Processing of Relative Clauses in Infants[1]

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1. Introduction

Investigation of children's early syntactic competence has relied, for the most part, on the analysis of spontaneous speech corpora and on the use of tasks that require explicit behavioural responses. In the majority of these tasks, children are asked to either perform an action (e.g., a pointing response) or to provide an answer (e.g., a true-value judgement), as a measure of their comprehension abilities. The last decade has seen an increase in the use of methods that measure moment-by-moment responses during on-line sentence processing in developmental psycholinguistic research. These methods often require only an implicit response from participants (e.g., their eye gazes, visual attention or brain activation) and they have been argued to provide a more sensitive measure of children's linguistic competence than off-line tasks, because they are less cognitively demanding and less prone to the use of heuristic strategies (e.g. Trueswell & Gleitmann, 2007). Implicit responses are spontaneous behaviours that allow us to make inferences about the participant's evolving interpretation of an utterance. In contrast, explicit responses make it obvious what the participant is referring to but they require an extra step, which is the planning and subsequent production of this response.

The use of implicit methods has allowed the uncovering of an early sensitivity to subtle syntactic phenomena that were, until recently, claimed to be set later in development. For example, it has been shown that between 15- and 20 months, infants start to have some understanding of subject as well as object wh-questions (Seidl, Hollich & Jusczyk, 2003) and may be sensitive to the word order properties of their native language, specifically the head-parameter (Franck, Millotte, Posada & Rizzi, 2013).

In this paper, we examined the on-line processing of restrictive relative clauses (RC) in English-learning 18-, 24-month-olds and adults. Using an adaptation of the preferential-looking-paradigm (Swingley, Pinto, & Fernald, 1998), we aimed at testing whether infants would fixate on the referent of the RC head noun as a sign that their parsing preferences are developing towards the adult, fully-specified sentence parser. Before presenting the details of the study (section 4), we will review some of the relevant properties of restrictive RCs (section 2) and provide an overview of the existing literature on acquisition and children's processing of RCs (section 3).

2. Restrictive relative clauses: definition and properties

In English, as in other head-initial languages, the head noun (i.e. *the cow* in (1) and (2)) precedes the embedded clause, which is indicated between squared brackets:

1) Where is the cow that [_ is chasing the monkey]?
2) Where is the cow that [the monkey is chasing _]?

While (1) is an example of a subject (-extracted) RC i.e., the head noun *cow* is assigned the subject role by the embedded verb *chase*), (2) is an object (-extracted) RC i.e., the head noun is the direct object of the embedded verb. In the two examples, these positions of subject and object of the verb are indicated by "_". In current linguistic theory (Radford, 2004), the sentence-initial position of the head noun is derived via syntactic movement, stemming from its original position as verb argument. Several RC types exist: this paper concentrates on restrictive ones. In English, like in many other languages, restrictive RCs are noun modifiers i.e. they operate in a way similar to adjectives. Importantly, their function is to restrict the set of potential head referents to one uniquely identifiable referent (Heim & Kratzer, 1998). This means that, in order to test RCs in a pragmatically appropriate context, at least two potential referents of the head noun (i.e. two cows in examples (1) and (2)) must be present in the context (Hamburger & Crain, 1982; Adani, 2011). We will now provide an overview of experimental work in relative clause acquisition and processing by children. Due to space restrictions, we will concentrate on recently published works only.

3. Relative clause acquisition and (children's) processing

In English, we observe that object RCs are harder to understand and to process than subject RCs. This asymmetry is attested in adults (e.g.

Traxler, Morris & Seely, 2002) as well as in children (e.g. Adani, Forgiarini, Guasti, & van der Lely, 2014). The adult processing difficulty manifests itself in terms of longer reading/looking times in object RCs compared to subject RCs. In contrast, children simply fail to identify the referent of the object RCs up to 5 years of age. Difficulty with object RCs is documented in a variety of head-initial languages, such as Hebrew (e.g. Arnon, 2010; Friedmann et al., 2009), Italian (e.g., Arosio, Adani, & Guasti, 2009), Portuguese (e.g., Corrêa, 1995), Greek (e.g., Stavrakaki, 2001) and English (e.g. Adani et al., 2014). All these studies involve explicit measurement of RC comprehension (act-out or pointing).

In two published studies, on-line RC processing was compared in English-speaking school-age children and adults. Using a cross-modal picture priming paradigm, Love (2007) showed that 5;6-year-olds (age range 4 to 6 years) were able to re-activate a sentence-initial RC head noun as the direct object of the embedded verb. This priming effect at the verb was similar to the one found in the adult group. Using a self-paced listening task, Contemori and Marinis (2013) found that 7-year olds revealed a processing profile similar to adults, despite their reactions times being overall longer and their off-line accuracy scores lower. Both Love (2007) and Contemori and Marinis (2014) argue for continuity between the adult processing system and the one of school-age children. Very recently, Adani and Fritzsche (2015) have compared implicit (i.e. eye gaze) and explicit (i.e. pointing) measures of RC processing in German-speaking 4-year-olds and adults, using a visual world paradigm. While in the pointing data the accuracy on object RCs remained below chance, the eye gaze measure showed an increase in looks to the referent of the RC head noun in both subject- and object RCs. However, the looks to the RC head referent increased more slowly in object RCs compared to subject RCs. These effects held in children as well as in adults. Hence, it appears that the subject-object asymmetry emerges when measuring both implicit and explicit responses and it affects children's and adults' processing in a similar way. To date, most studies that have looked at the on-line RC processing were conducted with school-age children and pre-schoolers as young as 4 years of age.

More controversial is Gagliardi and Lidz's (2009) finding that English-learning 15-month-olds already have a significant preference for the correct referent of the RC head in subject RCs, when they are tested using a visual world paradigm. Surprisingly, however, this preference disappeared in 20-month-olds, where there was no evidence that they could fixate on the correct referent in either subject- or object RCs. It should be noticed, however, that these effects were quite weak: they were found only in a one-sec-interval after the second occurrence of the sentence and when the last three trials were analysed in isolation. Collapsing across all trials made the effect disappear. Moreover, different groups of children were tested with subject- and object RCs, thus making it hard to draw conclusions about the rate of acquisition of different structures. Finally, Gagliardi and Lidz did not test an adult control group. It seems that having a control group is essential to establish, first, whether the experimental set-up works. Moreover, control groups can function as a reference point in the analysis, especially when it comes to interpreting unexpected developmental patterns, like the one found in the study by Gagliardi and Lidz. The authors argue that the correct parsing of subject RCs by 15-month-olds was based on a (non-syntactic) heuristic strategy. In contrast, 20-month-olds attempt to apply (still incomplete) linguistic knowledge to parse RCs but fail to do so.

4. Our Study

In order to explore how early in development, children and adults start to use similar parsing routines to process subject- and object RCs, we tested subject- and object RCs and we analysed the time course of fixation during the whole sentence stimulus. This allowed us to have a direct comparison of how the processing of subject and object RCs develops over time. In order to test our set-up, we also included a control condition: matrix clauses, which are simple declarative sentences that are not modified by an embedded clause e.g., *Where is the cow*?

Based on the existing literature, we formulate the following predictions. If our method is suitable to detect a gradient of sentential syntactic complexity, we expected to find a greater increase of looks to the correct referent in matrix questions, compared to RCs. The interpretation of this effect is quite straightforward: matrix questions lack the embedded clause and, as such, are syntactically less complex. We expected both adults and infants to discriminate matrix questions from RCs. Second, we expected looks to increase to the correct referent in subject RCs more quickly upon hearing the target, as compared to object RCs. This effect would be supporting evidence for the emergence of the subject-object asymmetry during the exploration of a visual scene. Notice that, while the adult subject-object asymmetry is robustly documented in the literature in terms of reading times, so far, only Adani and Fritzsche (2015) have detected it during the exploration of a visual scene. Our study aims at replicating this result with adult speakers of a different language, namely English. As for children, four years is the youngest age at which the subject-object asymmetry has been detected in terms of faster increase of looks to the correct referent in subject RCs compared to object RCs (Adani & Fritzsche, 2015). Whether this asymmetry is detectable at a younger age is still a matter of debate (Gagliardi & Lidz, 2009). The present study aims at elucidating this issue, using a design that allows the direct comparison of subject and object RCs (both structures are tested within the same participants) and of infants and adults (both groups are tested with the same material). We expect adult data to revel the subject-object asymmetry.

We investigated the processing of relative clauses in 18- and 24-month-olds for two reasons. First, there is evidence that 19-month-olds are already sensitive to word order properties of their native language, at least in declarative sentences (Franck et al., 2013). Additionally, 15-month-olds have been shown to be able to fixate the correct referent of a subject wh-question, with 20-month-olds succeeding on both subject- and object wh-questions (Seidl et al., 2003). Given that RCs are structurally more complex than both declaratives and wh-questions, we decided to test a group of 18-month-olds and a group of 24-month-olds. Based on Seidl et al's results it is possible that 18-month-olds will show some understanding of subject RCs only, whereas 24-month-olds may be expected to fixate on the correct referent in both subject and object RCs.

Method

Participants

Seventy-three participants took part in the study. They were divided into three groups: 18-month-olds (N=31), 24-month-olds (N=32) and adults (N=10). The adult participants were monolingual and the infants had 90% or more exposure to English as determined by a language questionnaire (Sundara & Scutellaro, 2011) administered to parents. Infants' productive vocabulary was measured using the MacArthur Communicative Development Inventory (Fenson, Dale, Reznick, Bates, Thal & Pethick, 1994). Eighteen-month-olds had a mean raw vocabulary score of 18 (range: 2-45); 24-month-olds had a mean raw vocabulary score of 56 (range: 18-100). Adults were all undergraduate students at the Department of Linguistics, University of California Los Angeles and they received course credit for their participation.

Material

Visual stimuli

The visual stimuli for the test trials were short movie clips (mean duration: 14.2 sec, SD: 0.07 sec). In each trial, participants saw three cartoon animals. The configuration of animals on the screen reproduced the one used by Adani (2011). The animals were placed as far apart from each other as possible, either along the diagonal or in a row on a 46-inch TV screen (actual viewing area 32in by 22in). The animal in the center was always different from the two animals on the sides, which were identical. The center animal always had a two-syllable name - i.e. puppy or monkey. The animals on the sides had a one-syllable name - i.e. cow or pig. Each animal pair was only presented once. Table XXX-1 reports the frequency for each of animal name and verb used in the experiment, calculated using the CLEX database (Jørgensen, Dale, Bleses & Fenson, 2009)[2]:

	% Production[3]		**% Comprehension (% Production)[4]**
Word	**24 mos**	**18 mos**	**18 mos**
Cow	74.1	38.8	80.3 (30.3)
Pig	74.8	27.2	72.7 (28.8)
Monkey	66.7	22.3	65.2 (19.7)
Puppy	77.0	39.8	71.2 (37.9)
Splash	43.7	7.8	74.2 (13.6)
Chase	19.3	2.9	n.a.

Table XXX-1: Frequency of occurrence of nouns and verbs used in the experiment.

Each animal pair was presented performing one of two transitive actions - chase and splash. The two verbs were chosen because they did not require contact between the agent and patient. Thus, target and distractor animals could be positioned as far as possible from the animal in the center. There were four trials with *splash* and four trials with *chase*. On half the trials, animals performed the action facing left and on the other half, they were facing right. On test trials, the target animal appeared equally often on the left- or right-hand side of the screen.

The visual stimuli for filler trials were eight movie clips that included the same four animals used in the test trials. For fillers, we used a matrix question such as *"Where's the puppy?"* when only one puppy was on the screen with two different animals (e.g. a monkey and a pig). The fillers were included to confirm that the children were able to associate the cartoons of animals with their names. For fillers as well, the target position was balanced between left and right. No direction of action was identifiable given that two of the three animals were always facing each other. Each participant was presented 4 subject RCs (1), 4 object RCs (2) and 8 matrix questions, yielding a within-subject design with a total of 16 trials.

Auditory stimuli

Each video was synchronized with the auditory presentation of a sentence. A 25-year-old female native speaker of American English recorded all sentences. Her speaking rate was slow and she produced the sentences in an animated voice in order to make the stimuli engaging to children. The sentences were recorded in a soundproof booth. PRAAT was used to digitize the sentences at 22 KHz sampling frequency and 16-bit quantization rate. We measured the overall duration, average intensity and range of intensity, average pitch and range of pitch for the object and subject RCs; there was no significant difference between the two types of target sentences when compared using a t-test (all p-values > .3).

	Duration in sec (SD)	**Intensity in dB (SD)**	**Pitch in Hz (SD)**
Subject RCs	5.05 (0.06)	70.86 (0.40)	248.07 (1.67)
Object RC	5.04 (0.01)	70.95 (0.33)	252.44 (6.86)
Matrix Questions	3.76 (0.12)	71.80 (0.38)	265.1 (7.26)

Table XXX-2: Duration, Intensity and Pitch for the three trial types

Procedure

Adult and infant participants were tested individually. No instructions were provided to infants; adults were instructed to simply watch the video. The infant sat on the parent's lap approximately 2 meters from the screen. Outside the booth, the researcher started the trial when the participant looked at the screen. Parents as well as the experimenter wore headphones that delivered masking music. This was done to ensure that the parent and the experimenter were blind to the auditory stimulus and thus, could not influence the test results. The experiment lasted for approximately 6 minutes. Each testing session started with a 12-second-long pre-recorded preamble with a puppet saying: "*Hello! I'm Meggy the monkey. I'm going to show you my animal friends! They are always very silly! Would you like to play with us? Show me the right animal!*". This preamble was used to engage the participant's attention and introduce the rest of the experiment.

At the beginning of each trial, a colourful looming circle accompanied by a child giggling was used to attract the participant's attention to the screen. Once the participant looked at the screen, the audio and video stimuli were presented. Stimulus presentation was controlled using Habit X (Cohen, Atkinson, & Chaput, 2004). The order of presentation of the trials was randomized across subjects. Visual fixations were recorded using a Sony DCR-DVD 308 digital camera.

Each trial started with a green screen and had three parts: an introduction, a silent baseline interval and a test interval. During the introduction, each of the three animals appeared one after the other. The first animal was presented on the left on half the trials, and on the right on the other half. Each animal was named as it appeared on the screen. The animal in the middle was always the last one to appear. This was done to direct the child's gaze to the center of the screen before looking time measurements began. After the introduction, a baseline interval consisted of approximately 3 seconds of silence during which the three animals remained on the screen. A comparison of the proportion looks to each of the three animals during the baseline interval allowed us to determine the saliency of each cartoon presented on the visual display for each participant.

The test interval followed the baseline interval. During the test interval, the critical sentence (test trial or filler trial) was followed by approximately 1 sec of silence and by the question *'Can you find it?'*. Mean duration for each trial subpart is reported in Table XXX-3.

	Introduction	**Silent Baseline**	**Test interval**
Subject RCs	5.97 (0.02)	3.20 (0.04)	4.08 (0.03)

Object RCs	5.99 (0.05)	3.16 (0.04)	4.08 (0.01)
Matrix Question	5.47 (0.15)	2.57 (0.11)	2.69 (0.4)

Table XXX-3: Mean duration of each subpart of each condition (SD)

The trial structure of matrix and RC questions is illustrated schematically in Figure 1.

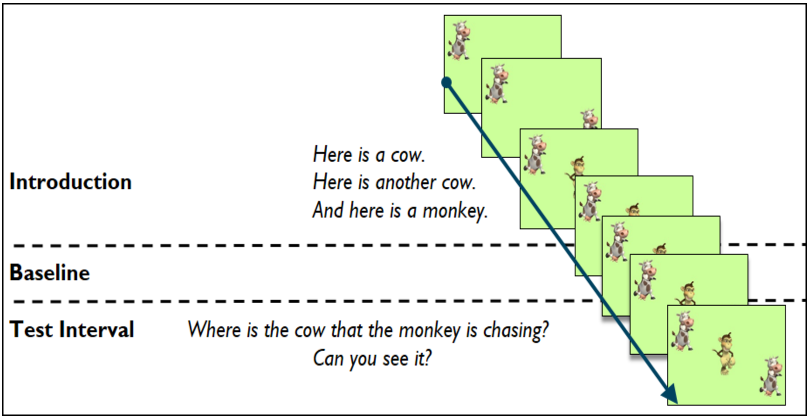

Figure XXX-1: Example of trial structure for an object RC.

Coding eye-movement

For each session, the videos were digitalized at 30 frames per second and coded off-line, frame-by-frame by 5 experienced coders using the Sony Picture Motion Browser software. The coders were blind to the auditory stimuli and to the purpose of the experiment. For every frame between the onset of the 3 seconds of silent baseline till the offset of the trial, the eye gaze was judged to be left, right, central or off (e.g. looks to the floor or looks to the parent). Looks to the target animal were coded as ‘1’, looks to the distractor animal (i.e. the other animal of the same kind) were coded as ‘-1’ and looks to the animal in the center were coded as ‘0’. Blinks were coded as continuation of the fixation preceding the blink, if the first available fixation after the blink was in the same direction. If pre- and post-blink fixations differed, the first half of the relevant frames was coded as the preceding fixation and the second half as the second fixation.

A minimum of 3 out of 16 trials were randomly selected and double-coded for each child to ensure inter-coder reliability.

Trial exclusions

A trial was excluded for one of four reasons: (a) there were no fixations recorded during the silent baseline interval; (b) there were no fixations during the first 500ms after the RC head noun onset, since this might have caused a delay in looking times with respect to those trials where the participant was oriented towards the screen from the RC head onset; (c) there were missing fixations for longer than 1 sec during test trials; (d) the participant's eyes were out of the video camera range during some part of the trial. These criteria led to the exclusion of 39 (out of 496) trials in the group of 18-month-olds and 23 (out of 512) trials in the group of 24-month-olds. No trials were excluded for the adults.

All missing data points were excluded and proportion of looks to target "T" (the referent of the RC head for test trials and the correct animal in filler trials) and to distractor "D" (the other animal of the same kind in test trials and the animal on the other side of the screen in filler trials) and to the animal in the center "C" were computed as relative proportions of the total fixations to target, distractor and center.

Data Analysis

We analyzed the time course of online comprehension in children and adults. The preferential looking procedure (Swingley, Pinto, & Fernald, 1998) relies on infants' tendency to look more at an image that matches an auditory stimulus than to an image that does not match. Specifically, the analysis involves two crucial comparisons: first, the proportion of looks to target animals in the test interval are compared to the silent baseline interval; second, the proportion of looks to target images in the test interval are compared to the proportion of looks to distractor animals in the test interval. By using these two matrices, we generated accuracy data for all participants.

First, the proportion of fixations to each animal during the entire period of silence (approximately 3-sec-long) was used as a baseline measure of interest in the target animal in the absence of speech. Next, looks to the target and to the distractor were compared as follows: the time interval where the speech stimuli occurred was divided into 1-sec-bins, starting from the onset of the RC head noun until the offset of the trial. This binning generated five consecutive 1-sec-bins for test sentences, and four consecutive 1-sec-bins for filler sentences. To make test and filler sentences comparable in the statistical analysis, the last two bins in test sentences (4^{th} and 5^{th}) were merged into one bin. Proportions of fixations to target (pT), to distractor (pD) and to center (pC) in each one-sec-bin were computed.

Crucially for our research questions, a difference score between pT and pD was computed (pDif = pT-pD). This variable indexes the increase in proportion fixation to the target in each test interval. Comparing the difference score pDif in the baseline and in each test interval will give us a measure of how pDif develops as the test sentence unfolds. The distribution of this difference score is illustrated in Figure XXX-2. Notice that a difference score of zero can be obtained when both pT and pD have the same value or when participants did not look at either target or distractor in the given time interval.

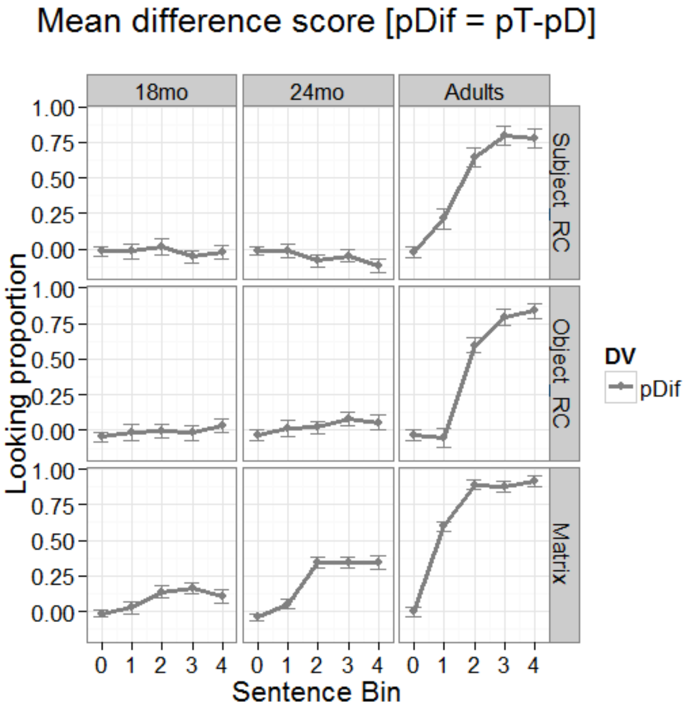

Figure XXX-2: Difference in proportion fixation scores (pT –pD) are plotted for each level of sentence (Subject RC; Object RC; Matrix questions) for each participant group (18-month-olds; 24-month-olds; adults). Bin 0 is the silent interval; bins 1-4 are during test interval. Error bars indicate 1 standard error, corrected for within-subject variance.

Visual inspection of Figure XXX-2 reveals that pDif is different from 0 in adults in all conditions and in infants on only the matrix questions.

We used linear mixed models (LMMs) to analyse the results. LMMs have several advantages over repeated measures ANOVA (Kliegl, Wei, Dambacher, Yan & Zhou, 2011; Baayen, 2008), as they allow by-item and by-participant variance to be taken into account simultaneously; second, LMMs suffer less severe loss of statistical power due to missing data. Loss of data is unavoidable in infant research and eye-movement research more generally.

The statistical and graphical outputs used in this paper were generated using the R language (R Development Core Team, 2011). We present coefficient estimates, their standard errors and t-scores. An absolute t-score of 2 or greater indicates significance at the alpha level of .05. Note also that the t-score is not accompanied by degrees of freedom or p-values, because in LMMs degrees of freedom can only be approximated (Baayen, 2008; Gelman & Hill, 2007).

The difference between the proportion of fixations to target and to distractor (pDif=pT-pD) was specified in the model as the dependent variable. Subjects and Item were specified in the model as random factors; sentence and bin were specified as within-subject fixed factors and Age was a between-subject fixed factor. We tested adult subjects to validate our procedure, thus results from adult subjects are presented first.

Adult Data

In this analysis, only the data from adult participants are considered. In the model, sentence was a fixed effect (subject RC, object RC and fillers/matrix questions), so was bin (0,1, 2, 3 and 4). We also included their interaction. Bin was reference coded, that is each successive bin was compared to the baseline, namely bin 0. Effects of sentence were explored with contrasts. The first contrast compared subject and object RCS together compared to fillers. This was done to check whether matrix questions are easier to process compared to RCs. The second contrast compared subject RCs to object RCs. This was done to check whether subject RCs are easier to process as compared to object RCs.

To estimate the effect of sentence, we specified the following contrast matrix:

cmat <- matrix(c(-1/2, -1/2, +1, -1, +1, 0), 3, 2)

When assigned to factor sentence, the inverse of *cmat* delivers the comparisons illustrated in Table XXX-4 (1a & 1b). Contrasts within the factor bin were assigned using the *contr.treatment()* function. This function compares the first level of a fixed factor (in our case, the baseline) to each other level, thus yielding the set of comparisons illustrated in Table XXX-4 (2a-d):

Fixed Factor	**Contrasts**
Sentence	1.a) Filler sentence – Test sentence
	1.b) Object RCs – Subject RCs

Bin	2.a) Bin 1 – Bin 0
	2.b) Bin 2 – Bin 0
	2.c) Bin 3 – Bin 0
	2.d) Bin 4 – Bin 0

Table XXX-4: Definition of contrast coding

We fitted the model *m.adults* where all the above contrasts and their interactions are estimated simultaneously:

*m.adults <- lmer(pDif ~ Sentence*BinF + (1 | Subject_ID) + (1 | Item))*

The statistical analysis revealed that adults distinguished fillers and the RCs early. There was an increase in the proportion looks to the target in the test phase compared to the baseline for both fillers and RCs. However, this difference was larger for fillers in bin 1 and 2. Thus, adults fixate on the target in the matrix clauses earlier than in the RCs.

Differences between the subject and object RCs also emerged early, but were even more restricted in time. There was a greater increase in proportion looks to the target in the test phase compared to the baseline for subject RCs than for object RCs in bin 1. This indicates that adults fixate on the target of the subject RCs before object RCs. Finally, there was a significant main effect of bin with the increase in proportion looks to the target increased in every bin compared to bin 0. This indicates that with increasing time, adults fixated more at the target across all sentence-types.

Estimate coefficients for the adult model are reported in Table XXX-5:

Fixed factor	**Coefficient**	**SE**	**t**
(Intercept)	-0.02	0.04	-0.49
Sentence (Filler – Test)	0.02	0.06	0.42
Sentence (ORC-SRC)	0.01	0.08	0.15
Bin (1 – 0)	0.27	0.04	6.87*
Bin (2 – 0)	0.73	0.04	18.42*
Bin (3 – 0)	0.84	0.04	21.31*
Bin (4 – 0)	0.86	0.04	21.68*
Sentence (Filler – Test):Bin (1-0)	0.49	0.07	6.59*
Sentence (Filler – Test):Bin(2-0)	0.24	0.07	3.21*
Sentence (Filler – Test):Bin(3-0)	0.06	0.07	0.76
Sentence (Filler – Test):Bin(4-0)	0.09	0.08	1.18
Sentence (ORC-SRC): Bin (1-0)	0.25	0.11	2.38*
Sentence (ORC-SRC): Bin(2-0)	0.03	0.11	0.30

Sentence (ORC-SRC): Bin(3-0)	-0.01	0.11	-0.13
Sentence (ORC-SRC): Bin(4-0)	-0.07	0.11	-0.68

Table XXX-5: Output of the adult model. SRC: subject RC; ORC: object RC. Significant effects are indicated with *

Infant Data

Filler Sentences

In this analysis, first we consider the data for filler sentences. Again, in the LMM, we modelled the difference in proportion looks to the target and distractor. This time age (18 m.o. and 24 m.o.) as well as bin (0, 1, 2, 3, 4) and their interaction were included in the model as fixed-effects. Just as with adults, bin was reference coded, that is every bin was compared to the silent baseline, namely bin 0.

We fitted the model *m.infant.filler*:

*m.infant.filler <- lmer(pDif ~ Age*Bin + (1 | Subject_ID) + (1 | Item))*

The statistical analysis revealed a significant main effect of bin when comparing the difference score between proportion of looks to target and proportion of looks to distractor in matrix clauses. This effect starts at bin 2 and it lasts until the end of the trial. Furthermore, the interaction between bin and Age reveals that 24-month-olds look significantly longer than 18-month-olds to the target animal (rather than the distractor animal), starting from bin 2 in test interval till the end of the trial. These results support our hypothesis that this is a sensitive method to reveal the expected asymmetry between matrix clauses and embedded clauses in 24-month-olds. The 18-month-olds' increase of looks during test interval was not significant, showing that the visual display with three animals is probably too complex for them. Estimate coefficients are reported in Table XXX-6:

Fixed factor	**Coefficient**	**SE**	**t**
(Intercept)	-0.01	0.06	-0.24
Age (24-18)	-0.03	0.06	-0.42
Bin (1 – 0)	0.04	0.05	0.72
Bin (2 – 0)	0.15	0.05	2.81*
Bin (3 – 0)	0.18	0.05	3.28*
Bin (4 – 0)	0.14	0.06	2.49*

Age (24-18): Bin (1 – 0)	0.05	0.07	0.71
Age (24-18): Bin (2 – 0)	0.23	0.07	3.10*
Age (24-18): Bin (3 – 0)	0.20	0.07	2.70*
Age (24-18): Bin (4 – 0)	0.27	0.08	3.46*

Table XXX-6: Output of the *m.infant.filler* model. Significant effects are indicated with *

Test Sentences

In this analysis, only the data of infant participants for test sentences (subject and object RC) are considered. We fitted the model *m.infant.test*, which is reported below:

*m.infant.test <- lmer(pDif ~ Age*Sentence*Bin + (1 | Subject_ID) + (1 | Item))*

The statistical analysis revealed no evidence for any difference between looks to subject RC and object RC, either in 18-month-olds or in 24-month-olds. Thus, in our study infants up to 2 years of age do not show a subject-object asymmetry, in contrast to adults and older children. Neither do they show evidence of being able to fixate the target animal in either RC type correctly.

Estimate coefficients for *m.infant.test* are reported in Table XXX-7:

Fixed factor	**Coefficient**	**SE**	**t**
(Intercept)	-0.01	0.05	-0.31
Age (24-18)	0.01	0.06	0.06
Sentence (ORC-SRC)	-0.03	0.07	-0.41
Bin (1 – 0)	0.01	0.06	0.03
Bin (2 – 0)	0.03	0.06	0.52
Bin (3 – 0)	-0.04	0.06	-0.57
Bin (4 – 0)	-0.01	0.06	-0.03
Age (24-18):Sentence (ORC-SRC)	0.01	0.09	0.10
Age (24-18):Bin (1 – 0)	-0.01	0.09	-0.03
Age (24-18):Bin (2 – 0)	-0.10	0.09	-1.14
Age (24-18):Bin (3 – 0)	0.01	0.09	0.01
Age (24-18):Bin (4 – 0)	-0.10	0.09	-1.13
Sentence (ORC-SRC):Bin(1 – 0)	0.03	0.10	0.31
Sentence (ORC-SRC):Bin (2 – 0)	0.01	0.09	0.04
Sentence (ORC-SRC): Bin (3 – 0)	0.06	0.10	0.67

Sentence (ORC-SRC): Bin (4 – 0)	0.08	0.10	0.82
Age(24-18):Sentence(ORC-SRC):Bin(1-0)	0.02	0.13	0.13
Age(24-18):Sentence(ORC-SRC):Bin(2-0)	0.12	0.13	0.92
Age(24-18):Sentence(ORC-SRC):Bin(3-0)	0.10	0.13	0.65
Age(24-18):Sentence(ORC-SRC):Bin(4-0)	0.12	0.13	0.89

Table XXX-7: Output of the *m.infant.test* model. SRC: subject RC; ORC: object RC. There are no significant effects.

5. Discussion

The central aim of the study was to explore how early during development the subject-object asymmetry might emerge. We know from previous works that the subject-object asymmetry is present in adult on-line data (e.g. self-paced reading). We also know that, when collecting off-line data (e.g., pointing), children show the subject-object asymmetry up to the age of 5. After this age, the accuracy on object RCs starts to converge towards the much easier to process subject RCs. Recent studies that used implicit measures of sentence processing (i.e. eye gaze) have allowed the detection of an on-line subject-object asymmetry already at four years of age (Adani & Fritzsche, 2015)[5]. Extending this further, we argue that implicit measures are less taxing for young children and might be useful to investigate the existence of the subject-object asymmetry even in younger infants. In the present study, we investigated the on-line processing of subject and object RCs using the same method for English-learning infants (18- and 24-month-olds) and adults. Matrix questions were also tested as a control condition.

We found that the correct referent is fixated significantly earlier and for a longer time in matrix questions as compared to RCs. This effect was attested in 24-month-olds and adults. This result reveals that our adaptation of the preferential looking paradigm with three objects displayed on the screen instead of only two, is not too taxing for two-year-olds. When they hear a matrix question e.g., *Where is the cow?* (with one cow and two different animals displayed on the screen), infants as young as 24 months are able to identify it.

When it comes to the comparison between subject- and object RCs, adults fixated significantly faster on the correct referent of the RC head noun in subject RCs compared to object RCs. However, this difference was only significant in the first one-second-bin. Afterwards, object RCs catch up and the adult's eye gaze reveals a steady increase in both conditions until the end of the tested interval. In contrast, in both groups of infants, the difference in looks between the correct referent of the RC head and its competitor (i.e. the other animal of the same type) never differed.

This difficulty may depend on several factors, which are hard to disentangle in the current study. One reason could be that infants are sensitive to their native language word order properties only when they hear simple declarative sentences (Franck et al., 2011), but they are not yet able to discriminate between canonical and non-canonical word orders in more complex sentential contexts. However, in line with Gagliardi and Lidz's (2009) proposal to explain their effect in 15-month-olds, infants may apply a simple processing heuristic, for instance an agent-first strategy with no real attempt at parsing the sentence. This hypothesis makes the prediction that we should find a preference for canonical word order very early on as, arguably, the correct referent in subject RCs could be identified simply because it is first-mentioned and it is the agent of the action. As a result, in our experiment, infants would be expected to succeed on subject RCs, where the application of this heuristic would lead them to fixate the agentive cow. However, the application of this simple heuristic does not seem to be reflected in our data, where subject and object RCs appear to be equally hard for the two infant groups.

An alternative could be that the source of difficulty stems from the subsetting operation that needs to be applied in order to identify the correct RC head noun referent out of two potential alternatives. We speculate that this indeed might explain the pattern attested in the infant data. The fact that the difference score (target – distractor) never differed from zero in RCs means that infants are looking equally long to the target and the distractor animals. We can therefore infer that they have understood that they should look for a cow (this is also supported by the data on matrix questions in 24-month-olds), they are looking at both but fail to identify the correct one.

In summary, we did not find evidence that infants up to 24 months of age have any (implicit) ability to parse (subject- and object) RCs. Whether infants this age parse RCs at all (or even have full grammatical knowledge of this structure), remains to be explored in future research. For the moment, we would like to point out two methodological aspects of our experimental set-up that might have influenced these results. First, it is still an open question whether the lack of a significant difference between the two RC types in our experimental design is due to the relative short time (approximately five seconds) that was given to the participants to identify the target. Should infants be given more time and, alternatively or in addition, more instances of the test sentence, we may observe that their performance improves. Moreover, the target and distractor animals that we have been using in the task are identical. This might have unnecessarily complicated the identification task from the infant's perspective.

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[2] http://www.cdi-clex.org/vocabulary/about/index/corpora/1

[3] Based on Words & Sentences checklist norms. These norms do not provide comprehension data.

[4] Based on Words & Gestures checklist norms. These norms only provide data up until 18 months.

[5] It should be noticed, however, that Adani and Fritzsche carried out a different analysis, with respect to the one described in this paper. Their dependent variable was the proportion of target looking (rather than the difference score target – distractor). Their argument is based on how fast the proportion of looks to target increases dynamically, passing from one temporal bin to the next one. The difference score, used as dependent variable in the current paper, allows an analysis that is closer to the analyses performed within the (traditional) preferential looking paradigm.