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Processing Intransitive Verbs: How Do Children Differ from Adults?

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ABSTRACT

Previous studies have demonstrated that, for adults, differences between unaccusative verbs (e.g., "fall") and unergative verbs (e.g., "dance") lead to a difference in processing. However, so far we don't know whether this effect shows up in children's processing of these verbs as well. This study measures children's processing of intransitive verbs using the Visual World Paradigm. We found that children differentiate in processing between unaccusative and unergative verbs, yet in a different way than adults do. We identify and discuss potential sources for this difference.

Introduction

A striking characteristic of language is that superficially similar strings can have quite different underlying representations. A case in point can be found in sentences with intransitive verbs as in (1).

(1a) The hobbit danced
(1b) The hobbit fell

Both sentences contain an NP that is followed by an intransitive verb. Yet the surface similarity of these strings is deceiving and masks crucial underlying differences. Verbs like "dance" assign the role of agent to their argument NP, and are called unergative verbs. These contrast with the set of unaccusative verbs like "fall" whose argument bears the theme role. In addition, unlike the argument of unergative verbs, the argument of unaccusative verbs has properties that are typically associated with syntactic objects, although (in many languages including English and Dutch) the argument itself appears in subject position—informally, the position where it can agree with the finite verb (Burzio, 1986; Perlmutter, 1978; Rosen, 1981). In different terms, the argument of an unaccusative verb behaves like a VP-internal argument that is realized in the subject position, whereas the argument of unergative verbs behaves like a VP-external argument realized in the subject position. This can be represented as in (2), where the position of the trace t_i represents VP-internality versus externality. The argument NP of unaccusative verbs thus performs a duty both in a position external to the VP ((syntactic) subject–verb agreement) and internal to the VP (semantic argument–verb integration). There is a considerable literature on this division within the class of intransitive verbs (see, for instance, Perlmutter, 1978; Burzio, 1981; 1986; Rosen, 1981; Levin & Rappaport Hovav, 1995; Reinhart, 2002; for extensive discussion).

(2a) The hobbit$_i$ … t_i [$_{VP}$ danced]
(2b) The hobbit$_i$ … [$_{VP}$ fell t_i]

It is puzzling how children figure out that these superficially similar sentences have different underlying structures, as the strings do not come labeled with their underlying structure or

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interpretation. In fact, there is a debate in the literature as to whether unaccusativity is acquired early or late. Some studies claim that unaccusativity is acquired early (e.g., Friedmann, 2007; Hyams & Snyder, 2006; Snyder, Hyams, & Crisma, 1995), whereas other studies claim a late acquisition of unaccusativity (after age 5, with full maturation even much later, after around age 8) (Babyonyshev, Ganger, Pesetsky, & Wexler, 2001; Wexler, 2004, 2013).

There is evidence that children distinguish between verb types from data on auxiliary selection in Italian, for instance (Hyams & Snyder, 2006; Snyder et al., 1995), and children's production of verb–subject NP word orders with unaccusative verbs (e.g., "fall") in Hebrew (Friedmann, 2007). Surely this shows that children have acquired some aspect of the unaccusative–unergative distinction by a certain age, but this does not necessarily mean that children correctly assign distinct structures to unaccusative vs. unergative sentences, i.e., with the subject NP being an internal argument for unaccusative verbs. The surface string does not provide any information as to the underlying syntactic structure (cf. Babyonyshev et al., 2001; van Hout, 2004). Moreover, if the child for instance selects the right auxiliary with the right verb type, it is unclear whether the child learned this on an item-by-item basis or whether auxiliary selection is indeed related to the underlying structure.

The surface similarity of unaccusative (e.g., "fall") and unergative (e.g., "dance") structures thus underlies the lack of consensus regarding the age of acquisition of unaccusativity. The puzzle is how we get access to the child's underlying representation of a sentence with an intransitive verb. The solution we provide in this article moves us one step closer to an answer to the question to what extent children have acquired unaccusativity. In order to present our solution, we first need to spell out what characterizes the unaccusative–unergative distinction in (adult) grammar and processing.

The difference between unaccusative and unergative verbs gives rise to a different behavior of the verb types in particular syntactic environments. For instance, in Dutch, unaccusative verbs select the auxiliary "be" in the perfect (3a), whereas unergative verbs select the auxiliary "have" (3b) (Hoekstra, 1984). Furthermore, unergative verbs can passivize, yielding the impersonal passive in (4b), but unaccusative verbs cannot be passivized (4a) (Perlmutter, 1978).

(3a) De hobbit is gevallen
The hobbit is fallen
(3b) De hobbit heeft gedanst
The hobbit has danced
(4a) #Er is gevallen
#There is fallen
intended: "There is being fallen"
(4b) Er is gedanst
There is danced
"There is dancing"

The psycholinguistic literature shows that adult processing reflects the structural distinction between unaccusative and unergative verbs in a difference in timing in the reactivation of the argument (Burkhardt, Pinango, & Wong, 2003; Friedmann, Taranto, Shapiro, & Swinney, 2008; Koring, Mak, & Reuland, 2012; Poirier, Walenski, & Shapiro, 2011) as well as a difference in neural processing (Agnew, Van De Koot, McGettigan, & Scott, 2014; Shetreet & Friedmann, 2012; Shetreet, Friedmann, & Hadar, 2010). More specifically, data from both eye-tracking and cross-modal priming studies showed that the argument of unaccusative verbs is reactivated after the offset of the verb and peaks about 750 msec after verb offset (Burkhardt et al., 2003; Friedmann et al., 2008; Koring et al., 2012). For unergative verbs on the other hand, Koring et al. (2012) showed that the argument is reactivated at a much earlier point, starting from verb onset. That is, argument-verb integration for unaccusative verbs happens only after verb offset, which is much later than the point at which an unergative verb and its argument are integrated.

This shows that the more elaborate unaccusative structure in which the argument both performs a duty outside of the VP and internal to the VP is reflected in processing as a reactivation of the argument after verb offset. There is no definitive answer yet as to why exactly reactivation of the internal argument of unaccusative verbs (e.g., "fall") happens at a later point (see Koring et al., 2012 for suggestions). It could be that integration of the argument and verb into one semantic object for interpretation has to await computation of the more elaborate structure in order to assign the verb's thematic role VP-internally (see Koring et al., 2012).[1] That is, argument–verb integration can only take place once the necessary computations have been performed.

But regardless of the exact link between structure and reactivation effects, the results from adult processing clearly demonstrate a close match between grammatical computation and processing: a different computation gives rise to a distinct processing signature. This also means that data on processing give us a window onto underlying structural representations. As such, the approach to the puzzle this article takes is to investigate children's processing of sentences with intransitive verbs. If the child performs the additional computation that unaccusative structures require, then the distinction should be visible in children's processing of these sentences, just like it is in adults.

There are, however, reasons to expect that the child might still show a different pattern than adults do. Even if children do assign distinct structural representations to unaccusative (e.g., "fall") and unergative (e.g., "dance") structures, this difference might show up differently than it does in adults, because of differences between the child and adult parser. There is no reason, however, to expect that the child parser operates in a completely different way than the adult parser does. For instance, it has been shown that children's processing is incremental in nature, as it is in adults (Fernald, Swingley, & Pinto, 2001; Huang & Snedeker, 2011; Nation, Marshall, & Altmann, 2003; Sedivy, Demuth, Chunyo, & Freedman, 2000; Sekerina & Brooks, 2007; Trueswell, Sekerina, Hill, & Logrip, 1999). Children use phonological, semantic, and syntactic information to make predictions about the upcoming structure.

There is, however, a difference in processing between children and adults such that children have much more difficulty inhibiting active representations (Huang & Snedeker, 2011; Novick, Trueswell, & Thompson-Schill, 2005). For instance, phonological cohort competitors remain active for a longer time in 5- and 6-year-old children than in adults (Sekerina & Brooks, 2007). Similarly, visual objects (e.g., *a key*) that are semantically related to a phonological competitor (e.g., *lock*) (which is itself not present in the display) of a spoken target word (e.g., *logs*) remain active for a longer time in children than in adults (Huang & Snedeker, 2011). The difficulty in inhibiting active representations also leads to a difficulty in reanalysing previous commitments about the structure (Orfitelli & Hyams, 2012, Trueswell et al., 1999; Weighall, 2008). That is, once a representation is active, the child has difficulty inhibiting it, and consequently a difficulty revising it. This is one factor that could potentially affect children's processing of sentences with intransitive verbs.

A further, related, factor that might play a role is that the child needs to learn which of the unaccusative verbs (e.g., "fall") allow for a causative counterpart. That is, a subset of the unaccusative verbs allows for a transitive counterpart in addition to the intransitive structure. The sentence pair in (5) illustrates the inchoative/causative alternation (see Levin (1993) for relevant references). In both sentences, the role "the ring" plays is the same; it is undergoing the event of breaking, but in (5a) also an agent is present which is realized in the subject position. The unaccusatives are related to their transitive counterpart by an operation of *decausativization*, as in (5a), with *Frodo* bearing a cause role, which is absent in (5b) (Reinhart, 2000, 2016).[2]

(5a) Frodo broke the ring
(5b) The ring broke
(5c) *Frodo fell the ring
(5d) The ring fell

Not all unaccusative verbs allow for a causative alternate (see (5c-d)), even though it is easy to conceptualize that someone makes a ring fall down. In fact, in all cases such a causative counterpart is easily conceptualized (see Deal (to appear) for experimental support). Reinhart (2000, 2016) argues that all unaccusatives—also the ones without a transitive counterpart—have a reduced external cause role.[3] This makes it unpredictable which of the verbs have such an alternate which makes figuring out which of these verbs do so a particularly daunting task in acquisition. Conceptually, all unaccusative verbs take a cause argument, but only a subset of those verbs in fact realizes an alternative transitive structure.

In fact, until late in development, children spontaneously produce causatives for intransitive verbs that do not have a transitive counterpart in the adult grammar. The examples in (6) from Bowerman (1982) illustrate this phenomenon. These causativization "errors" can persist until as late as the age of 12 (Bowerman, 1996). Even though children produce new causatives for both unergative (e.g., "dance") and unaccusative (e.g., "fall") verbs, they produce more new causatives for unaccusative than for unergative verbs (Pinker, 1989). This means that, even when children know the distinction between unaccusative and unergative verbs, they might consider a transitive counterpart a possible alternative structure for intransitive verbs, and in particular for unaccusative verbs.[4]

(6) Children's new causatives
(a) C, 6;8: It's rising me [C in tub, warm water making her float up].
(b) E, 5;3: you cried her! [After M drops E's doll and it squeals]
(c) C, 7;8: Did they vanish "knock-knock" cups? [Noticing Dixie cups in new pack no longer have knock-knock jokes on them]
(all from Bowerman (1982), pp. 15, 17, 18)

In this article, we will access children's underlying structural representations of sentences with unaccusative (e.g., "fall") vs. unergative (e.g., "dance") verbs by measuring their processing of such sentences. The question is whether we will find a processing signature of an additional computation in unaccusative structures. We will do this by comparing children's processing to adults' processing for which we know that unaccusative vs. unergative structures give rise to distinct processing patterns. We saw that even if the child performs the required computation, she might still not perform fully adult-like, because:

(i) She hasn't learned yet which verbs are purely unaccusative verbs that do not realize a causative alternate in the language they are acquiring.
(ii) She has to inhibit alternative (causative) structural representations.

Children's online processing of intransitive verbs was measured using the Visual World Paradigm (VWP) (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). This method allows us to obtain a record of activation of the argument NP throughout the entire sentence (Koring et al., 2012). As such, we can compare the trajectories of activation of the arguments of unergative vs. unaccusative verbs. In addition, this method is very suitable for measuring processing in young children (e.g., Fernald, Zangl, Portillo, & Marchman, 2008).

Method

The experiment measured children's processing of intransitive verbs by following their gaze while they listened to sentences with an intransitive verb. Importantly, there was always one visual object present in the visual display that was semantically related to the argument of the intransitive verb. Whenever the argument is active, this visual object will be looked at more than distracter objects. The argument is of course active when it is presented in the sentence, but more crucially, it will be active again in the participant's mind in the region around the verb in order to be able to integrate the argument and verb into one semantic object for interpretation. As such, looks to the target visual object are a measure of when the argument is *re*activated in participants' minds. This method largely follows Koring et al. (2012). Deviations will be indicated.

Participants

Seventy-nine five- to seven-year-old children participated in this study (22 five-year-olds, 28 six-year-olds, and 29 seven-year-olds). Twenty-one children (4 five-year-olds, 6 six-year-olds, and 11 seven-year-olds) were not included in the analyses, because there was a track loss for more than 1 sec consecutively during the test trials in more than 50% of the trials. Track loss was either due to technical issues (9 cases), excessive movement (9 cases), or not paying attention (looking away from the screen) (3 cases). The final sample consisted of 18 five-year-olds (seven girls, mean age: 5;6), 22 six-year-olds (eight girls, mean age: 6;6), and 18 seven-year-olds (five girls, mean age: 7;5) (mean age of entire group: 6;6). A group of 30 adults (consisting of mostly students from Utrecht University) participated in the experiment as a control. Three adults were not included in the analyses because of track loss in more than 50% of the test trials. Another participant was excluded because she was dyslexic. The remaining adult group had normal or corrected to normal vision and did not suffer from dyslexia.

Selection of verbs

The verbs included are a subset of the verbs used in Koring et al. (2012). The experiment included a set of ten non-alternating unaccusative and ten unergative verbs that did not differ in lemma frequency. Lemma frequency of the verbs was determined using the WebCelex database (Max Planck Institute for Psycholinguistics, 2001) that provides web-access to the lexical database for Dutch. The Log transformed mean frequencies of unaccusative and unergative verbs (1.70 and 1.48, respectively) did not differ significantly ($t(18) = .667$, $p = .513$). All verbs included in the experiment are acquired at the age of five at the latest according to Krom (1990). For a list of the verbs see Appendix A.

The difference between unaccusative and unergative verbs results in the different behavior of these verbs in particular syntactic environments. As such, we can use these environments to classify the verbs. We used five syntactic diagnostics as proposed in the literature to determine whether the verbs were unaccusative or unergative (see Koring et al., 2012) (Hoekstra, 1984; Levin & Rappaport Hovav, 1995; Perlmutter, 1978; Zaenen, 1993). The diagnostics used are type of auxiliary (7), impersonal passive construction (8), prenominal past participle (9), -er nominalization (10), and reflexive resultative construction (11).

(7a) Bert heeft gedanst
Bert HAS danced
(7b) Bert is gevallen
Bert IS fallen
(8a) Er werd gedanst
There was danced
(8b) *Er werd gevallen
*There was fallen
(9a) *De gedanste clown
The danced clown
(9b) De gevallen clown
The fallen clown
(10a) De danser
(10b) *De valler
*The faller
(11a) Bert danste zich kapot
Bert danced himself broken
(11b) *Bert viel zich kapot
*Bert fell himself broken

Selection of arguments and targets

Each argument NP (e.g., *the squirrel*) was paired with a semantically related target object (e.g., *an acorn*). The target object was presented on a visual display among three distractor objects as shown in Figure 1.

In a semantic relatedness judgment task (cf. Perraudin & Mounoud, 2009), the strength of the semantic relation between the argument NP and target object was determined. For most of the pairs, data from Koring et al. were used, but some new pairs were tested on different adult Dutch speakers. Participants were presented with word pairs (e.g., *squirrel - acorn*) as well as unrelated word pairs (e.g., *dolphin – acorn*) for which they had to indicate the strength of the relation between the meanings of these two words on a scale from 0–5. All pairs included had an average strength that was higher than 4 (mean of 4.68 for unergatives, mean of 4.78 for unaccusatives).

In addition, the degree of a semantic relation between the verb and the argument as well as the verb and a target object was determined. There should be no such relation as it might introduce confounding looks to the target due to the verb itself priming the argument or the target object. That is, if the experiment were to include the hypothetical argument-target combination of *dog – to bark*, looks to the target *dog* would be expected to increase upon presenting the verb *to bark*, because the verb *bark* activates *dog*. Only pairs for which the semantic relation had an average lower than 2 were included in the experiment (e.g., *squirrel – disappear*) (argument – verb mean unaccusatives: 0.76, unergatives: 0.5; target – verb mean unaccusatives: 0.56, unergatives: 0.31).

The pre-test was run on adult participants only, but should apply to children as well. The pairs included were related schematically (objects you come across in the same context, e.g., *squirrel – acorn*) and not categorically (objects belonging to the same category, e.g., *squirrel – marmot*). Research indicates that there is a development in the child's conceptual organization suggesting that objects are first primarily related to their action representations, and only later categorized on the basis of shared semantic properties to other objects (Perraudin & Mounoud, 2009). A stronger priming effect is therefore expected for schematically related pairs than categorically related pairs for children and, indeed, Perraudin and Mounoud (2009) showed that children do show a priming effect for functionally related pairs (a subset of schematic relations), but not for categorically related pairs. As such, the expectation is that children will show a priming effect like adults do, which was confirmed in a pilot experiment reported in Koring (2013).

Pictures and sentences

The test visual displays consisted of four visual objects that were all black-and-white line drawings. In part, they were taken from Szekely et al. (2004) with additional pictures created in the same style.

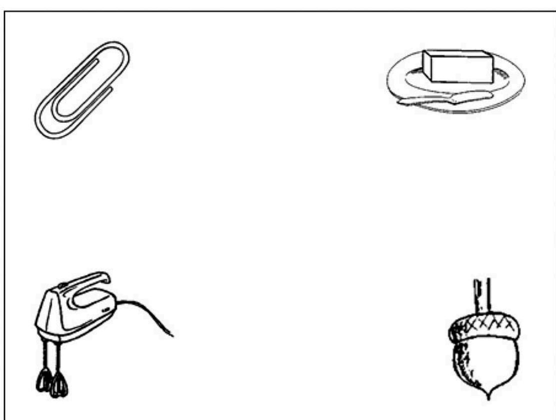

Figure 1. Example of a visual display that is paired with a spoken sentence. Target object is "acorn" (related to the spoken word "squirrel"). The pictures are taken from the on-line picture set created by Szekely et al. (2004).

Sentences were constructed following Friedmann et al. (2008) and Koring et al. (2012). Examples of a sentence in both the unaccusative and unergative condition are presented in (12) and (13), respectively. They all had an embedded structure as shown in (12) and (13). In between the argument (*squirrel*/*pilot*) and the verb (*disappeared*/*talked*), a PP modifying the NP and an adverbial phrase (5–7 words), unrelated to the NP, were added in order to make sure the degree of activation of the argument, and so looks to the target object, would decay. In addition, 6–10 words were added after the verb to enable capturing a late reactivation effect.

(12) Kapitein Willem zei dat de eekhoorn met de nieuwsgierige
Captain Willem said that the squirrel with the curious
blik plotseling **verdween** toen het oude deksel vreselijk kraakte
look suddenly **disappeared** when the old lid heavily creaked
"Captain Willem said that the squirrel with the curious look suddenly disappeared when the old lid heavily creaked."

(13) Kapitein Willem zei dat de piloot met de grote bruine hoed heel
Captain Willem said that the pilot with the big brown hat very
zachtjes **praatte** toen de piraten steeds een stukje
softly **talked** when the pirates more and more a bit
dichterbij kwamen
closer came
"Captain Willem said that the pilot with the big brown hat had spoken very softly when the pirates came more and more closer."

The experiment included ten unaccusative and ten unergative verbs. Each child saw all of the 20 test sentences. Sixty-six filler displays were included to fill up the story. The filler displays contained either one, two, or three visual objects that directly matched or were related to a word or phrase of the accompanying sentence.[5]

The sentences were recorded at a slow-to-normal speaking rate by a female native speaker of Dutch, sampled at 48,000 Hz. The visual displays were presented on a 17″ viewing monitor at a resolution of 1024 × 768 pixels.

Procedure

Children were recruited from a school near Utrecht, The Netherlands, and tested individually in a separate room in their school. The child was seated in front of the computer on an adult-sized chair with a child add-on if necessary. The eye-tracker was positioned on a child-sized (low) table. After completion of the experiment, children were rewarded with a sticker for participation. Adults were tested in the lab in a sound-treated cabin. Eye movements were measured by a Tobii 1750 sampling at 50 Hz. Each session started out with a calibration procedure with nine fixation points. Adults were paid for participation.

Participants did not perform any explicit task so as to have a most natural measure of processing. In order to engage the children in listening to the sentences and watching the displays, the sentences were not separate units, but were instead embedded in a story about pirates. Therefore, as far as the (child) participants were concerned, they were simply watching a pirate movie. They were instructed that the movie they were going to watch was about a bunch of pirates going on a journey to hunt for some gold. During their journey, they would enter various curious events. Then, the children were asked if they knew what a compass was for. Most children did and explained that it helps in finding your way. If not, the purpose of a compass was explained to the child. They were then told that a compass would also guide the pirates on their journey and that a picture of this compass would appear every now and then on the screen. The compass was used as a fixation point in between trials. The compass was also presented during test trials in between the argument and the verb (0.93–0.96 sec view) in order to force the eyes to move away from the target. Similarly, the compass was presented during some filler trials so that the test trials would not stand out in this way. There was a 1 sec preview of the display before the onset of a spoken sentence. After each sentence, there was another 2 sec of silence before the fixation compass appeared. The entire experiment lasted about 20 min.

Results

In adult processing, we see that unaccusative verbs (e.g., "fall") lead to a late reactivation of the argument NP compared to an early reactivation for unergative verbs (e.g., "dance") (Friedmann et al., 2008 for unaccusative verbs; Koring et al., 2012). The question is whether the difference between the verb types is reflected in children's processing of the verbs as well. In order to assess this, we will first compare the adult and child data directly. We will then go on to discuss the patterns for adults and children separately for two pre-defined time windows to pinpoint the locus of the differences between children and adults.

Data selection

Trials were deleted if there was a track loss for more than 1 second consecutively. This led to the deletion of 65 trials for the five-year-olds, 88 trials for the six-year-olds and 45 trials for the seven-year-olds (198 trials in total, 17% of the data). For the adult control group, 34 trials were deleted (6.5% of the data).

Analysis

In order to keep analysis consistent across experiments, we chose to analyze the same two time frames as in Koring et al. (2012). The first time frame, the verb frame, (700 msec before verb offset until 1100 msec after verb offset = 1800 msec) takes verb offset as its mid-point. The mid-point is verb offset plus 200 msec as it takes between 150 and 200 msec to program and initiate an eye movement (Altmann & Kamide, 2004; Dahan, Magnuson, Tanenhaus, and Hogan, 2001; Huettig & Altmann, 2005). The starting point of this time frame corresponds to the average onset of the verb. The end point of this time frame is then 200 + 900 = 1100 msec after verb offset. This time frame enables us to capture any early reactivation effects, as previously observed for unergative verbs.

The second time frame, the post-verb frame, (from 200–1700 msec after verb offset = 1500 msec) takes 950 msec after verb offset as its mid-point. The position of the mid-point corresponds to the late reactivation effect that was observed in CMLP (Friedmann et al., 2008) (and later in VWP (Koring et al., 2012)). As such, the post-verb frame enables us to capture a late reactivation effect, as previously observed for unaccusative verbs. In the following, we will first present the analyses for the verb frame and then continue to the analyses for the post-verb frame.

As the data obtained constitute time course data, we analyzed the change over time in fixation proportion using growth curve analyses (cf. Mirman, 2014; Mirman, Dixon, & Magnuson, 2008). The dependent variable is the proportion of looks to the target object. We model the change in the dependent variable over time by including time as a predictor in our model. Given that the time course data do not represent a straight line (which would be captured by a first-order polynomial), we included higher-order polynomials to capture the curvature (Mirman, 2014; Mirman et al., 2008). More specifically, the second-order polynomial captures a curve that changes its direction once. A negative value for the second-order (quadratic) term corresponds to a rise (activation) followed by a fall (deactivation), whereas a positive value corresponds to a fall followed by a rise. The third-order polynomial captures a curve that changes its direction two times (e.g., rise – fall – rise or fall – rise – fall). Our model included condition (unaccusative or unergative verb) and age group (child vs. adult) as fixed effects and we assessed the effect of the interaction between these independent variables on

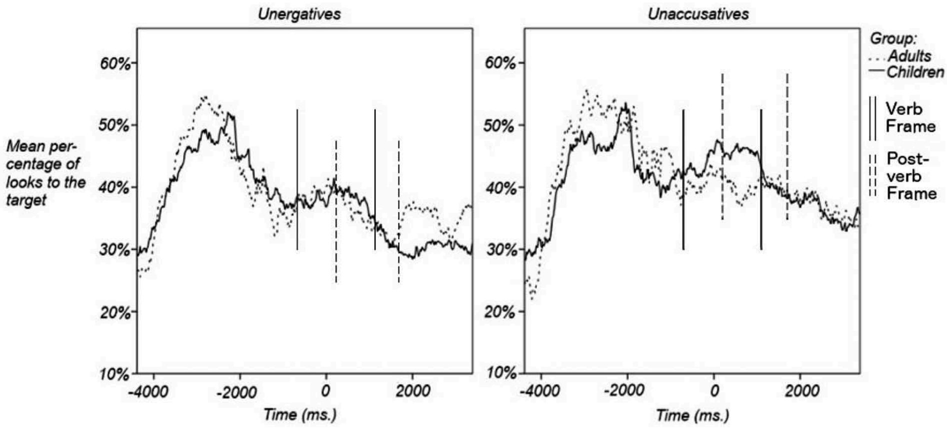

Figure 2. Mean percentage of looks to the target from 4,000 msec before verb offset until 3,000 msec after verb offset: A comparison of children and adults. Data from the unergative condition (*dance*-type verbs) are represented on the left and data from the unaccusative condition (*fall*-type verbs) on the right.

each time term. In addition, participant random effects on all time terms were included (see Appendix D for discussion).

Figure 2 compares children to adults in the two conditions (unaccusative (e.g. "fall)) and unergative (e.g., "dance")). Given that we are interested in whether the curve changes as a result of presenting the verb as opposed to an average amount of looks to the target at a certain point, we will not discuss the intercept in the following. The graphs already indicate that children and adults do not demonstrate the exact same effect. We assessed the effect of an age group x condition interaction on each of the time terms and the outcome supports our visual inspection as it indicates a significant age group x condition interaction effect on time terms in both the verb frame and the post-verb frame. Let us point out in the following how the age groups (child vs. adult) differ exactly for each of the two time frames. To this end, two kinds of effects are of interest. One is the shape of the change in fixations over time; the other is the effect of condition on fixations. We will therefore discuss both types of effects, starting from an investigation of whether there are effects of condition on fixations and continuing to investigate the nature of the effect by looking at the particular shape of fixations in each condition.

Verb frame

Adult – child comparison

We started from a base model that included up to the third order polynomial and main effects of age group (child vs. adult) and condition as predictors. We then gradually added the age group x condition interaction effect on the different time terms, assessing whether the model significantly improved as a result of adding an interaction on a particular time term. In the verb frame, adding an age group x condition interaction on the quadratic term resulted in a significantly better fitting model than the model that included main effects up to the quadratic term, but an interaction effect up to the linear term only (χ^2 (1) = 4.41, $p < .05$). Adding an interaction effect on the cubic term did not significantly improve the model fit as compared to a model with an interaction effect up to the quadratic term only (χ^2 (1) = 0.56, p = .45). The optimal model, with an interaction on the quadratic term, displayed a significant interaction effect on the quadratic term (b = 0.09, SE = 0.043, $p < .05$). This means that the effect of condition on the quadratic term, which represents a fall – rise or rise – fall curve, is different in the adult group as compared to the child group (see Table 1 for the full model and interaction effects). In what follows, we will investigate the effect of condition on the quadratic term for adults and children separately to understand this interaction effect.

Table 1. Output of the model that includes the group x condition interaction for the verb frame. Standard errors are in brackets..

	Fixed Effects		
Group x Condition	Estimate	t-value	p<
Intercept	−0.047 (0.004)	−10.47	.0001
Linear	−0.024 (0.043)	−0.57	n.s.
Quadratic	0.090 (0.043)	2.10	.05
	Random Effects		
Intercept	0.023 (0.153)		
Linear	0.320 (0.566)		
Quadratic	0.091 (0.302)		
Cubic	0.091 (0.302)		
Main: Group	Estimate	t-value	p<
Intercept	0.050 (0.036)	1.38	n.s.
Linear	0.036 (0.12)	0.31	n.s.
Quadratic	−0.041 (0.077)	−0.53	n.s.
Main: Condition	Estimate	t-value	p<
Intercept	−0.020 (0.004)	−5.49	.0001
Linear	−0.09 (0.035)	−2.55	.05
Quadratic	−0.088 (0.035)	−2.49	.05

Final model <- lmer(DV ~ (ot1+ot2+ot3) + (ot1+ot2)*(condition*age group) + (ot1+ot2+ot3 | subject), data = data, REML = F)

Adults in the verb frame

Figure 3 plots the observations as well as the model fits for the adults in the verb frame. We ran the same model, which includes an effect of condition up to the second orthogonal polynomial, on the adult data separately (the results can be found in Table 3 in Appendix B). We found significant effects of condition on both the linear (b = -0.09, SE = 0.032, p < .005) and the quadratic term (b = -0.088, SE = 0.032, p < .01). The quadratic effect is the result of a negative quadratic component for unergative verbs (b = -0.129, SE = 0.070, p = .06) which represents a rise (activation) – fall

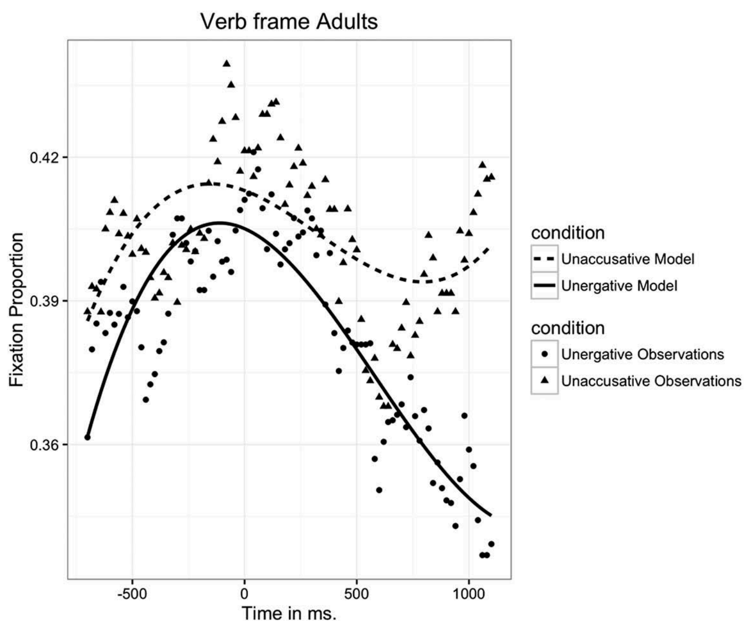

Figure 3. Mean percentage of looks to the target for adults in the verb frame (700 msec before verb offset until 1,100 msec after verb offset). The curves are synchronized to the acoustic offset of the verb. Hence, 0 sec is verb offset.

Table 2. Output of the model that includes the age group x condition interaction for the post-verb frame. Standard errors are in brackets.

Group x Condition	Fixed Effects Estimate	t-value	p<
Intercept	−0.033 (0.005)	−6.88	.0001
Linear	0.157 (0.042)	3.70	.0005
Quadratic	0.024 (0.042)	0.57	n.s.
Cubic	−0.097 (0.042)	−2.29	.05
	Random Effects Estimate		
Intercept	0.026 (0.16)		
Linear	0.205 (0.45)		
Quadratic	0.077 (0.28)		
Cubic	0.039 (0.20)		
Main: Group	Estimate	t-value	p<
Intercept	0.034 (0.039)	0.87	n.s.
Linear	−0.239 (0.111)	−2.15	.05
Quadratic	−0.121 (0.07)	−1.68	.1
Cubic	0.133 (0.055)	2.40	.05
Main: Condition	Estimate	t-value	p<
Intercept	−0.044 (0.004)	−10.87	.0001
Linear	−0.222 (0.035)	−6.32	.0001
Quadratic	0.011 (0.035)	0.30	n.s.
Cubic	0.078 (0.035)	2.24	.05

Final model <- lmer(DV ~ (ot1+ot2+ot3)*(condition*group) + (ot1+ot2+ot3 | subject), data = data, REML = F)

(deactivation) shape. This effect is absent for unaccusative verbs (b = -0.042, SE = 0.070, p = .55). That is, the unergative verbs (e.g., "dance") displayed an early reactivation effect (activation and then deactivation) in this time frame. The unaccusative verbs (e.g., "fall") are different as a result of a late rise in looks to the target at the end of this time frame.[6] This result replicates the more pronounced rise and fall (early reactivation) for unergative verbs compared to unaccusative verbs as reported in Koring et al. (2012).

Children in the verb frame

For adults, the difference between unergative and unaccusative verbs is thus reflected by a significant effect of condition on the quadratic term. Unergative verbs displayed an early reactivation effect, an activation–deactivation pattern. Unlike the adult data, the child data did not display an effect of condition on the quadratic term (b = -0.0017, SE = 0.025, p = .9) (see Table 4 in Appendix B for the model outcome). In fact, both unaccusative (e.g., "fall") and unergative (e.g., "dance") verbs displayed a significant negative quadratic term (rise – fall shape, activation - deactivation) (unergatives: b = -0.079, SE = 0.041, p = .05; unaccusatives: b = -0.081, SE = 0.041, p < .05). That is, both unaccusatives and unergatives yielded an early reactivation effect (see Figure 4). Like adults, there was a significant effect on the linear term (b = -0.11, SE = 0.025, p < .0001) such that the slope for unergative verbs was significantly more negative over the whole time frame than for unaccusative verbs. As we will understand better when analyzing the post-verb frame, this results from a more sustained early reactivation in unaccusative verbs.

Post-verb frame

In the post-verb frame, the model that included an age group x condition interaction on the third-order polynomial was a significantly better fit than the model that included an interaction effect on time terms up till the quadratic term (χ^2 (1) = 5.26, p < .05). The cubic model displayed a significant interaction effect on both the linear (b = 0.157, SE = 0.042, p < .0005) and the cubic term (b = -0.097,

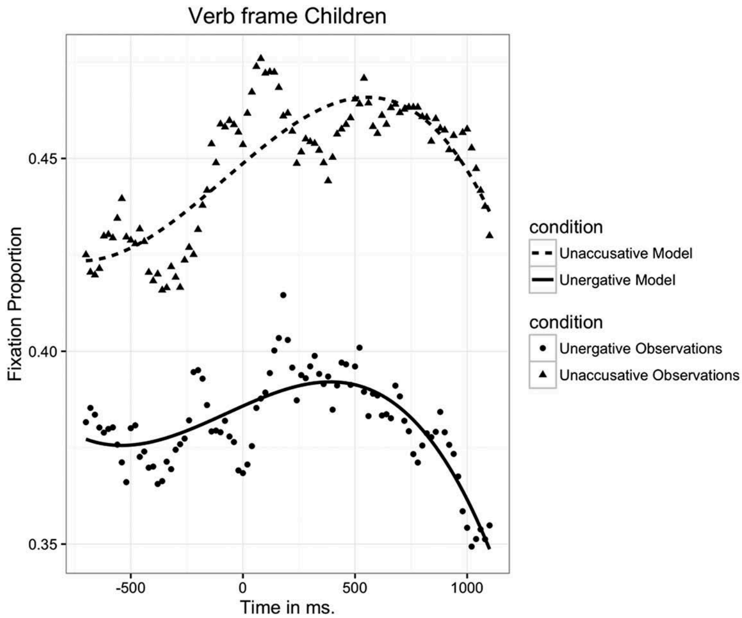

Figure 4. Mean percentage of looks to the target for children in the verb frame (700 msec before verb offset until 1,100 msec after verb offset). The curves are synchronized to the acoustic offset of the verb. Hence, 0 sec is verb offset.

SE = 0.042, p < .05). Let's see what gives rise to the significant age group x condition interaction effects by analyzing the adult and child data separately (see Table 2 for the full model and interaction effects).

Adults in the post-verb frame

Table 5 in Appendix C provides the results of running the optimal model with an effect of condition up to the third order polynomial for adult data in the post-verb frame (see Figure 5 for the observations and model fits). Analyses showed a significant effect of condition on the linear (b = -0.222, SE = 0.032, p < .0001) and cubic term (b = 0.079, SE = 0.032, p < .05). The unergative verbs (e.g., "dance") did not display a reactivation effect in this time frame. The slope is simply falling (deactivation) (b = -0.207, SE = 0.098, p < .05). The unaccusative verbs (e.g., "fall"), however, displayed a fall-rise-fall shape (resulting in a significant cubic component: b = -0.083, SE = 0.043, p = .05), indicating deactivation, then reactivation, followed by deactivation again. The post-verb frame therefore replicates the late reactivation effect for unaccusative verbs. More specifically, the peak in the raw observations for unaccusative verbs is around 1000 msec after verb offset, which is at the same time as observed in Koring et al. (2012). The model peak is slightly later. Furthermore, a difference between these data and Koring et al. (2012) is the absence of a final rise at the end of the post-verb frame in the current data.

Children in the post-verb frame

Analyses of the child data in the post-verb frame showed that, in contrast to adults, there was no significant effect of condition on the cubic term (b = -0.019, SE = 0.025, p = .45) (for the complete model output, see Table 6 in Appendix C). For children it is not the case that the difference in verb types is reflected in an early reactivation effect for unergative vs. a late reactivation effect for unaccusative verbs (see Figure 6).

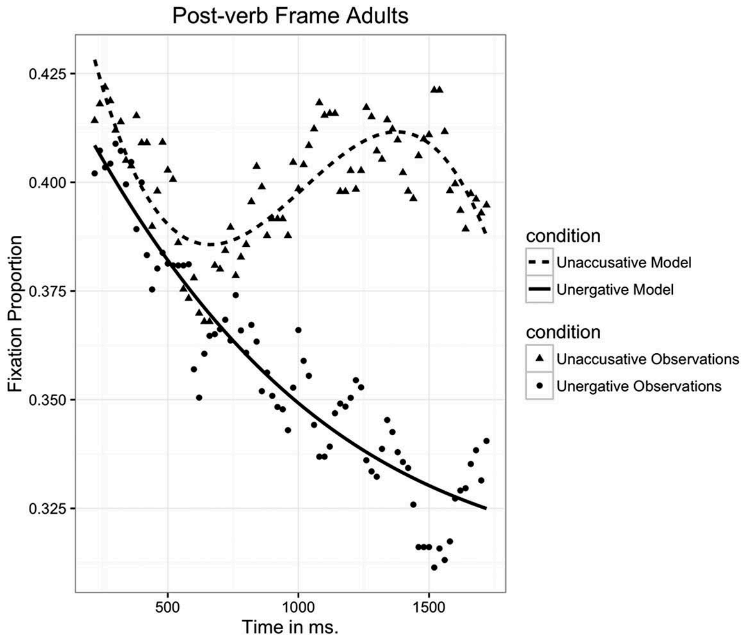

Figure 5. Mean percentage of looks to the target for adults in the post-verb frame (200 msec after verb offset until 1,700 msec after verb offset). The curves are synchronized to the acoustic offset of the verb. Hence, 0 sec is verb offset.

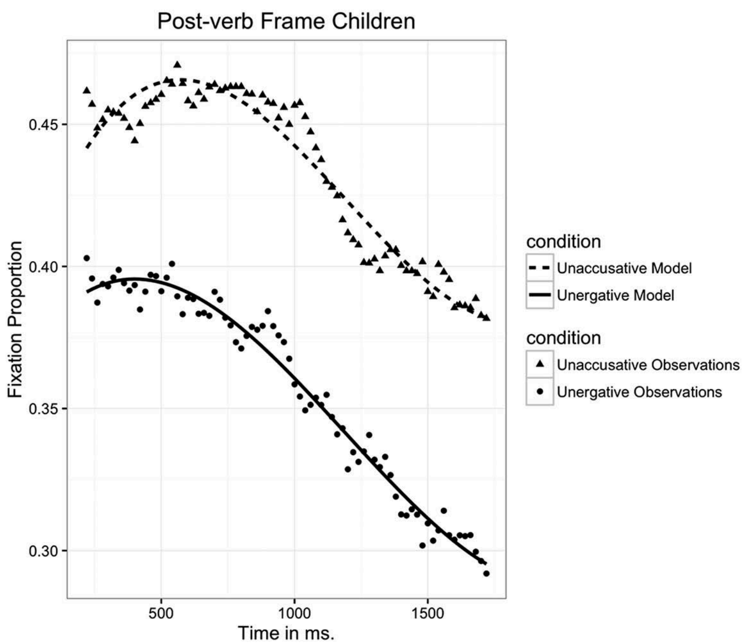

Figure 6. Mean percentage of looks to the target for children in the post-verb frame (200 msec after verb offset until 1,700 msec after verb offset). The curves are synchronized to the acoustic offset of the verb. Hence, 0 sec is verb offset.

Yet, like the analyses of the verb-frame, the analyses of the post-verb frame did indicate that children distinguish between the verb types. There was a significant effect of condition on the linear term ($b = -0.065$, $SE = 0.025$, $p < .01$). This effect reflects more of a fall in looks to the target for unergative verbs (e.g., "dance") than for unaccusative verbs (e.g., "fall") overall. Like for adults, looks to the target for the unergative verbs were simply falling in this time frame (deactivation). For unaccusative verbs, the fall seems to set in later.

In conclusion, children distinguish between unaccusative and unergative verbs. The way in which this difference is reflected in the child data, however, differs from what we see in the adult data. For children, the difference is reflected by a larger and longer lasting reactivation of the argument of unaccusative verbs compared to the argument of unergative verbs.

Discussion

The present study investigated the question whether children assign distinct structural representations to sentences with unaccusative (e.g., "fall") vs. unergative (e.g., "dance") verbs. We approached this puzzle by looking at children's processing of intransitive verbs. In particular, we studied the (re) activation pattern of the argument of unaccusative verbs for which the single NP argument is an internal argument even though it appears in subject position on the surface. Unaccusative verbs differ from unergative verbs for which the single argument is an external argument.

Given that the subject NP argument of unaccusative verbs is an internal argument, unaccusative sentences trigger a process that is absent in unergative sentences. Once the parser retrieves the lexical (unaccusative) entry, this entails that a structure needs to be computed in which the argument NP performs a duty both external and internal to the VP. Thematic role assignment has to wait for the necessary structure to become available in the case of unaccusative verbs, whereas it is fast in unergative verbs for which no such additional computation is required (both syntactic and semantic integration are external to the VP). In adults this leads to a late reactivation of the argument of unaccusative verbs (e.g., "fall") that is not found for unergative verbs (e.g., "dance").

The children's eye movement data showed that the syntactic difference between unaccusative and unergative sentences is reflected in children's processing, like in adults. For children, both the argument of unaccusative verbs and the argument of unergative verbs displayed an early reactivation in the verb frame. The difference is that this early reactivation continued into the post-verb frame for unaccusative, but not unergative verbs. That is, in 5- to 7-year-old children, the index for an additional computation displayed itself as a longer lasting reactivation effect for unaccusative verbs compared to unergative verbs. We thus successfully used a measure of children's processing to get access to the underlying structural representations and we saw that in children, as well as in adults, a different syntactic computation results in a different processing signature.

Yet the processing signature still does not look adult-like. Whereas children keep looking to the target during computation of the unaccusative structure, adults look away. The question is what gives rise to this difference. That is, why does the required process, which manifests itself as a delayed reactivation compared to unergatives for adults, show up as a longer lasting reactivation for children? In the introduction we identified two additional requirements for adult-like behavior and we will argue that it is a combination of these two requirements that is the source for the effect. Recall that we noted that in order to behave fully adult-like, the child should:

(i) have learned which of the unaccusative verbs realise a causative alternate in the language they are acquiring; and
(ii) inhibit active alternative (causative) structural representations

The way in which this could result in the observed difference between adults and children is as follows. If the child thinks that a transitive counterpart is also compatible with the verb, the verb's entry might activate a transitive structure with an external argument position as well.[7] If so, the child should inhibit this alternative structure in which the subject NP could be taken to be an external argument, given that there is only one argument present to be integrated with the verb. Given the child's difficulty with inhibiting active representations, it might be difficult to suppress the alternative structure and, as such, difficult to suppress an incorrect instruction to retrieve the argument NP for argument–verb integration. The argument NP might therefore be more active for the child than for the adult from verb onset.

Another possibility that we cannot exclude is that, even though the child does perform an additional computation, this computation (having the argument perform a duty both VP-externally and -internally) is still difficult for children. There are reasons to consider the possibility that this computation could indeed present difficulties for the child. For instance, the Universal Phase Requirement (UPR) states that children have trouble linking the internal argument position to the subject position before the age of seven or even later (Wexler, 2004, 2013). The reason is that the verb phrase and the higher functional (agreement) material are processed in separate cycles, or phases, for the child. The question then is what this would imply for children's processing of these verbs.

Prima facie, one option could be that the child will not be able to finish the required grammatical computation after all, and integrates the argument eventually as an external argument. The question then is whether this option is conceivable at all. Would it be conceivable for the child to know some core aspects of the meaning of the unaccusative verbs, but yet try to integrate the argument of the verb as an external argument? Of course, even though processing data provide us with a measure of whether there is a difference in computation between unaccusative and unergative verbs, the measure does not tell us what the computation exactly is. It is therefore a possibility that we cannot exclude. We would like to point out, however, that under approaches hypothesizing a strong connection between meaning and the associated syntactic structure (Reinhart, 2002, 2016) and also a strong correspondence between the grammar and the parser (see Koornneef & Reuland, 2016; Phillips, 1996; Pritchett, 1992; for discussion), assigning a different structure to the string necessarily means that the meaning is different. The child would then end up with some sort of theme unergative predicate ultimately, like *glitter, sparkle*, or *glow*, but again the question is what it would mean to end up with such a predicate.

These issues could be addressed in future research by detailed investigation of children's interpretation of the interaction between unaccusative verbs and other sentential material. For example, do five-year-old children display knowledge of the subtle (meaning) differences between sentences with unaccusative and unergative verbs (see footnote 3)? Do children know that unaccusative, but not unergative verbs, allow "by-itself" (in the "without outside help" meaning) (e.g., *the diamond fell by itself* vs. *#the diamond glittered by itself*) for instance?

Another option is that, although the computation is difficult for the child, she is eventually able to compute the correct, unaccusative, structure (and thus the correct interpretation). The difficulty would then display itself in more looks to the target during computation. It is unclear, however, whether the longer lasting reactivation could be taken as an index of difficulty with the computation. A difficulty in computation might, but does not necessarily have to, result in more looks during computation. Alternatively, one might expect that a difficulty with computation would lead to an even bigger delay in reactivation of the argument. This is exactly what was found in processing of unaccusative verbs in Broca's aphasics (Burkhardt et al., 2003). The child data, however, showed that the reactivation pattern is of a different *type* in children than it is in adults; it is not simply delayed.

In conclusion, the main finding of this study is that the difference between unaccusative and unergative verbs and the syntactic structures in which they occur is reflected in children's processing. That is, sentences with unaccusative vs. unergative verbs give rise to distinct processing signatures in children. The distinction between unaccusative and unergative sentences still plays out differently for children than it does for adults. We suggested that possible candidates for this difference could both be a difficulty in the underlying grammatical computation as well as a difference in processing between adults and children that can be teased apart in further research by looking at children's interpretation of different intransitive verb types. Importantly, the child data, as well as the adult data, display a close match between grammatical computation and processing.

Notes

1 An alternative way to understand this is that sentences with unergative verbs are compatible with a default parse in which the subject NP is the VP-external argument, whereas sentences with unaccusative verbs are not. As such, sentences with unaccusative verbs require a reanalysis during processing that unergative verbs do not require. Argument-verb integration can only take place after the alternative structure has been computed (see Koring et al., 2012).

2 A way of capturing this in a derivational approach is to say that roots like "break" are both compatible with an unaccusative (intransitive voice) structure and a structure with transitive voice.

3 As such, another useful diagnostic in determining unaccusativity in Dutch is the possibility to add the modifier *vanzelf* "by itself" in the meaning of "without outside help" (for English see Levin & Rappaport Hovav, 1995; Reinhart, 2000, 2016). The without-outside-help reading identifies a cause, and is therefore possible for unaccusative verbs as in (i), but not for unergative verbs as in (ii). Notice that this is not a matter of animacy. The without-outside-help reading is also impossible for so-called theme unergative verbs like *glitter* in (iii) that assign the role of theme to their argument, yet the argument is an external argument.

(i) Ik deed niets, de sleutel viel vanzelf
I didn't do anything, the key fell by itself

(ii) #Ik deed niets, de bruid danste vanzelf
#I didn't do anything, the bride danced by herself

(iii) #Ik deed niets, de diamant glinsterde vanzelf.
#I didn't do anything, the diamond glittered by itself.

4 In a Cross-Modal Priming experiment, unaccusative verbs that allow for a transitive alternate did not give rise to a clear reactivation pattern like unaccusative verbs without such an alternate (Friedmann et al., 2008). In fact, the alternating unaccusative verbs presented a mixed set with some verbs behaving like unaccusative verbs, some verbs like unergative verbs, and some verbs different from both verb types. Yet, it is unclear to us what the significance of a verb-by-verb analysis is. Furthermore, the diagnostics used to select alternating unaccusative verbs do not seem to pick out a unified set of verbs.

5 Some of the filler visual displays just contained one visual object in order to make it look more like a movie clip.

6 This also caused the difference in the linear component. Overall, the unergative verbs displayed more of a negative slope, because the unaccusative verbs have a late rise at the end of the time frame.

7 In fact, the mere presence of a conceptualized cause might activate a transitive structure. Alternatively, a default parse with an external argument position that needs to be suppressed might be active.

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Appendix A

Unaccusative verbs

Verb	Argument	Target picture
vallen (*fall*)	clown (*clown*)	circustent (*circus tent*)
verdwijnen (*disappear*)	eekhoorn (*squirrel*)	eikel (*acorn*)
groeien (*grow*)	papegaai (*parrot*)	vogelkooi (*bird cage*)
schrikken (*be shocked*)	boer (*farmer*)	tractor (*tractor*)
lukken (*work out well*)	kleurplaat (*coloring page*)	kleurpotloden (*pencils*)
barsten (*crack*)	sleutel (*key*)	slot (*lock*)
mislukken (*be unsuccesfull*)	schilderij (*painting*)	palet (*pallet*)
zinken (*sink*)	schroef (*screw*)	schroevendraaier (*screwdriver*)
verdwalen (*get lost*)	kabouter (*gnome*)	paddestoel (*toadstool*)
omvallen (*fall over*)	mus (*sparrow*)	nest (*nest*)

Unergative verbs

Verb	Argument	Target picture
praten (*talk*)	piloot (*pilot*)	vliegtuig (*airplane*)
lachen (*laugh*)	timmerman (*carpenter*)	hamer (*hammer*)
huilen (*cry*)	indiaan (*Indian*)	wigwam (*teepee*)
dansen (*dance*)	aap (*monkey*)	banaan (*banana*)
wandelen (*stroll*)	politieagent (*police officer*)	pistool (*hand-gun*)
vloeken (*swear*)	koningin (*queen*)	kroon (*crown*)
fietsen (*cycle*)	kerstman (*Santa Claus*)	kerstboom (*christmas tree*)
zeuren (*nag*)	visser (*fisherman*)	hengel (*fishing rod*)
huppelen (*hop*)	dokter (*doctor*)	stethoscoop (*stethoscope*)
toeteren (*hoot*)	kapper (*hair dresser*)	schaar (*scissors*)

Appendix B

Output verb frame

Table 3. Output of the final model for adults in the verb frame. Estimates are the effect of condition on the time terms with standard errors in brackets.

Adults Fixed Effects			
Model	Estimate	t-value	p<
Intercept	−0.020 (0.003)	−6.15	.0001
Linear	-0.090 (0.032)	−2.86	.005
Quadratic	-0.088 (0.032)	−2.79	.01
	Random Effects		
Intercept	0.037 (0.19)		
Linear	0.304 (0.55)		
Quadratic	0.115 (0.34)		
Cubic	0.111 (0.33)		

Final Model <- lmer(DV ~ (ot1+ot2+ot3) + (ot1+ot2)*(condition) + (ot1+ot2+ot3 | subject), data = data, REML = F)

Table 4. Output of the final model for children in the verb frame. Estimates are the effect of condition on the time terms with standard errors in brackets.

Children Fixed Effects			
Model	Estimate	t-value	p<
Intercept	−0.067 (0.003)	−25.7	.0001
Linear	-0.11 (0.025)	−4.59	.0001
Quadratic	0.002 (0.025)	0.069	n.s.
	Random Effects		
Intercept	0.017 (0.13)		
Linear	0.325 (0.57)		
Quadratic	0.080 (0.28)		
Cubic	0.079 (0.28)		

Final Model <- lmer(DV ~ (ot1+ot2+ot3) + (ot1+ot2)*(condition) + (ot1+ot2+ot3 | subject), data = data, REML = F)

Appendix C

Output post-verb frame

Table 5. Output of the final model for adults in the post-verb frame. Estimates are the effect of condition on the time terms with standard errors in brackets.

Adults			
Model	Estimate	t-value	p<
	Fixed Effects		
Intercept	−0.044 (0.004)	−11.87	.0001
Linear	-0.222 (0.032)	−6.90	.0001
Quadratic	0.011 (0.032)	0.33	n.s.
Cubic	0.079 (0.032)	2.45	.05
	Random Effects		
Intercept	0.035 (0.19)		
Linear	0.24 (0.49)		
Quadratic	0.099 (0.31)		
Cubic	0.034 (0.18)		

Final Model <- lmer(DV ~ (ot1+ot2+ot3)*(condition) + (ot1+ot2+ot3 | subject), data = data, REML = F)

Table 6. Output of the final model for children in the post-verb frame. Estimates are the effect of condition on the time terms with standard errors in brackets.

Children			
Model	Estimate	t-value	p<
	Fixed Effects		
Intercept	−0.077 (0.003)	−27.40	.0001
Linear	-0.065 (0.025)	−2.66	.01
Quadratic	0.035 (0.025)	1.42	n.s.
Cubic	-0.019 (0.025)	−0.75	.n.s.
	Random Effects		
Intercept	0.022 (0.15)		
Linear	0.19 (0.44)		
Quadratic	0.068 (0.26)		
Cubic	0.041 (0.20)		

Final Model <- lmer(DV~ (ot1+ot2+ot3)*(condition) + (ot1+ot2+ot3 | subject), data = data, REML = F)

Appendix D: Statistical analysis of the data

In this appendix, we set out the details of our statistical model and provide the reasons for choosing this type of analysis and the particular structure for our models. We analyzed the data using growth curve analyses, a multilevel regression technique suitable for analyzing time course data (Mirman et al. 2008, Mirman 2014). This particular type of analysis is appropriate for our data as we are interested in the question whether presenting the verb gives rise to *re*activation of the argument. As such, a high level of looking to the target at a certain position is not particularly informative (and renders time binned analyses unsuitable). Even if we find a difference between unaccusatives and unergatives in the average amount of looks to the target at a particular time point, this does not warrant the conclusion that the argument is *re*activated at that point. We could at most conclude that the argument is active at that point, not answering the question whether this is a continuous activation or a reactivation effect. We therefore analyze the change in looks to the target over time for particular pre-defined time windows.

The dependent variable in our statistical model is target fixation proportion, obtained by aggregating data over items. We modeled the change in target fixation proportion over time, including higher-order polynomials to capture non-straight lines. Our model included condition (unaccusative or unergative verb) and age group (adults/children) as fixed effects and we assessed the effect of the interaction between these independent variables on each time term. In addition, participant random effects on all time terms were included, giving rise to the full model as implemented in R (using the lme4 package) in (1).

(1) Full model <- lmer(DV ~ (ot1+ot2+ot3)*(condition*age group) + (ot1+ot2+ot3 | subject), data=data, REML=F) ot1 = linear term, ot2 = quadratic term, ot3 = cubic term

This model does not include a maximal random effects structure and we will now turn to the reasons for not including a maximal random effects structure.

Random effects structure

Our model allows each time term to vary per participant, but it does not include subject-by-condition random effects on any time terms. In this, our model differs from the approach Mirman (2014) adopts, as well as from Barr et al.'s (2013) urge to "keep it maximal". One practical reason not to include the maximal random effects structure is that these models often do not converge.[1] A way to make the models converge is by simplifying the random effects structure. There are, however, more pressing reasons *not* to include a maximal random effects structure in our model as a result of the structure of the data.

[1]This seems to be less of a problem with lme4, but it still varies per optimizer.

The important question to answer when deciding on the structure for the random effects is whether or not taking up the full random effects structure is justified for the particular data set at stake. As Bates et al. (2015) and Barr (2013) point out, a maximal random effects structure could lead to overparameterization of the data.[2] Each dataset requires a separate investigation of this question (Bates et al. 2015). In the following, we will show that adopting a maximal random effects structure is not justified for our data set.

For our particular dataset, there is a very important reason not to include a full random effects structure, namely that there is only one observation per cell. In our analysis, we aggregated over items which means that we end up with only one observation per participant per condition (or more precisely, one ot1 (= linear term), one ot2 (= quadratic term) etc. per participant per condition). In that case, Barr et al. (2013) and Barr (2013) suggest that the subject:condition interaction should not be implemented:

"The following new guideline is therefore proposed: *models testing interactions in designs with replications should include random slopes for the highest-order combination of within-unit factors subsumed by each interaction*. Designs with replications are designs where there are multiple observations per sampling unit per cell." "If observations are not replicated (i.e., there is only a single observation per unit per cell), random slope variance cannot be distinguished from random error variance and thus random slopes need not be included." (Barr 2013, para. 1).

Now if we do run the models with the full random effects structure, we indeed see that the effects move from the fixed effects structure to the random effects structure, which is expected when they cannot be distinguished. That is, when running the relevant models with a full random effects structure, there are no significant fixed effects on the relevant time terms.

The output of the model (relevant interaction components only) with the full random effects structure (maximal model <- lmer(DV ~ (ot1+ot2+ot3)*(condition*group) + (ot1+ot2+ot3 | subject) + (ot1+ot2+ot3 | subject:condition), data=data, REML=F)) for the post-verb frame is as follows.

	Fixed Effects		
Group x Condition	Estimate	t-value	p<
Intercept	0.033 (0.045)	0.74	n.s.
Linear	-0.157 (0.180)	-0.87	n.s.
Quadratic	-0.024 (0.113)	-0.22	n.s.
Cubic	0.097 (0.094)	1.03	n.s.

The output for the model with the full random effects structure for the verb frame (maximal model <- lmer(DV ~ (ot1+ot2+ot3) + (ot1+ot2)*(condition*group) + (ot1+ot2+ot3 | subject) + (ot1 +ot2 | subject:condition), data=data, REML=F)) is the following.

	Fixed Effects		
Group x Condition	Estimate	t-value	p<
Intercept	-0.047 (0.041)	-1.13	n.s.
Linear	-0.024 (0.225)	-0.11	n.s.
Quadratic	0.090 (0.139)	0.65	n.s.

Note: This model converges with optimizer *optimx*.

A follow-up question might be why we chose to aggregate over items. Another possibility is to use a categorical (target vs. non-target) variable as our dependent variable instead of fixation proportion.

[2]Bates et al. provides tools to explore whether including it is justified or not for a particular dataset. This involves checking how much variance each random effect accounts for with a Principal Components Analysis, using the RePsychLing package in R.

In that case, we would have multiple observations per participant and could potentially include a maximal random effects structure. However, such analyses do not lead to converging (or sometimes even printable) output model.

The non-convergence of the models with non-aggregated data means that it is impossible to estimate the relevant time terms for this type of data.

These reasons led to the conclusion that we should analyze the target fixation proportion using a model that is warranted for our data set, which is a model in which all time terms are allowed to vary per participant, but which does not include subject-by-condition random effects.