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Abstract knowledge of word order by 19 months: An eye-tracking study

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Abstract

Word order is one of the earliest aspects of grammar that the child acquires, since her early utterances already respect the basic word order of the target language. However, the question of the nature of early syntactic representations is subject to debate. Approaches inspired by formal syntax assume that the head-complement order, differentiating Verb-Object and Object-Verb languages, is represented very early on in an abstract, rule-like format. In contrast, constructivist theories assume that it is initially encoded as lexicalized, verb-specific knowledge. In order to address this issue experimentally, we combined the preferential looking paradigm using pseudo-verbs (following Gertner, Fisher & Eisengart, 2006) with the weird word order paradigm (following Akhtar, 1999) adapted to comprehension. The results, based on highly reliable, coder-independent eye-tracking measures, provide the first direct evidence that as early as 19 months French-speaking infants have an abstract representation of the word order of their language.

Key words: Language development, grammar, word order, preferential looking, eye tracking

Introduction

Most syntactic models agree that syntactic structures share the same basic ingredients across natural languages: the structure of a sentence consists of a hierarchical arrangement of phrases, each phrase being constituted of a nucleus element called 'head' (e.g., the verb in the verb phrase), its complement (e.g., the object) and a phrase specifying the head called 'specifier' (e.g., the subject). Though the hierarchical structure tends to remain constant across languages, linear order of the head and its complement is variable; for example, there are Verb-Object languages (VO), like English or French and Object-Verb languages (OV), like Japanese or Turkish. Interestingly, besides this variability across languages, studies in syntax have revealed surprising stability within a given language, as the order of the head-complement order tends to be the same throughout all the constituents of the language (even though disharmonic orders are occasionally permitted, Greenberg, 1963). For example, in head-complement languages, verbs precede objects (*the cat chases the mouse*) but also main clauses precede subordinate clauses (*I know that the girl crossed the street*), nouns precede their complements (*the picture of the man*), and adpositions are prepositions that precede nouns (*of the man*). In contrast, in complement-head languages verbs follow objects, main clauses follow subordinate clauses, nouns follow their complements, and adpositions are postpositions that follow nouns.

Within the theoretical framework of parametric syntax (Chomsky, 1981), an approach in which cross-linguistic variation is expressed by means of a system of binary parameters, this variation in the word order of the languages is captured by the *head direction parameter*: a head either precedes or follows its complement. In this view, language acquisition is conceived of as a process of *parameter setting* by which the child, on the basis of the input she receives from her linguistic environment, selects the correct settings of the parameters for

her language (e.g., Wexler, 1998; Rizzi, 2006). Like for other parameters, the child is assumed to learn the word order of her language by setting the head direction parameter[1].

For such a hypothesis to be plausible, one needs to establish the presence of cues to head-complement order in the linguistic environment. Two types of cues were identified. First, head direction correlates with prosodic properties of the language as prominence always falls on the complement within phonological phrases (Nespor & Vogel, 1986). Hence, while prominence falls on the right edge of constituents in head-complement languages, it falls on the left in complement-head languages. Babies as young as 3 months old were found to rely on this cue to discriminate between languages with different head-complement orders (Christophe, Nespor, Guasti & Van Ooyen, 2003). Second, head direction correlates with statistical regularities in the distribution of grammatical morphemes in the sentence. Whereas head-complement languages typically have their function words in initial position in complex phrases, complement-head languages have them in final position (Gervain, Nespor, Mazuka, Horie & Mehler, 2008). Gervain and colleagues found that at 8 months infants already show preference for an artificial language with frequent words (i.e., typically function words) situated in the same position as the target language they are exposed to.

These observations were argued to support the view that acquisition of word order relies on a mechanism by which the infant, on the basis of prosodic and statistical cues present in the input, rapidly develops an abstract representation of head direction. Crucially, in this view, children develop rule-like knowledge of the basic word order of their language before and independently of any knowledge of the lexicon.

This theoretical framework stands in clear opposition to constructivist, usage-based theories of grammatical development according to which word order is acquired via the lexicon (e.g., Abbot-Smith, Lieven & Tomasello, 2001, Akhtar, 1999; Tomasello, 2000). In this view, word order is learned on a verb-by-verb basis as the child initially encodes word

order as lexicalized, verb-specific knowledge, in the form of 'verb islands'. The learning process involves slow, gradual generalization across an important sample of lexically-specific examples by way of general inferential mechanisms.

Studies in experimental psycholinguistics suggest that knowledge of the interpretive properties of word order, that is, of the mapping between the position of the words in the sentence and their thematic role, develop quickly. Initial research using the preferential looking paradigm reported that English infants as young as 17 months old interpret the noun phrase following a familiar verb as the patient of the action (Hirsh-Pasek & Golinkoff, 1996). More compelling evidence in favour of early abstract word order representations comes from studies involving novel verbs for which children cannot rely on lexical knowledge. A number of studies have shown that children as young as 2 years old hypothesize about the meanings of novel verbs on the basis of the frames in which these verbs appear (e.g., Naigles, 1990; 1996; Naigles & Kako, 1993; Bavin & Growcott, 1999; Kidd, Bavin & Rhodes, 2001). Transitive frames, either with full or pronominal noun phrases, lead children to prefer causative meanings, whereas intransitive frames, either with single or conjoined noun phrase subjects, lead children to prefer non-causative meanings. More recently, Gertner, Fisher and Eisengart (2006) tested the comprehension of NP-V-NP sentences involving pseudo-verbs in even younger children, aged 21 months. Sentences were illustrated by two competing videos illustrating either the correct Subject-Verb-Object interpretation or the incorrect Object-Verb-Subject interpretation. Infants looked longer at the matching than at the mismatching video, again suggesting that they interpret the argument preceding the pseudo-verb as the agent, and the argument following it as the patient. Similar results were obtained by Fernandes and colleagues on 28 month old children in a forced-choice pointing task (Fernandes, Marcus, Di Nubila & Voloumanos, 2006). These authors also reported that when presented with

intransitive NP-V sentences, children preferred the animation illustrating the NP being the agent of the action to the animation illustrating the NP being the patient of the action.

These findings are in line with the parametric approach according to which the child, on the basis of surface cues (prosodic/phonological and distributional) present in the input, and independently of the acquisition of lexical knowledge, rapidly develops an abstract representation of word order. However, the results just reported do not bear directly on the acquisition of the head-complement order.

Moreover, a number of studies of children's early productions conducted within the constructivist approach have been argued to provide counter-evidence to the hypothesis that the child has abstract representations of word order properties from early on. The main experimental support comes from observations of children's elicited productions in experiments using the Weird Word Order experimental paradigm (e.g., Abbot-Smith, Lieven & Tomasello, 2001; Akhtar, 1999; Akhtar & Tomasello, 1997; Matthews, Lieven, Theakston & Tomasello, 2005; 2007). The core argument of these studies is the claim that young children (below age 3;6), in contrast to older children, tend to re-use the ungrammatical word orders modelled by the experimenter when they do not know the verb. This finding was taken to support the hypothesis that it is not until age 3;6 or even 4 that children develop abstract knowledge of word order, whereas word order is encoded lexically, on a verb-by-verb basis below that age.

Along these lines, the results obtained by Gertner et al. (2006) were recently challenged by a study by Dittmar and colleagues (Dittmar, Abbot-Smith, Lieven & Tomasello, 2008). The authors questioned the role of the training phase used by Gertner and colleagues which involved the same nouns (duck, bunny) as those used in the test, presented in transitive sentences with familiar verbs. Hence, the children may have had the opportunity to learn that the word 'duck' used in sentence-initial position indicated the duck causing the action while

the same word ‘duck’ used in sentence-final position indicated the duck as patient of the action. In line with this possibility, Dittmar and colleagues replicated Gertner and colleagues’ findings on English infants with 21 months old German infants tested with a similar training phase. However, infants who had been tested after a training phase consisting only of familiar verbs, without the nouns used at test, failed to show any preference for the SVO order. This report was taken to support the authors’ hypothesis that the preference found by Gertner and colleagues was due to lexical knowledge acquired during training, along the lines of the constructivist view, and that “there are no experimental findings in either production tasks or act out comprehension tasks of children using novel verbs productively in any language before about 2.5 years of age” (Dittmar et al., 2008, p. 576).

Aim of the present study

The aim of the present study is to reconcile the apparent contradiction in the empirical findings. A first line of research we followed was to finely reanalyse the studies using the Weird Word Order paradigm. In independent work, we pinpointed a number of shortcomings in the methods, results and argumentation developed (Franck, Millotte & Lassotta, in press). A second line of research consists in collecting new empirical evidence while taking into account a number of issues in previous work on the acquisition of word order. This is the aim of the present study conducted in yet another language, that is, French. The experiment combines the preferential looking paradigm used in comprehension experiments with the Weird Word Order (WWO) paradigm used in production experiments, adapted here to comprehension.

The experiment addresses three potential problems of previous studies. The first issue was that raised by Dittmar about the potential role of a training phase in which infants may learn

some relevant syntactic information that would help them parse the test sentences. In our study, test nouns were not included in sentences during the training phase.

The second issue concerns the choice of the mismatch condition. We contrasted infants' capacity to interpret grammatical, NP-V-NP sequences and ungrammatical, NP-NP-V sequences with pseudo-verbs. Critically here, each sequence was paired with two videos: one depicting a causative action (an agent executes an action on a patient) and the other depicting the same action executed non causatively (the agent executes the same action on himself). In the previous preferential looking studies using pseudo-verbs (Gertner et al., 2006; Fernandes et al., 2006; Dittmar et al., 2008), two causative actions were contrasted with reverted agent and patient corresponding to the SVO and OVS interpretations of the test sentence. The rationale behind our choice is the observation that the overwhelming majority of human languages manifest the Subject–Object order (irrespective of the position of the verb) whereas the OS order is extraordinarily rare (about 3%; Tomlin, 1986), and arguably always a derived order. Hence, infants' preference for the SVO over the OVS order in previous studies may reflect universal constraints on the form-meaning mapping, rather than tapping into the grammatical property of word order as set by the head direction.

A third issue arising in the studies by Gertner and colleagues and by Dittmar and colleagues is that the pairs of videos used in the experimental contrasts depicted two different actions; hence, the two videos differed not only with respect to who is the agent and who is the patient, the critical issue in word order, but also with respect to the action that is being carried out. In the present experiment, similarly to Fernandes et al. (2006), infants were presented with pairs of videos illustrating the same action with the same characters, but playing different roles. This ensures that the focus is on the characters' roles, that is, on the processing of word order, and not on the lexical content of the verb.

Infants' early abstract knowledge that French is VO is expected to manifest itself in terms of a significant preference for the causative scene upon presentation of NP-V-NP sequences. In contrast, if word order is encoded as a lexical property of the verb, no such preference is expected since experimental sentences contain pseudo-verbs. Both hypotheses predict a lack of preference in the ungrammatical NP-NP-V condition, although for different reasons. Whereas the hypothesis of abstract knowledge predicts a lack of preference because ungrammatical sentences fail to adequately describe any of the scenes[2], the lexical hypothesis predicts a lack of preference due to the fact that infants have no lexical knowledge of the pseudo-verbs. In sum, whereas the abstract representation hypothesis predicts distinct performance for the two word orders, similar performance is expected under the lexical hypothesis. By increasing the validity of the procedure, we anticipated that it would be possible to test even younger infants than those previously studied: infants aged between 19 and 20 months were therefore examined. Eye movements were recorded via an infrared eye-tracker (Tobii 1750). Although the eye tracking of young infants has started to develop in the area of lexical development (Fernald, Zangl, Portillo & Marchman, 2008), our experiment is, to our knowledge, the first to use high-resolution video-oculographic measures for the study of very early grammatical development.

Method

Participants

The participants were nineteen infants with a mean age of 19 months (age range 1;7,8 - 1;8,5). Seventeen of them had a native French speaking mother, two had a native French speaking father, and all of them were attending French-speaking kindergartens in Geneva. Eight of the infants were also exposed to another language (English, Spanish, Portuguese, Italian, Tagalog, Dutch and Russian). Four additional infants participated in the study but

were not included in the results because of bad eye calibration or because of the infant's lack of compliance with the task. Infants' comprehension vocabulary was measured using the adapted French version of the MacArthur Communicative Development Inventory (*Inventaire Français du Développement Communicatif "mots et phrases"*; Kern, 2003). Infants achieved a mean score of 87 words (range 8 – 389).

Materials

Two variables were manipulated: the grammaticality of the test sentence (grammatical word order vs. ungrammatical word order) and the type of action depicted in the video (causative vs. non causative). Grammatical sentences had NP-V-NP as word order whereas ungrammatical sentences had NP-NP-V as word order. Noun phrases consisted of a definite article (le, la) and a highly frequent animal name (dog, cow, horse, sheep, lion, and donkey).

Two bisyllabic pseudo-verbs were selected ('daser' and 'pouner') following the phonological and phonotactic constraints of the French language. They were selected so that verbs in the phonological neighbourhood of the two pseudo-verbs (following Luce & Pisoni, 1998) showed a similar distribution of transitivity. Statistics computed on the French database Lexique (New, Pallier, Ferrand & Matos, 2001) relative to the number of verbs showed that respectively 80% and 66.7% of the verbs in the phonological neighbourhood of 'daser' and 'pouner' were transitive. Statistics on the number of words balanced with frequency showed a distribution of 88.4% and 87.9% of transitive verbs for 'daser' and 'pouner', respectively. Given the slight imbalance in the statistics on the number of words, 'pouner' was used in the grammatical, transitive NP-V-NP condition whereas 'daser' was used in the ungrammatical NP-NP-V condition. The six test sentences are listed in Table 1.

Insert Table 1 about here

Each sentence was associated to a synchronized pair of videos depicting the animals (puppets) realizing actions that are not typically lexicalized in French (‘daser’: to put a crown on someone’s head; ‘pouner’: to catch someone’s head under a net). One video illustrated the action realized causatively with the first NP as agent and the second NP as patient (causative action, e.g., the cow putting a crown on the lion’s head), the other video depicted the same action realized reflexively with both NPs as agents (reflexive, non causative action, e.g., the cow and the horse each putting a crown on their own heads). The six test items were presented in pseudo-random order with the presentation of the causative and non causative actions counter-balanced across the left and right sides of the screen and across the grammatical and ungrammatical conditions.

Procedure

The experiment took place in a quiet room of the laboratory. The infant sat on her parent’s lap at about 60 cm from the computer screen. The testing started with a procedure of eye calibration which was reinitialised until a pre-determined criterion reached a satisfying level of validity. A training session, divided into three phases, preceded the experimental test. The audio stimuli accompanying the videos were created such that at no time they provided the infant with a transitive or intransitive description of the scenes. The first phase familiarized infants with the puppets and to the fact that videos would appear to the left and right sides of the screen. Each animal was presented once, either on the left or on the right window, together with an audio stimulus naming the animal (e.g., *Look, do you see? It’s the cow!*). The second phase familiarized the infant with the simultaneous presentation of two videos on the screen. Two different animals were presented on each screen while the audio asked the infants whether they saw one of them (e.g., *Look, do you see the horse? Where’s the horse?*). The

third phase familiarized infants with the novel actions used in the experimental videos. Each action was presented once on the left side of the screen, once on the right side of the screen, and once in its causative form, once in its non causative form. The videos were paired with sentences that did not introduce the pseudo-verbs or the animals' names (e.g., *Look, what's happening?*).

The experimental session involved the six pairs of experimental videos. Each pair lasted 20 seconds during which the action was presented continuously loopwise. The 20 seconds-long sequences were spread into five windows. During the first 4-seconds window, an attentional sentence was presented with the videos (e.g., *Look, do you see? What is it?*). During the following 16 seconds, the test sentence was presented 3 times, so that the offset of the first presentation fell at the end of the 4-8 s window, the offset of the second presentation at the end of the 8-12 s window and the offset of the third presentation at the end of the 12-16 window. The last time window involved the videos on their own, without the sentences.

To capture infants' attention, the Rising Baby from the Teletubbies (a laughing baby's face is seen to rise slowly towards the sky) was presented at seven moments in the experiment. The whole session lasted less than 15 minutes.

Data analyses

For each of the five windows of analysis, only infants with more than 55% of detected signal and at least 2 good test sentences over the total of 3 (within each experimental condition) were taken into account. The number of participants analysed for each window varied between 12 and 18. Statistical contrasts involved pairwise comparisons on proportions using the non parametric Wilcoxon matched-pairs test and bivaried paired student t tests for means' comparisons. For multiple comparisons, we used the Bonferroni correction. In addition, multilevel modelling was performed on gaze durations for each type of video

(causative and non causative) in each condition (grammatical and ungrammatical). The model used looking times in the 0-4 s window as baseline against which the evolution of looking preferences in the following windows was estimated. The baseline allowed us to assess changes in preferential looking due to the introduction of the linguistic materials taking into account potential pre-existing preferences due to other, uncontrolled factors.

Results

The evolution of looking times to the causative video in the five time windows of interest is illustrated in Figure 1. Mean looking times are reported in Table 2.

Insert Table 2 about here

Insert Figure 1 about here

Preference for the causative over the non causative action in the grammatical condition emerges in window 8-12 s (mean = .58), thus after the first presentation of the grammatical sentence, peaking at the next time window (12-16 s) after the second presentation of the test sentence (mean = .69), and then decreases in the last window (mean = .57 at 16-20 s). Analysis of the proportion of looking time to the causative video against chance level showed a significant effect in the grammatical condition in window 12-16 s only ($Z(11,1) = -3.06$, $p < 0.01$, p-corrected = .02). Looking times in the other windows of the grammatical condition as well as in all the windows of the non grammatical condition were at chance level.

Comparison of gaze fixations in each condition and each time window showed that infants looked longer at the causative video than at the non causative video only in the grammatical

condition, and only in window 12-16 s ($t(11,1) = 4.27$, $p < .01$, p-corrected = .01). In window 12-16 s, the proportion of gazes towards the causative video was significantly higher in the grammatical condition (mean = .69) than in the ungrammatical condition (mean = .45) ($Z(11,1) = 2.59$, $p < 0.01$, p-corrected = .04).

Multilevel modelling was computed using mean gaze durations for each time window with the Y axis crossing the X axis at the 4-8 s mean point. Coefficients are reported in Table 3.

Insert Table 3 about here

Successful models were only found for the grammatical condition with a positive slope in the causative video (coefficient = 306.2; standard error = 96.3) and a negative slope in the non causative video (coefficient = -258.4; standard error = 89.8). This confirms the significant preference for the causative video in the grammatical condition reported in the previous analyses. The best fit model for the causative video also shows a negative quadratic coefficient (-100.9; standard error = 41.6) confirming the decrease of looking time to the causative video in the last time window (16-20 s).

Discussion and conclusion

High resolution eye-tracking measures were recorded as 19 month old infants watched pairs of videos presented simultaneously with audio sentences. When infants heard grammatical SVO sentences, they looked at the video depicting the causative action significantly above chance, showing a significant preference for the causative interpretation of the sentence over the non causative interpretation, as illustrated in the alternative video. This effect was significant in the 12-16 s time window, corresponding to the end of the second presentation of the test sentence. However, it emerged as early as the initial time windows, as

attested by the continuously increasing preference shown by infants for the matching screen in the grammatical condition. Although 12-16 s may seem late in comparison to Gertner and colleagues' study who reported an effect during the first two seconds of the first test trial, our study critically differed from theirs in that whereas in our design the first sentence arose during the 4-8 s window, in Gertner et al.'s study a practice sentence (of a similar structure to the test sentence) was already presented during a 5 s blank screen before the videos. Hence, the preference they report actually arises during the second presentation of the sentence. In contrast, infants looked at chance level to the two videos when ungrammatical sentences containing two preverbal noun phrases were presented.

The preference observed in the grammatical condition cannot be explained by a variety of biases that were uncontrolled in previous studies (Gertner et al., 2006; Fernandes et al., 2006; Dittmar et al., 2008). It cannot be accounted for by a universal bias for Subject-Object over Object-Subject order, since the alternative, mismatching video did not illustrate the OS interpretation as was the case in previous studies. The preference cannot be explained either by some general preference for actions executed causatively since no preference was observed for the causative scene when ungrammatical sentences described it. The application of some 'one-to-one mapping' principle, according to which infants are biased to assume that verbs in sentences with two NP arguments should be mapped onto actions with two semantic roles (agent and patient; Lidz, Gleitman & Gleitman, 2001) cannot account for the results either. Indeed, if such a principle was applied independently of word order constraints, a similar preference for the causative scene should have been found in the ungrammatical condition which also contained two NPs. Finally, the preference observed in the grammatical sentence condition is not due to the learning of a mapping between the position in the sentence and the thematic role of a specific noun during the training phase, as argued by Dittmar et al. (2008)

to be the case in Gertner et al., since no linguistic information, lexical or structural, was provided in the training phase[3].

The results reported cannot be explained by the constructivist view that children slowly develop knowledge of word order on a verb-by-verb basis and abstract knowledge only appears around age 3;6 or 4. If this were the case, 19 month olds should not have demonstrated any preference in their interpretation of grammatical sentences containing pseudo-verbs. It is also interesting that vocabulary scores (ranging from 8 to 389 words, as measured by the French version of the MacArthur Communicative Development Inventory) failed to correlate with individual preferences for the matching video ($r = -0.24$, $p = 0.21$). Again, such a correlation was predicted if infants' interpretation of the sentences was depending on their lexical knowledge.

The data therefore provide a clear-cut demonstration that infants at that age not only know that the postverbal NP in NP-V-NP configurations expresses the patient of the action, following the grammatical SVO order of French, but also that the second preverbal NP in NP-NP-V configurations cannot express the patient of the action as would be the case in a grammar with SOV order. Such knowledge, available very early on in French infants, is particularly interesting in consideration of recent experimental evidence for the preferred SOV order in improvised gesture communication in adults of both SOV and SVO languages (Langus & Nespor, 2010). These findings, in line with independent empirical facts, support the view that whereas SVO presents certain advantages for syntactic computations, simple communication that relies on the direct interaction between the sensory-motor and the conceptual system seems to prefer the SOV order. If indeed SOV is in some sense the default order for cognitive systems underlying simple communication, this further reinforces our conclusion that the performance exhibited by our 19 month old French infants reflects grammatical knowledge.

Our data are in line with those by Gertner and colleagues, and fail to replicate the finding by Dittmar and colleagues that infants' preferences require a training phase involving transitive sentences with familiar verbs and the same characters as in the test sentences, occupying the same syntactic positions. A closer look at the data reported by Dittmar et al. however shows that the difference between the Training and No training condition is actually mostly due to one window: the first 4 seconds of the first trial (corresponding to the second presentation of the test sentence). Critically, the difference between the two conditions in that window fails to attest of any preference for the matching video in the Training condition since the proportion of looking times for the matching screen in that condition is .49 (against .41 in the No training condition). Mean looking times averaged over the last three presentations of the sentence are actually very similar in the Training and No training conditions: .57 and .55 respectively. Hence, although the data by Dittmar and colleagues do indeed seem to differ from Gertner et al.'s in English and from ours in French, this difference seems to be more adequately captured by variations in the strength of infants' looking preferences rather than by an effect of a training phase, as hypothesized by Dittmar et al. Weaker representations of word order are indeed expected in German infants, given that word order is much less reliable in German than in English or French. Critically, corpus analyses reported by Dittmar and colleagues show that 21% of the transitive sentences German infants are exposed to contain a preverbal object and a postverbal subject, which may well contribute to slowing down the development of an abstract representation of SVO as the canonical word order.

In sum, our data provide the first direct evidence for the hypothesis of early abstract word order representations in 19 month old French infants: (1) preference for the correct interpretation of word order was found with pseudo-verbs without any training on the materials, (2) this preference is anchored in abstract parametric grammatical knowledge and not in some universal predominance of the Subject-Object order, and (3) this preference is

found in even younger infants, aged 19 months. The finding that infants demonstrate an abstract representation of the head direction of their language very early on, independently of the lexicon, is hard to explain under usage-based theories of language acquisition according to which grammatical constructions are acquired progressively on a lexical basis[4]. Rather, it finds a natural explanation in the theoretical framework that views acquisition as a process of parameter setting, by which the infant sets the direction of the head prelexically and on the basis of limited input, thanks to the limited range of pre-wired abstract structural representations that her cognitive architecture allows for.

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Table 1. Experimental sentences.

Grammatical condition	Le chien poune l'âne The dog PSEUDO-VERB1 the donkey Le lion poune le cheval The lion PSEUDO-VERB1 the horse La vache poune le mouton The cow PSEUDO-VERB1 the sheep
Ungrammatical condition	La vache le lion dase The cow the lion PSEUDO-VERB2 L'âne le chien dase The donkey the dog PSEUDO-VERB2 Le mouton le cheval dase The sheep the horse PSEUDO-VERB2

Table 2. Mean looking times (in ms) towards the causative and non causative videos in the grammatical and ungrammatical conditions across the five time windows ($p < .05$ in bold).

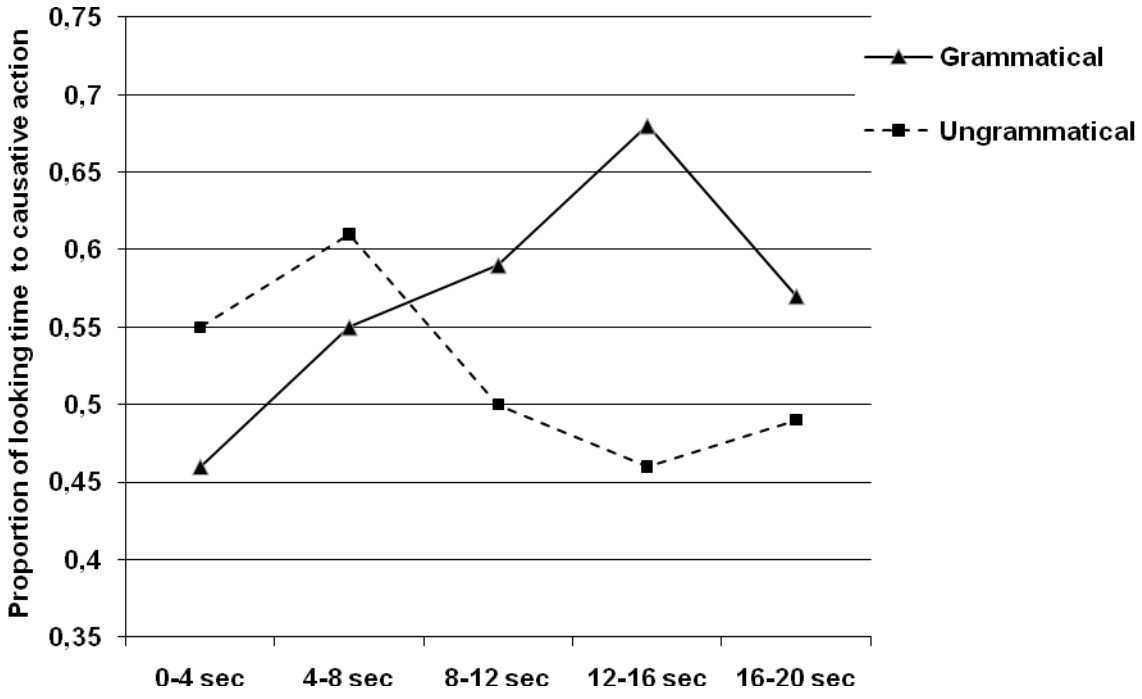
	Grammatical		Ungrammatical	
	Causative	Non causative	Causative	Non causative
0-4 sec	1591 ± 647	1846 ± 655	1912 ± 756	1536 ± 766
4-8 sec	1981 ± 813	1595 ± 835	2148 ± 872	1367 ± 759
8-12 sec	2056 ± 903	1434 ± 767	1759 ± 635	1749 ± 631
12-16 sec	**2410 ± 535**	**1121 ± 607**	1491 ± 761	1774 ± 833
16-20 sec	1919 ± 736	1434 ± 638	1593 ± 706	1678 ± 783

Table 3. Coefficients of the multilevel modeling of gaze duration towards the causative and non causative videos in the grammatical and ungrammatical conditions (standard errors in parentheses and $p < .05$ in bold).

	Grammatical		Ungrammatical	
	Causative	Non causative	Causative	Non causative
Fixed Effects				
Repeated-2	**306.2 (96.26)**	**-258.44 (89.82)**	77.09 (100.37)	-101.68 (104.56)
Repeated-2sq	**-100.85 (41.62)**	62.35 (38.83)	-8.075 (43.39)	-6.94 (45.21)
Random Effects				
Measures	372898 (69271)	324434 (60288)	406872 (75518)	442739 (82082)
Individual variability	176728 (89312)	165020 (81256)	136664 (79491)	117929 (76824)

Figure captions.

Figure 1. Proportion of looking time to the causative action for the grammatical condition (NP-V-NP sentences) and the ungrammatical condition (NP-NP-V) in the five windows of analysis.



Footnotes

[1] The parametrisation is expressed not directly on structure building but on movement in the alternative parametric analysis developed in Kayne (1994). The exact formulation of the fundamental word order parameter is immaterial for our purposes.

[2] A pilot study conducted over 20 French speaking adults showed a variety of interpretations of NP-NP-V structures. The two interpretations corresponding to the causative action and to the reflexive action were selected at a similar rate (25% and 18% respectively).

[3] It was also argued that the data may be accounted for in terms of some cue-based mechanism by which sentences ending in a NP would be interpreted as causative whereas sentences ending in a verb would be interpreted as non causative, independently of head direction. Although such a mechanism is plausible in English, it is not in French. Indeed, this cue is barely reliable in French given that transitive frames end with the verb when the object is pronominalised (e.g., *Le chien le pousse*, The dog it pushes). Moreover, such a cue-based mechanism would obviously fail in head-final languages. So, if ever such a mechanism exists, it must be linked to the head-complement order in a particular language; hence, its application presupposes the fixation of the headedness parameter.

[4] Unless such theories are modified to the effect that the construction of abstract grammatical knowledge is much faster than currently assumed in the constructivist literature (i.e., around age 4).