comparisons (related versus control) are made between the same type of decision (i.e., 'NOT edible'). Because there are an equal number of YES/NO decisions, the literature has demonstrated that either decision can be used provided that the comparisons are performed within decision type. See for example Holmes (1996); McGinnis et al (1997); Swinney et al (1979); Vivevitch et al (1998) among others.

In addition to button press responses, children were also stopped ten times throughout the experiment (and two times during the practice trials) and asked a question about the sentence they had just heard (e.g.: for the sample sentence presented above, children were asked: ‘Who was kissed on the nose?’ Correct response: ‘zebra’). This comprehension task was performed to ensure that all participants were actually listening to and understanding the sentences while also monitoring the screen for the presentation of the visual probe. Anyone making two or more errors on any visit was not continued in the study. Overall percent correct for participants was 94%, demonstrating minimal difficulty in performing this dual task. The sentence immediately following a comprehension question was always a filler item.

Procedure

Once the parent arrived at our laboratory, the children were given a tour of the laboratory and the equipment. Children were trained in this experiment in stages. First, the children were asked some questions about what their favorite foods were. Following that, the experimenter asked the child if s/he could eat, for example, a truck. Every child replied NO (usually with a giggle). Children were then presented with 20 picture cards containing either animals/objects (ten non-edible items) or food items (ten edible). These 20 items were NOT the items that would be seen in the subsequent study. The children were asked to decided, for each picture, if they could eat the item. Once children were at 100% accuracy, they were then presented with the button response box and shown another set of pictures. This time, however, the pictures were presented via the computer and the children were trained (again to 100% accuracy criteria) to press the right button if they could eat the item represented by the picture or the left button if they could not eat the item represented by the picture. Children were encouraged to make accurate yet speeded responses. Once the child had mastered the button box (making YES/NO decisions to a set of practice pictures), the experiment began. The children were fitted with their headphones and instructed that they would be hearing sentences about animals. They were instructed to listen and understand each of the sentences. They were told that at some point during each sentence that a picture would appear on the screen and they would get to decide if it was a picture of something they could eat or not, just as they had done in the practice session. The experimenter played the first couple of practice sentences and encouraged the child to make his/her decision as fast as s/he could. Then, the experimenter would stop the tape and talk to the child about some of the sentences s/he had just heard. Once confidant that the child was listening and understanding the sentences and using the button box appropriately, the experiment continued.

Results

Only correct responses were included in the analysis discussed below. Incorrect responses were characterized as either the wrong button press (e.g., “edible” response for a “non-edible” item) or a response that exceeded the allotted time (“clock-out”). In addition, any data point that was two standard deviations above or below an individual participant’s mean reaction time was excluded from analysis. This resulted in a loss of an average of 1.6 experimental data points per participant (out of possible 128 data points). Three participants made more than one error in the comprehension test,

Table 1 Mean reaction times (RTs) in milliseconds for Experiment 1

(NB: The SLOWER reaction time in each related-control probe contrast is in **BOLD Font**, to allow reader to easily distinguish priming versus inhibition effects).

	Probe point 2 (gap)$-N = 25$
First NP	
Related	1597 $p = 0.0003$
Control	**1750**
Second NP	
Related	1680 n.s
Control	**1694**

and, based on our a priori decision criteria, were dropped from further analysis. Overall percent correct for the remaining participants was 95%, demonstrating minimal difficulty in performing this dual task. Mean response times over the four conditions were averaged across participants and items and are shown in Table 1.

As can be seen from Table 1, there was a priming effect of 153 ms found for NP1 probes but only a priming effect of 14 ms for NP2. A priori planned comparisons revealed the priming effect (related versus control conditions), for NP1 was significant (NP1: $subjects - t_{24} = -4.25, p = 0.003, items - t_{15} = -2.786, p = 0.014$) but not for NP2 ($subjects\text{-}t_{24} = -.46, p = 0.65, items-t_{15} = 0.059, p = 0.95$).

Experiment 2—examination for residual activation at a pre-gap baseline probe point with children

While it is clear from Experiment 1 that the structurally appropriate NP (NP1), but not the other 'potential' object candidate, is active immediately after the verb for which it is the direct object in the sentence, this evidence cannot distinguish whether such activation is re-activation of a previously processed NP (as found typically in adult studies) or whether the activation found is simply 'continued activation from the NP when first encountered. In order to distinguish these two possibilities, it is necessary to determine whether the NPs are active at some point prior to the verb (but after they fist are encountered). Experiment 2 investigated this issue employing the same materials and procedures as Experiment 1, with a picture-probe presentation point occurring earlier in the sentence.

Subjects

A separate group of twenty children took part in this study. They were drawn from the same child subject pool as employed in Experiment 1, which included individuals recruited from throughout the San Diego, California, area. The children's parents brought the children to our laboratory for four separate one-half hour sessions, with a minimum of three weeks separating each visit. Each child received a toy of his or her choice upon completion of each experimental visit. The children ranged in age from 4 to 6 years at the time of testing (Mean age = 5.1, SD = 0.8)

Table 2 Mean reaction times (RTs) in milliseconds for the variables of interest in Experiment 2

	Probe point 1 (baseline)$-N = 17$
First NP	
Related	1783 n.s
Control	**1792**
Second NP	
Related	**1806** n.s
Control	1778

NB: the SLOWER reaction time for each related-control probe contrast is in **BOLD Font**, to allow reader to easily distinguish priming versus inhibition effects.

Methods (materials, design, and procedure)

The methods (including materials, design, and procedure) were identical to those in Experiment 1, with the exception that the picture probe presentation point occurred with the onset of NP2 (two words before the critical verb was heard).

Results

As in Experiment 1, only 'correct' answers were included in the analysis for Experiment 2. This resulted in a loss averaging 1.3 experimental data points per participant (out of a total of 128 possible data points). In addition, based on our a-priori decision criterion, three children were dropped from further analysis for making more than one incorrect responses to the comprehension questions during the study. Table 2 presents mean reaction time data for the major experimental conditions, averaged across subjects and items.

As can be seen in Table 2 there was a priming effect of 9 ms for probes related to NP1 at this baseline test point. There was an inhibition effect of −28 ms for probes related to NP2 at this same test point. Neither of these effects was significant. A-priori planned comparisons revealed no significant differences for either NP1 or NP2 (related versus control conditions): NP1: subjects $-t_{16} = -0.147$, $p = 0.89$, items $-t_{15} = 0.613$, $p = 0.55$; NP2: subjects $-t_{16} = .382$, $p = 0.71$, items $-t_{15} = 0.073$, $p = 0.94$. Thus, at this initial baseline probe point, there is no significant activation (priming) or inhibition for items related either to NP1 (the critical NP) or to NP2.

Test for re-activation versus continued-activation of 'fronted' direct object at gap

The issue of 'continued activation' as opposed to 're-activation' of moved NPs in LDD is an empirical question that can be determined in part via examination of the pattern of priming effects found in Experiments 1 and 2 (as discussed above). In addition to these individual analyses, however, it is important to examine the changes in the level of activation from the baseline probe position (Experiment 2) to the canonical gap site (Experiment 1) to ultimately determine the issue of 'continued' versus 're-' activation. This is accomplished by submitting the data from both Experiments 1 and 2 to an overall ANOVA [employing both Subjects and Items as random factors. The between-subjects factor in this analysis is the probe position condition (baseline and gap); the within-subjects factors are the Noun Phrase condition (NP1 and NP2) and the Relatedness conditions (related and control picture probes)]. Significant interactions between probe position and relatedness for each of the NPs tested in the experiment would indicate a true change in the pattern of activation across the two probe points.

Examination of the results for NP1 [the noncanonically-positioned (fronted) direct object constituent] and NP2 reveal very different patterns of activation. In addition to a main effect of relatedness for NP1 ($F1(1, 40) = 6.25$, $p < 0.017$), there was a significant interaction of relatedness (related versus control) by probe position (baseline versus gap) in both subjects and items analyses ($F1(1, 40) = 5.008$, $p = 0.03$, $F2(1, 30) = 5.025$, $p < 0.03$) for NP1, demonstrating a significant re-activation effect for the structurally appropriate filler at the gap site. There were no significant main effect or interaction found for NP2 ($F1(1, 40) < 1$; $F2(1, 30) < 1$).

There is a clear interpretable pattern in the overall data. For children ages 4–6, we find that there is a change in activation level between the baseline and the gap-site only for the non-canonically positioned direct object (NP1). This suggests that once a verb is encountered which requires a direct object in a sentence in which a fronted direct object has been encountered earlier, that direct object is immediately re-activated (at the post-verb gap site). Importantly, this effect is not happening for all NPs, but just for the fronted direct object.

In order to demonstrate that the re-activation effects previously shown for adults work for the particular materials and procedures used in this study, two experiments were undertaken with adults. Experiment 3 examined for activation at the post-verb gap probe position and Experiment 4 examined for priming at the baseline position.

Experiment 3—Examination for filler re-activation at post-verb gap site with adults

Subjects

Twenty six undergraduates (Mean age = 19.7, SD = 1.1) from the University of California, San Diego participated in this study for course credit. All participants had normal or corrected-to-normal vision and hearing, and had no history of neurological problems.

Methods (materials, design, and procedure)

The methods (including materials, design, and procedure) were identical to those in the Experiment 1 (see above).

Results

Only 'correct' answers were included in the analysis for Experiment 3 (see Experiment 1 for more details). Mean response times for the critical factors were averaged across participants and items and are shown in the second data column of Table 3.

As can be seen from Table 3, there was a 28 ms priming effect for NP1 at the gap position for adult participants. A priori planned comparisons revealed this effect to be significant (subjects $-t_{25} = -1.724$, $p < 0.049$, items $-t_{30} = 0.48$, $p = 0.32$). There was a non-significant inhibition effect for NP2 response times of −23 ms (subjects

Table 3 Mean reaction times (RTs) in milliseconds for Experiments 3 (probe point at gap) and Experiment 4 (pre-gap probe point (baseline)) for adult participants

	Pre-gap probe point (baseline)$-N = 20$		Probe point at gap $-N = 26$	
First NP				
Related	**961**	$p = 0.015$	877	$p < 0.05$
Control	909		**905**	
Second NP				
Related	**980**	$p = 0.03$	**923**	n.s
Control	915		900	

NB: The slower reaction time in each related-control contrast is in bold font.

$-t_{25} = 0.89, p = 0.19$, items $-t_{30} = 0.003, p = 0.501$). An overall ANOVA on these data also revealed a significant main effect for a main effect of NP ($F1(1, 25) = 4.817$, $p = .038$).

Experiment 4—examination for residual activation at baseline probe point with adults

Subjects

A separate group of 20 undergraduates (Mean age = 19.7, SD = 1.7) from the University of California, San Diego participated in this study for course credit. All participants were native English-speaking, right-handed individuals who had normal or corrected-to-normal vision and hearing, and had no history of neurological problems.

Methods (materials, design, and procedure)

The methods (including materials, design, and procedure) were identical to those in Experiment 2, above.

Results

Only correct answers were included in the analysis. Mean response times over the four conditions were averaged across participants and items and are shown in the first data column of Table 3.

As can be seen in the first column of Table 3, there was a 52 ms inhibition effect for NP1 and a 65 ms inhibition effect for NP2 at this pre-gap baseline test point. An ANOVA on these data reveal a main effect for relatedness ($F1(1, 19) = 11.16$, $p = .0034$). A priori planned comparisons revealed significant inhibition (SLOWER reaction times for the related probes as compared to the control probes) for both NP1 and NP2 (NP1: subjects $-t_{19} = 2.333, p = 0.015$, items $-t_{30} = -0.999, p = 0.17$, NP2: subjects $-t_{19} = 2.063, p < 0.03$ items $-t_{30} = -1.654, p = 0.054$).

Test for re-activation versus continued-activation of direct object at gap for adults

An overall ANOVA employing both Subjects and Items as random factors was performed on the data from Experiments 3 and 4 in order to analyze for interactions (as well as main effects) across all the experimental conditions. The between-subjects factor is the two probe position conditions [baseline and gap]; the within-subjects factors are the two Noun Phrase conditions [NP1 and NP2] and the two Relatedness conditions [related and control picture probes]).

Examination of the results for NP1 (the noncanonically-positioned (fronted) direct object constituent) and NP2 reveal very different patterns of activation. For NP1 there was an interaction of relatedness (related versus control) by probe position (baseline versus gap) ($F1(1, 44) = 8.718$, $p = 0.0049$). There were no significant main effects involving NP1... For NP2 the only main effect found was for the relatedness condition ($F1(1, 44) = 4.734, p = 0.035, F2(1, 60) = 1.517, p = 0.223$). No other significant main effects or interactions were demonstrated involving NP2.

Discussion

College age adults in this study demonstrate re-activation of the structurally correct antecedent (filler) at the offset of the verb during the comprehension of object-relative constructions. This finding, employing the cross modal picture priming methodology, replicates a well-established result in the adult literature derived from a range of other methodologies. The reflex underlying the recovery of sentence constituents in canonical order for comprehension appears to be a robust effect in the adult processor.

Our examination of processing of these same LDDs in children supports the view that children as young as 4 years of age demonstrate the processing reflexes demonstrated by adults. As for adults, the reactivation process occurs as soon as it is licensed (by the verb) and only the syntactically correct NP is re-activated.

These results concerning less ‘visible’ LDDs appear to be in line with evidence of overt anaphor processing as studied by McKee et al. (1993). In addition, our results support the general but somewhat underdetermined claim that “... the 4 years old has a sophisticated competence grammar and a parsing mechanism of essentially the same structure as the adult’s...” (Goodluck, & Tavakolian, 1982). Our findings are in line with the claims of overarching reliance on syntactic structure by young children in their sentence comprehension and production (McKee, McDaniel, & Snedeker, 1998; Felser, Marinis, & Clahsen, 2003; Roberts et al. 2006, in press).

Overall, there appears to be a strong drive by the comprehension system to recover the underlying canonical order of language input. Our data suggest that this process is in place very early in development, before children appear to overtly or consciously produce these constructions to any major or fluent degree.

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Appendix A: Experimental materials from all four experiments

1. The *zebra* that the *hippo* had kissed on the nose ran far away.
2. The *skunk* that the *raccoon* had surprised in the woods rolled down the hill.
3. The *kitten* that the *baby* had visited before breakfast crawled across the floor.

4. The *dolphin* that the *shark* had poked on the side splashed in the waves.
5. The *bear* that the *gorilla* had scared by accident went swimming in the pool.
6. The *chick* that the *turkey* had chased around the yard climbed on a rock.
7. The *duck* that the *fish* had seen in the morning floated in the pond.
8. The *owl* that the *goose* had teased all day flew through the air.
9. The *kangaroo* that the *ostrich* had raced down the road came to the river.
10. The *toad* that the *snail* had met near the rose bushes rested after dinner.
11. The *dog* that the *cat* had patted on the back napped in the grass.
12. The *wolf* that the *elephant* had heard in the dark stared at the moon.
13. The *horse* that the *cow* had kicked in the field trotted into the barn.
14. The *duckling* that the *lamb* had called in the meadow danced in a puddle.
15. The *bee* that the *ant* had rubbed on the back dreamed about flowers.
16. The *reindeer* that the *walrus* had smelled in the air slipped on the ice.
17. The *camel* that the *rhino* had watched from a distance peeked through the leaves.
18. The *chipmunk* that the *squirrel* had startled near the log hopped up and down.
19. The *pig* that the *puppy* had liked so much played in the garden.
20. The *whale* that the *seal* had raced to the shore blinked in the sun.
21. The *tiger* that the *lion* had followed in the woods hid behind a tree.
22. The *hen* that the *rooster* had loved for years sat in the dust.
23. The *turtle* that the *frog* had bumped from behind moved through the weeds.
24. The *giraffe* that the *monkey* had greeted at the zoo jumped over the fence.
25. The *mouse* that the *snake* had helped in the afternoon slept in the sun.
26. The *rabbit* that the *bird* had touched very carefully went to the playground.
27. The *parrot* that the *pigeon* had frightened at night landed in the tree.
28. The *flamingo* that the *alligator* had tapped on the head ate early in the morning.
29. The *donkey* that the *goat* had pushed through the door fell in the mud.
30. The *calf* that the *chicken* had tickled in the hay drank from a bowl.
31. The *butterfly* that the *spider* had pinched for no reason looked for a new home.
32. The *otter* that the *penguin* had hugged at bedtime snored during the night.

Filler sentences:

1. The chimpanzee that the clown had carried onto the stage waved to the crowd.
2. The buffalo that had snorted at the bull on the prairie stomped his feet.
3. The hamster and the guinea pig that had eaten the lettuce chewed on the paper.
4. The seagull told the crab on the beach to catch a fish for dinner.
5. The poodle barked at the collie before scratching at the door.
6. The dragon that the unicorn had spotted near the castle disappeared in the mist.
7. The pelican that had looked at the stork stood on one leg.
8. The salamander and the newt that had stayed under the rock stretched out in the shade.
9. The ferret ordered the weasel in the cage to do a somersault.
10. The cockatoo squawked at the peacock before cleaning its feather.
11. The caterpillar that the beetle had admired from a distance fell off the leaf.
12. The leopard that had stared at the panther in the jungle leaped out of the cave.
13. The wasp and the mosquito that had buzzed around the room flew out the window.
14. The woodchuck asked the possum in the swamp to climb a tree before dark.
15. The dove hid from the quail before laying its eggs.

16. The lizard that the gerbil had seen in the terrarium drank from the water dish.
17. The moose and the deer that had stomped through the fields flattened all the plants.
18. The mole reminded the gopher in the yard to stay away from the garden.
19. The cockroach noticed the rat while climbing through the garbage.
20. The monkey that the baboon had knocked over grinned at the zookeeper.
21. The frog that had watched over the tadpole splashed in the pond.
22. The seahorse and the goldfish that had been in the bowl now lived in the fish tank.
23. The canary asked the finch with yellow eyes to sing a new song.
24. The cat saw the bird with the broken wing after reaching the window.
25. The mule that the goat had left behind the haystack chewed on an apple.
26. The bobcat that had roared at the mountain lion near the river walked along the bank.
27. The eagle and the hawk that had circled above the campground frightened the small animals.
28. The rhino told the hippo in the field not to fall into the ditch.
29. The spider listened for the bat after hanging from the ceiling.
30. The hen that the cow had bothered with noise snored in the barn.
31. The puppy that had drooled on the baby with the toy waddled across the room.
32. The duckling and the chick that had played near the barn ate all the seeds.
33. The fish ordered the otter in the stream not to throw the stone.
34. The koala waved to the panda before curling up in the tree.
35. The wolf that the chipmunk had bitten on the toe limped back home.
36. The calf that had said hello to the swan on the lake rippled through the water.

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