The visual trace of unaccusativity in online processing

1 Introduction

This squib makes three contributions to our understanding of the mapping between unaccusative syntax and processing.[1] First, it reports the findings of a replication of a study by Friedmann et al. (2008). Using the Cross Modal Priming Paradigm (CMPP), these authors found that unaccusative predicates give rise to a reactivation of their NP argument some time after the offset of the verb. Using a comparable data set, we obtained somewhat richer, but essentially identical results using the Visual World Paradigm (VWP; Cooper 1974, Tanenhaus et al. 1995). The fact that the distinctive processing signature of unaccusative sentences can be shown to be a robust and replicable effect using different experimental methods is particularly important in view of recent discussions about the reproducibility of experimental findings (cf. Open Science Collaboration 2015). The second contribution is the use of the VWP to directly compare reactivation effects in English and in Dutch. To date, only an indirect comparison could be made, in studies that used different methods (CMPP vs. VWP). The cross-linguistic comparison reveals that, even though English and Dutch are structurally different, the overall reactivation patterns are similar, with both languages showing the same late reactivation of the argument NP with unaccusative verbs. We also report some small differences that call for further exploration. The third contribution of this squib concerns the time course of argument reactivation. An 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 insight into the time course of reactivation effects and enables the detection of effects that might have gone unnoticed due to the poorer temporal resolution of the CMPP.

2 Traces of unaccusativity

Several robust (cross-linguistic) syntactic diagnostics distinguish unaccusative from unergative verbs. For example, Italian permits *ne*-cliticization of the (internal) argument of unaccusative verbs, but not unergative verbs (Burzio 1986). Hebrew permits post-verbal subjects, which are 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). As a final example diagnostic, unaccusative verbs in Dutch, German, French, and Italian select the auxiliary 'be,' whereas unergative verbs select the auxiliary 'have' in the perfect or past tense (Hoekstra 1984).[2]

English does not exhibit any of these robust syntactic diagnostics that distinguish intransitive verbs with a VP-internal argument from ones with an external argument. There are diagnostics that apply to subsets of unaccusative verbs, but no single test picks out all intransitive verbs with a VP-internal argument (Levin and Rappaport Hovav 1995). The absence of robust diagnostics for unaccusativity raises the question if it is possible to detect an effect of unaccusativity in online sentence processing. Previous research using the cross-modal priming paradigm (CMPP) suggests that it is possible (Friedmann et al. 2008).[3] In a CMP experiment, participants perform a lexical decision task in response to a string of letters that appears on a screen, while they are 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 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 for 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 internal argument of an unaccusative verb. The precise time course of this reactivation effect remains an open question, however. It is unclear whether 750 ms. represents the starting point, end point, or midpoint of the reactivation effect.

In contrast to CMP, VWP allows one to obtain a precise record of the time course of reactivation. VWP engages the same logic as CMPP, but instead of triggering a faster lexical decision, the working hypothesis is that a mentally active object triggers more looks to a semantically related visual object than to unrelated visual objects. Previous work using VWP in Dutch has shown a late reactivation effect for the argument of an unaccusative verb, as found in English (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.[4]

An additional finding of Koring et al.'s study was the detection of a reactivation effect for unergative verbs. This reactivation effect 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 of the point of argument-verb integration).[5] 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 CMP simply because the probe locations rendered its detection impossible.

In what follows, we investigate the time course of reactivation of argument NPs in English as compared to Dutch. There are reasons to expect that the time course of reactivation effects might be different in the two languages. One reason is the absence of robust unaccusativity diagnostics in English, as opposed to Dutch. Other factors that could contribute to timing differences include structural differences between English and Dutch in the canonical position of the internal argument, and more variable word order in Dutch (in particular regarding adverb placement).

3 (Eye)-tracking 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 (a passive task, based on Koring et al. 2012). The participants' eye movements were recorded using an Eyelink 1000, sampling at 500Hz. Each test sentence (see (1)) was combined with a visual display (see Fig. 1) that consisted of four visual objects, one of which was semantically related to the argument of the (unaccusative or unergative) verb. 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 and Altmann 2005, Altmann and Kamide 2007 a.o.). For example, participants will look more at the target object *broom* in Fig. 1 when they hear the semantically related argument *janitor* in sentence (1) than they will look to the three distractor objects. By hypothesis, participants will look back to the target object when they hear the verb (*waved*), due to reactivation of the argument.

(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)

insert Figure 1

To optimize comparison of the two experiments, the present experiment included Friedmann et al.'s frequency-matched sets of non-alternating unaccusative and unergative verbs.[6] The test sentences were minimally altered[7] versions of Friedmann et al.'s sentences and were all of the form '*DP… AP VP…*'. The sentences 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 (see (1)). A female native speaker of (Australian) 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 in the present experiment. 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.

Based on the preceding discussion, the experimental hypothesis was that reactivation of the argument would trigger an increase in looks to the semantically related target object. That is, by virtue of the argument being active in the participant's mind, their eyes will be drawn more to a visual object that bears a semantic relation to the argument, than they would be drawn to visual objects that bear no semantic relation. 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 from the test sentence solely in the argument that was used. For example, in our sentence (1), 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 looks to the target in the test condition minus looks in the control condition.[8] Importantly, we are interested in a *change* in looks to the target at the point when the verb was presented (reactivation). Therefore, the statistical model 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 or fall. 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, or a fall and then a rise. 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 two time frames for analysis: the post-verb frame (200 until 1700 ms. after verb offset), which allows us to capture late reactivation effects, and the verb frame (600 ms. before verb offset until 1000 ms. after verb offset), which allows us to capture early reactivation effects (see Koring et al. 2012 for the rationale for choosing those time frames).

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: $\chi^2(1) = 26.63$, $p<.0001$) (Fig. 2 plots the observations against the final fitted model). This effect follows from the unaccusatives displaying a significant positive quartic component (b=0.14, SE=0.04, $p<.0005$) that was 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 (as a result of reactivation of the argument) that peaks at 950ms. After the peak follows another fall in looks to the target (a decay in reactivation of the argument) which itself is followed by a final small rise. This final rise is not necessarily predicted, but was also observed in Dutch (see Koring et al. 2012).

Using VWP, we replicated the late reactivation effect for unaccusative verbs that was found with the CMPP. As compared to CMP, VWP more accurately shows that the reactivation effect sets in after the verb offset and peaks at 950 ms. Finally, the pattern for English unaccusatives in the post-verb frame showed the same effects as found in Dutch, which indicates that, even though syntactic diagnostics for unaccusativity are present in Dutch, but not in English, there is a similar reactivation effect.

insert Figures 2 and 3

It is less clear what to expect in the verb frame in terms of effects. CMP did not detect any early reactivation effects. Yet, in Dutch, Koring et al. (2012) observed an early reactivation effect for unergative verbs. Our current data (see Fig. 3) presents a fall in looks to the target for unergative verbs, but a curve with two bends (rise – fall – rise) for unaccusative verbs. Indeed, the model that included the effect of condition on the cubic term provided a better fitting model than the model with up to two time terms ($\chi^2(1) = 28.52$, $p<.0001$) (model fits and observations in Fig 3).

The effect of condition on the cubic component results from a significant cubic component for unaccusative verbs ($b=0.16$, $SE=0.05$, $p<.005$), that was not present in unergative verbs ($b=0.03$, $SE=0.05$, $p=.59$). Hence for unaccusative verbs, there was an early rise in looks to the target (early reactivation) followed by a fall (deactivation of reactivation), and then followed by another rise (late reactivation)[9]. We will discuss a potential reason for this effect below that relates to the findings for unergative verbs. For unergative verbs we found a significant fall in looks to the target ($b=-0.28$, $SE=0.13$, $p<.05$), but no significant rise-fall curve that would display early reactivation (as found in Dutch) ($b=-0.11$, $SE=0.06$, $p=.06$). This does not necessarily mean that there is no early reactivation for unergative verbs in English. We would rather argue that the reactivation starts even earlier than this time frame, so that what we are looking at in the verb frame is a decay following a super-early reactivation (the super-early rise is visible in Fig. 4). In the following, we will discuss a possible reason as to why reactivation might be so early.

insert Figure 4

Our suggestion is that the super-early reactivation relates to the structural differences between English and Dutch. In particular, it follows 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. The more rigid position of the English adverb provides the parser with unambiguous information that the verb is coming up. Given the incremental nature of the parser, the parser will use this information in processing.[10] 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 not only accounts for the super-early reactivation of the argument of unergative verbs, but it also accounts for the additional early reactivation that was found in unaccusative verbs, as the adverb does not indicate which verb will follow (and an anticipatory argument reactivation should thus be independent of verb type).[11]

4 Conclusion

In this squib we have replicated the CMP-based findings of Friedmann et al. (2008)

using the VWP, which showed that the argument of unaccusative verbs, unlike the argument of unergative verbs, gives rise to a late reactivation effect. Our experiment confirmed that the syntactic difference between unaccusative and unergative verbs is reflected in processing by a difference in the timing of argument reactivation. We also showed that the activation profiles for English sentences with unergative verbs and unaccusative verbs are largely identical to those reported by Koring et al. (2012) for Dutch. We tentatively attributed the fact that English shows early reactivation effects that are shifted forward as compared to Dutch to the effect of adverb placement on incremental parsing routines.

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[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.

[2] Unaccusativity is not the only factor that determines auxiliary selection (see for instance McFadden (2007)).

[3] 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), and in Agnew et al. (2014).

[4] 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 CMP (Koring et al. 2012).

[5] Previous work showed 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, yet is projected externally (Levin and 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.

[6] 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 and Mounoud 2009). The analyses did not reveal any significant differences between the stimuli sets.

[7] 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.

[8] 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).

[9] Note that this is the same late reactivation effect as we find in the post-verb frame as the time frames partly overlap.

[10] 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).

[11] It is unclear whether this early reactivation effect for unaccusative verbs shows up in Dutch as well. The graphs in Dutch (Koring et al. 2012 and in particular Koring et al. under revision) do display a small rise from verb onset, but this effect did not turn out to be significant by itself. In any case, the early reactivation in Dutch seems to be slightly later.

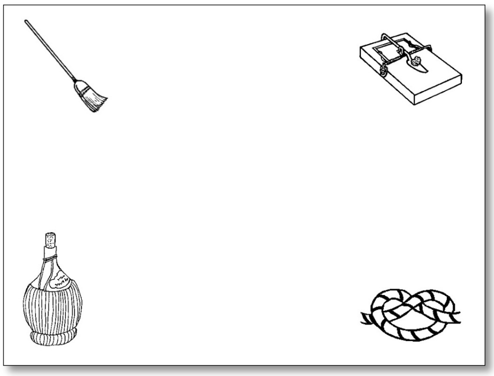
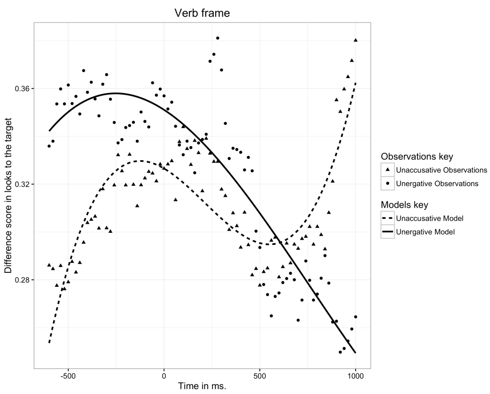


Fig. 1 Visual display that combines with sentence (1); target object is *broom*. (Pictures are taken from the picture set created by Szekely et al. 2004)



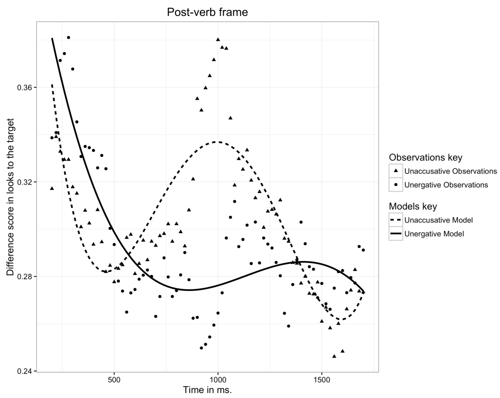


Fig. 2 Late reactivation

Fig. 3 Early reactivation

Time is synchronized to the acoustic offset of the verb (0 ms. = verb offset).

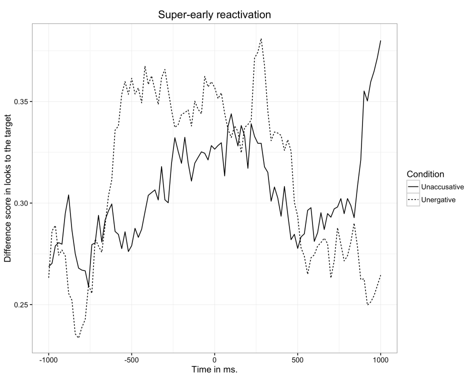


Fig. 4 Raw observations for a time frame starting 1000 ms. before verb offset and ending at 1000 ms. after verb offset.