Processing delays: The late reactivation of the argument of unaccusative verbs

Loes Koring and Hans van de Koot
Macquarie University / University College London

Abstract
Results from an eye-tracking experiment, using the Visual World Paradigm (VWP), show that in on-line sentence processing in English the argument of unaccusative verbs reactivates late after verb offset. In contrast to previous studies, VWP provides insight into the exact time course of this effect. Furthermore, the experiment uncovers an early reactivation of the argument of unergative verbs that has previously gone unnoticed. The observed time course for the late reactivation effect is the same as previously observed in Dutch, despite differences in word order between the two languages. Differences between the two languages do however seem to affect the early reactivation effect, which occurs earlier in English than in Dutch. We suggest that this effect is due to the more rigid word order of English, which provides the parser with more informative cues.

Keywords: unaccusativity; language processing; Visual World Paradigm (VWP); argument reactivation

1. Traces of unaccusativity[1]

Several robust (cross-linguistic) syntactic diagnostics distinguish unaccusative verbs that assign the role of theme to their single argument, which is merged VP-internally (e.g., *to slip*), from (agent) unergative verbs, which assign the role of agent to their single, VP-external, argument (e.g., *to wave*). For example, Italian permits *ne*-cliticization of the (internal) argument of unaccusative verbs, but not unergative verbs (Burzio 1986). Hebrew (among other languages) permits the argument of unaccusative, but not unergative verbs, to remain *in-situ* (post-verbally) (Friedmann 2007). In Dutch, a language that allows impersonal passives, unergative verbs can be passivized, but unaccusative verbs cannot (Perlmutter 1978). English does not permit impersonal passives, but,

[1] The unaccusative hypothesis (Perlmutter 1978) maintains that a subset of apparently intransitive verbs have a single argument originating as a VP-internal argument. This argument surfaces in the subject position in a language like English (see also Burzio 1986, Rosen 1981). Thus, sentences containing unaccusative verbs (e.g. *arrive, fall*) should have a different syntax than those projected from unergative verbs (e.g. *dance, jump*), for which the single argument originates as a VP-external argument.

similarly, shows that unergative verbs form prepositional passives, whereas unaccusative verbs do not (Perlmutter and Postal 1984).

Previous research using the cross-modal lexical priming (CMLP) paradigm suggests that it is possible to detect an effect of unaccusativity in online sentence processing in English (Friedmann et al. 2008).[2] In a CMLP experiment, participants perform a lexical decision task in response to a string of letters that appears on a screen, while listening to sentences. The supposition is that, if a word is active in the listener's mind, this speeds up their lexical decision to that (or a semantically related) word, relative to a lexical decision to an unrelated word. This is called a priming effect. Friedmann et al. (2008) found a priming effect after the verb for words related to the argument of unaccusative verbs, but no such effect was found with unergative verbs. The position of this effect was 750ms. after verb offset. The hypothesis was that the priming effect is the result of reactivating the moved internal argument of an unaccusative verb.

Even though the CMLP results give us reason to think that there is indeed a signature of unaccusativity in online processing in English, some crucial questions remain unanswered. In particular, the results of Friedmann et al. (2008) give little insight into the precise time course of the observed reactivation effect. It is unclear whether 750 ms. represents the starting point, end point, or midpoint of the reactivation effect. This is because CMLP only provides information about activation at pre-defined time points and cannot provide any information as to how activation changes over time (Yee & Sedivy 2006). In addition, and for essentially the same reasons, the results of Friedmann et al. cannot tell us whether the reactivation found at 750 ms. is the *sole* reactivation that takes place during the processing of a sentence with an unaccusative verb. Finally, the fact that no postverbal reactivation was found in sentences with unergative verbs tells us that such sentences are processed differently but leaves open the question whether the external argument of an unergative is also reactivated at any point during processing.

The above considerations suggest that we should investigate whether it is possible to obtain more fine-grained information about the reactivation profiles of sentences with intransitive verbs. For this reason, we conducted a Visual World experiment (Cooper 1974) to track the activation of the argument of unergative and unaccusative verbs over time. A major advantage of the VWP is that it allows one to track activation continuously instead of at certain pre-defined probe points. The VWP therefore provides a more detailed insight into the time course of reactivation effects. A related advantage is that it enables the detection of effects that might have gone unnoticed due to the poor temporal resolution of the CMLP. Finally, the VWP measures activation while

[2] Further evidence for a processing difference between the two types of English intransitive verbs is reported in Burkhardt et al. (2003), Poirier et al. (2012), Agnew et al. (2014), and in Momma et al. (2018).

participants perform a passive task (listening to sentences while watching visual displays), while CMLP requires participants to perform a lexical decision task during auditory processing. The requirement to perform a task may introduce resource demands that have the potential to affect the timing of activation. It is therefore best avoided.

Previous work using VWP in Dutch has shown a late reactivation effect for the argument of unaccusative verbs (Koring et al. 2012). Koring et al. (2012) not only detected a peak in reactivation at 950 ms. but also showed that the reactivation effect began soon after the offset of the verb.[3] An additional finding of Koring et al.'s study was the detection of a reactivation effect for unergative verbs, which appeared much earlier than the reactivation effect for unaccusative verbs. It started at the onset of the verb. Given that unergative verbs require integration of the argument and verb into one semantic object for interpretation, just as unaccusative verbs do, this reactivation effect was expected. The underlying structure determines the timing of this effect (and thus the point of argument-verb integration).[4] The question then is whether, using VWP, we can detect an early reactivation for unergative verbs in English as well. Potentially, the reactivation effect did not show up in CMLP simply because the probe locations rendered its detection impossible.

In what follows, we investigate the time course of reactivation of argument NPs of intransitive verbs in English. We should not necessarily expect the time course of reactivation effects to be identical in the two languages. Some factors that could contribute to timing differences include structural differences between English and Dutch in the canonical position of the internal argument, as well as the more variable word order in Dutch (in particular regarding adverb placement).

2. Tracking late reactivation effects

Forty-six adult native English speakers participated in an eye-tracking experiment. The participants' task was to look at a visual display while listening to sentences over headphones (following Koring et al. 2012). The participants' eye movements were recorded using an Eyelink 1000 (500Hz.). Each test sentence (see (1)) was combined with a visual display (see Figure 1) consisting of four objects,

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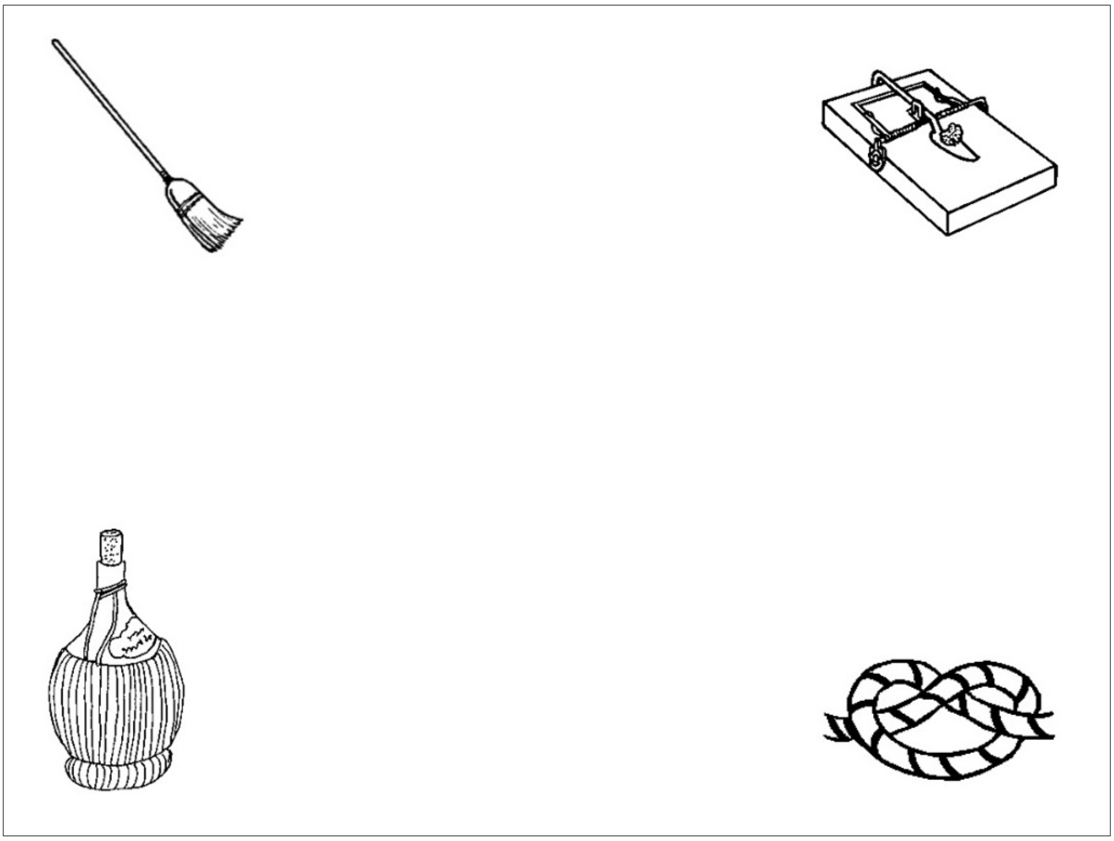
[3] If we take into account the time it takes to program and initiate an eye movement, it is likely that the 950ms. in VWP corresponds to 750ms. in CMLP (Koring et al. 2012).

[4] Previous work has shown that the timing of argument-verb integration is independent of the thematic role of the argument. Koring et al. (2012) included a set of *glow*-type verbs, for which the argument bears a theme role, which is however projected externally (Levin & Rappaport Hovav 1995, Reinhart 2000, 2002). These verbs showed the same reactivation pattern as unergative verbs that assign the role of agent to their argument.

one of which was semantically related to the argument of the (unaccusative or unergative) verb. Participants had a 1 second preview of each display before the accompanying sentence would start.

(1) The janitor with the orange silk trousers from Wisconsin spontaneously waved when a nice-looking woman with a floral dress entered the room with a charming smile.
(Friedmann et al. 2008: 374)

Fig. 1 Visual display combined with sentence (1). The target object is *broom*. (Pictures are taken from the picture set created by Szekely et al. 2004).



We know from previous work with the VWP that participants spontaneously look to objects that are semantically related to a (pronounced) word or (unpronounced) mentally active entity, even in the absence of any explicit instruction to do so (Huettig & Altmann 2005, Altmann & Kamide 2007 a.o.). For example, as a result of the semantic overlap between *janitor* and *broom*, participants will look more at the target object *broom* in Figure 1 when they hear the semantically related argument *janitor* in sentence (1) than that they will look to the three distractor objects. By hypothesis, reactivation of the argument (e.g. *janitor*) will guide participants to look back to the target object (*broom*). As such, argument-verb integration should trigger looks to the target visual object, as the argument will be reactivated for thematic role assignment. Importantly, this will happen both for unaccusative and unergative verbs, as both require argument-verb integration. The timing of argument-verb integration (and thus of argument reactivation) is expected to show a different profile as a result of differences in the underlying syntactic structure.

To optimize comparison of the CMLP and the VWP experiments, we included Friedmann et al.'s frequency-matched sets of non-alternating unaccusative and unergative verbs.[5] The test sentences were minimally altered versions of Friedmann et al.'s sentences and were all of the form '*DP… AP VP…*' (see Appendix A for the verbs and arguments used).[6] As exemplified in (1), they included padding words in between the argument and the verb, to allow for *de*activation of the argument (in order to enable detection of *re*activation), as well as padding words after the verb, to enable the detection of a late reactivation effect. A female native speaker of English recorded the sentences (sampling frequency: 48,000 Hz).

As far as possible, Friedmann et al.'s arguments and images of their related probe words served as the argument NPs and target visual objects. If the probe word was difficult to depict, we combined the argument with an alternative target object (e.g. we combined *runner* with *running shoe* instead of Friedmann et al.'s probe *track*). In case there was no clearly depictable target for an argument NP, we replaced both the argument and the target object (e.g. instead of *people – crowd*, we used *pilot – plane*). Visual displays were presented on a 1920x1080 screen, using 1280x960 visual displays for tracking eye movements.

In line with the preceding discussion, the experimental hypothesis is that reactivation of the argument will trigger an increase in looks to the semantically related target object. To ensure that reactivation of the argument is the *only* trigger for an increase in looks to the target, we included a control condition that paired the same visual displays with sentences that differed in the argument that was used only. In our sentence (1), for example, the argument (*janitor*) was replaced with an argument that bears no relation to the target visual object (*violinist*), providing a baseline of looks to the target. For analysis, we calculated the difference score, consisting of the percentage of looks to

[5] The lack of robust diagnostics in English makes it difficult to select verbs. In addition to Friedmann et al.'s sets, the experiment included alternative sets of verbs that were selected using different diagnostics. The alternative sets also controlled for a semantic relation between the argument NP and the verb. That is, based on the findings from a semantic relatedness judgment task, sentences were excluded if the argument NP and the verb were judged to be semantically related (e.g. *dog – bark*) (cf. Perraudin & Mounoud 2009). The analyses did not reveal any significant differences between the stimuli sets.

[6] In some cases, so as to prevent a rise in looks to the target visual object as a result of other related words in the sentence, we replaced semantically related words from Friedmann et al.'s original sentences with unrelated ones.

the target in the test condition minus the percentage of looks to the target in the control condition.[7] Importantly, we are interested in a *change* in looks to the target at the point when the verb was presented (reactivation). Even if we find a high average of looks to the target at a certain position, this would not be valid evidence that the argument is *re*activated as a result of presenting the verb. Note that this renders a measure of the percentage of looks to the target at a particular point uninformative. Therefore, the statistical model we used was not an average of looks to the target within a certain time window; rather, time was included as a predictor variable, and changes in the curve over time were modeled using growth curve analysis (GCA) (Mirman et al. 2008, Mirman 2014).

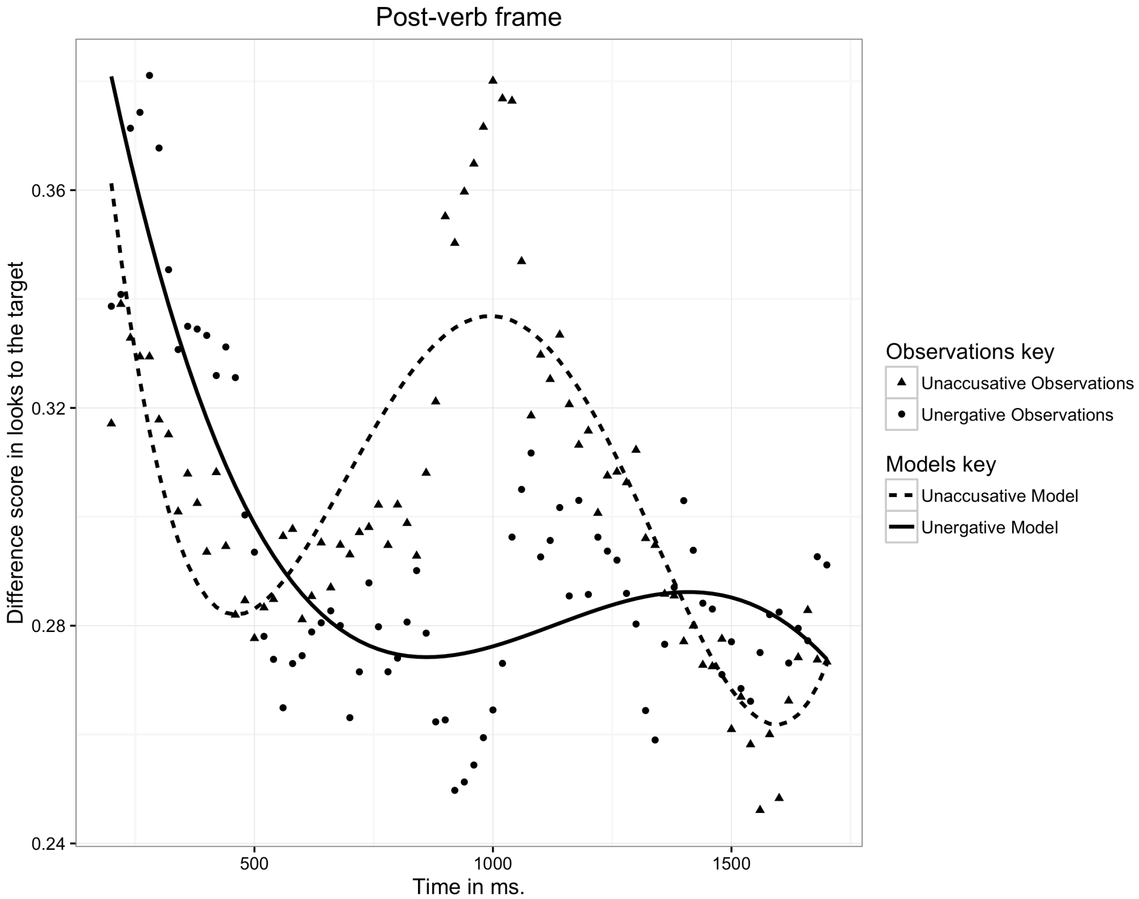
GCA allows one to model non-linear curvatures using higher-order polynomials. It is worth unpacking this further before presenting the results. For a given time window, we might expect looks to the target to either steadily rise ((re)activation) or fall (deactivation). This could be captured by the first-order polynomial (the linear term). On the other hand, the curve might change its direction during the time window, resulting in a rise and then a fall ((re)activation followed by deactivation), or a fall and then a rise (deactivation followed by reactivation). This could be captured by including a second-order polynomial (the quadratic term). We could continue adding higher-order polynomials to capture a greater number of times a curve would change its direction. We can then model the effect of a particular experimental condition (unaccusative vs. unergative in our case) on the different polynomial time terms.

We pre-defined a time frame starting 200ms. after verb offset and ending 1500ms. later as the post-verb frame, which should capture late reactivation effects (see Koring et al. 2012). In the post-verb frame, we predicted a late reactivation effect for unaccusative verbs, which would, by itself, yield a rise in looks to the target. In Figure 2 we see that the curve changes its direction more than once. In fact, the model that included the effect of condition (unaccusative vs. unergative) on the quartic term provided the best fitting model among the ones we tested (significant improvement compared to the model with up to the cubic component: $\chi^2(1) = 13.81$, $p<.0005$). This effect follows from the unaccusatives displaying a significant positive quartic component ($b=0.14$, $SE=0.04$, $p<.0005$), absent in the unergative verbs ($b=0.004$, $SE=0.04$, $p=.91$). The quartic component for unaccusatives indicates that the curve changed its direction three times. There is a fall in looks to the target at the beginning of the time frame (a decay in activation of the argument) followed by a rise in looks to the target (*re*activation of the argument) peaking at 950ms. After the peak follows another fall in looks to the target (a decay in reactivation) which itself is followed by a

[7] Trials were excluded from analysis if there was a track loss for more than 1 second consecutively. This led to the deletion of 50 trials in total (3% of the data).

final small rise. This final rise is not necessarily predicted but was also observed in Dutch (see Koring et al. 2012).

Fig. 2 Difference score in fixation proportions and model fits for the post-verb frame (200 until 1700 ms. after verb offset). Time is synchronized to the acoustic offset of the verb (0 ms. = verb offset). (Final model post-verb frame: final model <- lmer(DV ~ (ot1+ot2+ot3+ot4)*condition + (ot1+ot2+ot3+ot4 | subject), data=post, REML=F)



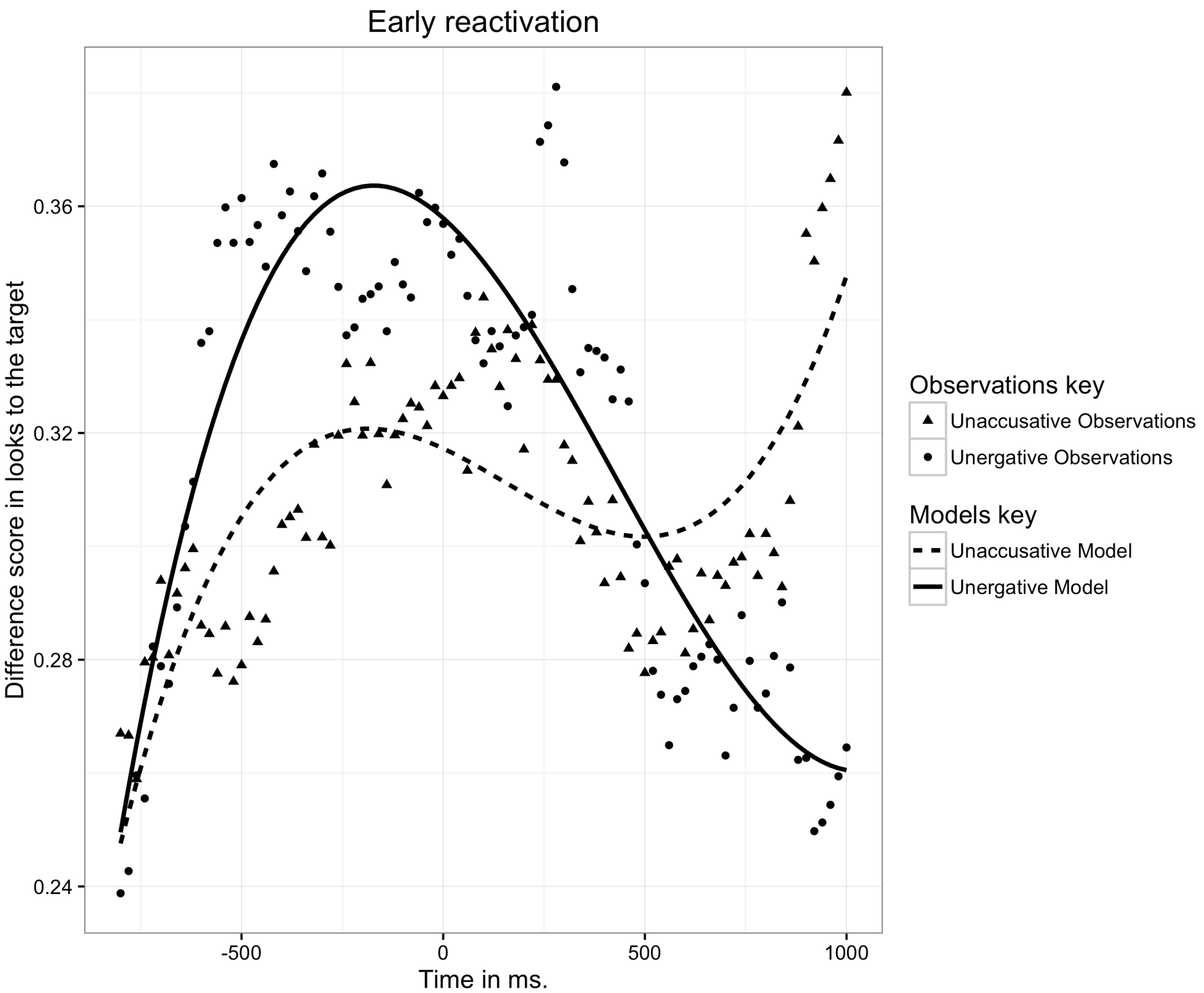
We may conclude that the VWP establishes the very same late reactivation effect for unaccusative verbs previously found with the CMLP. Furthermore, the pattern for English unaccusatives in the post-verb frame showed the same effects as found in Dutch, despite the difference in the canonical position of the internal argument in the two languages.

3. Tracking early reactivation effects

We analyzed a second time frame, called the verb frame (600 ms. before verb offset until 1000 ms. after verb offset), which should capture early reactivation effects (see Koring et al. 2012). CMLP did not detect any early reactivation effects, yet, in Dutch, Koring et al. (2012) observed an early reactivation effect for unergative verbs. In contrast to Dutch, we did not find a significant rise – fall pattern (reactivation – deactivation) for unergative verbs in this time frame in English.

It does not seem to be the case, however, that there is no early reactivation for unergative verbs in English at all. Consideration of the plot for a slightly larger time frame, as in Figure 3, suggests that reactivation starts even earlier than the verb frame in English, so that what we are looking at in the verb frame is a decay following a super-early reactivation. A post-hoc analysis indeed signalled a significant quadratic effect (rise – fall shape: reactivation – deactivation) in this earlier time frame for unergative verbs (b=-0.28, SE=.07, p<.0001), different from unaccusative verbs, indicating a super-early reactivation effect.

Fig. 3 Difference score in fixation proportions and model fits for a time frame starting 800 ms. before verb offset and ending at 1000 ms. after verb offset.



Why should reactivation be so early? At this point, we can only offer a post hoc explanation. Our suggestion is that the super-early reactivation relates to structural differences between English and

Dutch. In particular, it could follow from the role played by adverbs in processing in English. The reasoning is that an English adverb contains more information for the parser than a Dutch adverb. First of all, the adverb is morphologically marked in English (-*ly*), but not in Dutch. Furthermore, the position of the adverb is less variable in English than in Dutch. In Dutch (a V2 language), adverbs follow the inflected verb in matrix clauses, but precede the verb in embedded clauses. Finally, Dutch allows DPs to scramble across an adverb. One might then speculate that the more rigid position of the English adverb provides the parser with unambiguous information that the verb is coming up and that, given its incremental nature, the parser will use this information in processing.[8]

The missing step then to account for super-early reactivation is that the parser, when encountering an English sentence, will start retrieving the argument already at the adverb as it knows that the verb (requiring verb-argument integration) will come up next. This would not only predict a super-early reactivation of the argument of unergative verbs, but also a super-early reactivation in unaccusative verbs, as the adverb does not provide information regarding the verb class of the upcoming verb. It should be noted in this regard that Figure 3 displays an increase in looks to the target starting at the beginning of the time frame for unaccusative verbs as well. The time point at which the rise sets in looks the same for both unaccusative and unergative verbs; they differ in that the rising curve for unergative verbs is steeper. We hypothesize that listeners will reactivate the argument (of any verb type) on the basis of a cue that the verb is coming up (and thus a possibility for argument-verb integration). If the verb is unergative, argument-verb integration can straightforwardly continue. By contrast, if the verb is unaccusative, argument-verb integration must await the computation of a structure with an internal argument position, resulting in suppression of the early reactivation. The (internal) argument is then fully reactivated as soon as computation has terminated and the argument can be integrated with the verb as an internal argument.

4. Conclusion

In this paper, we have shown, using the VWP, that the argument of unaccusative verbs in English gives rise to a late reactivation effect in online sentence processing. In addition, our experiment points to an early reactivation effect for the argument of both unaccusative and unergative verbs.

[8] There is ample evidence for the incremental nature of the parser (e.g. Altmann 1998, Altmann & Steedman 1988, Crain & Steedman 1985, Frazier 1979, Kimball 1973, Tanenhaus et al. 1995).

Our study therefore confirms that the syntactic difference between unaccusative and unergative verbs is reflected in processing.

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Appendix A

Unaccusative verbs

Verb	Argument	Target picture
arrive	runner	running shoe
fall	fireman	fire
depart	teacher	chalkboard
arise	banker	money
flower	band	drum kit
occur	summer	sun
rose	lemonade	straw
bloom	brewery	beer
emerge	party	cake
remain	farmer	tractor
stand	carpenter	hammer
disappear	tailor	suit
depart	cook	chef’s hat
exist	computer	mouse (computer)
vanish	musician	guitar
arrive	cameraman	video camera
vanish	queen	king
appear	ballerina	ballet shoe

Unergative verbs

Verb	Argument	Target picture
smile	doctor	stethoscope
scream	hair dresser	scissors
laugh	pilot	plane
wave	fisherman	rod
cry	roofer	roof
sing	policeman	hand cuffs
jump	monkey	banana
sleep	lumberjack	axe
escape	photographer	camera
crawl	spider	web
laugh	producer	movie tape
hesitate	librarian	books
smile	sailor	sail boat

tremble	chiropractor	back
shout	dentist	tooth
bark	dog	cat
wave	janitor	broom
wink	plumber	plumbing tools