Doing It Again and Again May Be Difficult, But It Depends on What You Are Doing

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1. Introduction

Sentence interpretation is integrating the information of incoming lexical items into a coherent whole. But often the pieces of information do not fit together and have to be shifted in meaning to confirm with the rest of the sentence. These shifts are called coercion (Moens & Steedman, 1988; Pustejovsky, 1995). There is a growing body of experimental work that investigates the processing consequences of two different coercion phenomena: complement coercion (e.g. McElree et al., 2001) and aspectual coercion (for a review see Pylkkänen & McElree, 2006). Aspectual coercion itself encompasses a number of different types which have been systematically described in a seminal paper by Moens & Steedman (1988). Consider the examples in (1-a) to (1-d).

(1) a. John reached the top in two hours.
b. John built a house for two years.
c. John sneezed for two hours.
d. John dived through the pool for two hours.

Reach the top in (1-a) is an achievement but the *in*-adverbial requires an accomplishment. Hence a preparatory process (e.g. climbing) has to be added to the aspectual representation. This information isn't contained in the sentence but has to be inferred from world knowledge since many different processes are possible candidates (climbing, flying a helicopter etc.). Following Hamm & van Lambalgen (2005) I will call this type of coercion *additive coercion*. (1-b) is different; *build a house* is an accomplishment whereas the *for*-adverbial requires an activity. Thus, the accomplishment has to be stripped off its culmination. I will refer to this type of coercion as *subtractive coercion*. (1-c) and (1-d) involve *iterative coercion*. (1-c) must refer to a series of sneezing events and (1-d) is most naturally understood as John being engaged in a series of diving events.

The present research focuses on the question whether or not different types of aspectual coercion are equally easy to perform. This question is important because the answer to it can be used to decide between different semantic coercion accounts. Up to now, only a very small subset of coercion types have been experimentally tested. Psycholinguistic research on aspectual coercion has concentrated on iterative readings and the coercion type most often investigated has been iterated semelfactives. The debate has mostly focussed on the question whether aspectual coercion is cognitively demanding or not. The findings are mixed – some studies found coercion to be difficult (e.g. Piñango et al., 1999; Todorova et al., 2000; Brennan & Pylkkänen, 2008), others did not (Pickering et al., 2006).

1.1. Theories on Aspectual Coercion

During the last twenty years a lot of work in formal semantics has been devoted to aspectual coercion. The existing accounts can be roughly classified into the following three categories:

- **Operator-Based Accounts** assume that coercion is triggered by a type-mismatch between two expressions A and B that have to be composed (e.g. de Swart, 1998; Rothstein, 2004). Let expression A be a functor of type $\langle\beta,\gamma\rangle$ (meaning that A takes an argument of type β and outputs a value of type γ); let expression B be an argument of type $\langle\alpha\rangle$ with $\alpha \neq \beta$. A type-mismatch is a constellation $[A_{\langle\beta,\gamma\rangle}[B_{\langle\alpha\rangle}]]$. It can be resolved by inserting a type-shifting operator $OP_{\langle\alpha,\beta\rangle}$ from type $\langle\alpha\rangle$ to type $\langle\beta\rangle$ into the representation yielding $[A_{\langle\beta,\gamma\rangle}[OP_{\langle\alpha,\beta\rangle}[B_{\langle\alpha\rangle}]]]$. The latter can be interpreted compositionally.

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- **Underspecification Accounts** have been developed to represent ambiguities in an economical and elegant way (e.g. Dölling, 2003; Egg, 2005). They use a two-step procedure. First, an underspecified representation is computed. This representation - the semantic representation proper - leaves everything open which needs further disambiguation. In a second step, the underspecified representation is transformed into a fully specified representation using pragmatic information from discourse context, conceptual knowledge et cetera.

  A coerced sentence and its non-coerced counterpart share the same underspecified representation. Only the second step is different. While the non-coerced sentence is disambiguated by eliminating all potential coercion sites in the semantic representation, the coerced sentence is disambiguated by inserting coercion operators to fully specify the meaning.

- **Planning Accounts** (e.g. Steedman, 2002; Hamm & van Lambalgen, 2005) make use of planning formalisms which have been developed in artificial intelligence. According to these theories, the computation of the temporal profile for a piece of discourse can be viewed as coming up with a plan that permits a non-monotonic derivation of a goal state from an initial state. Coercion is characterized by shifts in meaning that result from the update of a plan when integrating new information.

  I will focus on the Event Calculus, a planning account presented in Hamm & van Lambalgen (2005) for which an incremental version has been developed in Bott (in preparation). It is formalized in constraint logic programming. A sentence is understood as an instruction to update the situation model in a way that makes the sentence true. Updates can differ with respect to the number of steps that are required[1]. The computed model is minimal in the sense that everything one doesn't have information about is assumed to be false. Every incoming piece of information is immediately incorporated into the model. Whenever possible, variables are unified with constants of the right type. I make the assumption that plausibility can only be evaluated after a model has been computed.

Let's look at the three examples (1-b), (1-c) and (1-d) to see what the theoretical alternatives say about them. Operator-based accounts predict difficulty at the *for*-adverbial in all three coercion types because all them involve a temporary aspectual mismatch. The complexity of repair may actually differ between (1-b), (1-c) and (1-d) since each example requires a different operator: in (1-b) the operator picks out a proper subpart of the more complex accomplishment, but (1-c) and (1-d) are repaired by plugging in a (potentially different) iteration operator. Thus, although all three coercion types are predicted to be difficult, they may not all be equally complex.

Underspecification accounts make somewhat different predictions. Under these accounts no mismatch is expected to occur. Thus, if coercion should be difficult at all, the difficulty is solely due to selecting a pragmatically appropriate type-shift operator. Assuming a single *iteration*-operator that can basically shift any Aktionsart into an iterative reading[2], (1-c) and (1-d) should be equally complex to process. (1-b) may be different because here another type of operator is needed.

Finally, the Event Calculus provides a detailed model for the computational steps in the three coercion types. Due to place limitations, I can only sketch these steps.

(1-b) *John built a house* is interpreted as an accomplishment consisting of a preparatory process *build* (=John building the house) followed by the culminating event *finish* (=John finishing the house). The *for*-adverbial contains a process-variable that has to be unified with a process constant from the discourse representation. The only available process is *build*. The adverbial further introduces a *stop*-event that will terminate *build* before *finish* happens. Hence, the default interpretation of the accomplishment is shifted non-monotonically into an activity. The Event Calculus allows us to achieve this result by a range of different computations – two computations of varying complexity have been spelled out in Bott (in preparation). To reduce the number of these algorithmic possibilities we need experimental data on the processing demands of the actual computation.

[1] *Number of steps* is a notion that is exactly defined in logic programming since it corresponds to the number of applications of the fixed point operator until the least fixed point, that is the minimal model, is reached.

[2] See for instance Egg (2005, p. 97).

(1-c) The semelfactive *John sneezed* enters a sneezing event in the aspectual representation. The *for*-adverbial requires a process constant but the representation lacks any process the adverbial could be composed with. As a result, the event has to be shifted into a process. In the Event Calculus there is a coding device which is explicitly dedicated to perform this type shift ($event \rightsquigarrow fluent$), namely imperfect nominalization (see Hamm & van Lambalgen, 2005, ch. 12). This operation is very frequent in language and this leads us to expect that it is also easy to perform.

(1-d) Initially, the sentence should be processed exactly like (1-b). The reader thus gets an interpretation in which John was engaged in a diving activity that lasted for two hours. However, this reading turns out to be pragmatically odd and has to be revised. To make sense of the sentence the accomplishment has to be iterated. This step involves the same operation as in (1-c). Taking everything together, (1-d) should be computationally more complex than the former two examples: while these require just one coercion step, (1-d) is predicted to require two coercions.

These predictions were tested in two reading time experiments which will be described in section 3. Experiment 1 tested accomplishments and Experiment 2 tested semelfactives.

2. Norming Studies

Before turning to the reading time experiments it is crucial to establish whether the materials we plan to use have the intended meanings. To this aim, the readings were tested in two offline questionnaires. The first (**Baseline**) established baseline preferences of the initial parts of the target sentences before the critical adverbial, the second (**Coercion**) assessed the readings of the coerced sentences including the adverbials.

2.1. Materials

40 sets of German accomplishment sentences were constructed in four conditions like the sample item in (2). (2-a) requires subtractive coercion; the short *in*-adverbial in (2-b) fits the Aktionsart of the accomplishment and is an aspectual control; (2-c) has to be iteratively coerced into a habitual reading; and the long *in*-adverbial in (2-d) yields an implausible sentence. The latter was included to compare coercion with aspectual mismatch. The whole set of materials can be found at www.sfb441.uni-tuebingen.de/~oliver/WCCFL27/materials.html

(2) a. Der Arbeiter belud die Schubkarre zwanzig Minuten lang, dann wurde er zum Chef
The worker loaded the wheelbarrow twenty minutes long, then was he to-the boss
gerufen.
called.
The worker loaded the wheelbarrow for twenty minutes then he was called to his boss.

b. Der Arbeiter belud die Schubkarre in zwanzig Minuten, dann...
The worker loaded the wheelbarrow in twenty minutes, then...

c. Der Arbeiter belud die Schubkarre zwanzig Jahre lang, dann wurde er woanders hin
The worker loaded the wheelbarrow twenty years long, then was he elsewhere to
versetzt.
posted.
The worker loaded the cart for twenty minutes then he was posted somewhere else.

d. *Der Arbeiter belud die Schubkarre in zwanzig Jahren, dann...
The worker loaded the wheelbarrow in twenty years, then...

The short and long adverbials were matched in length. Short adverbials had a mean of 17.6 characters, long adverbials a mean of 17.4 characters. A two-samples t-test revealed that the numerical difference was far from significant ($t(158) = .67$, $p = .51$).

The experimental sentences were always followed by a *then*-clause. There were two types of *then*-clauses depending on the adverbial. Following *short* adverbials the second clause introduced a concrete event which can plausibly interrupt the preparation. Participants are thus expected to understand subtractive coercion in (2-a) as implying that the culmination didn't happen. By contrast, in (2-b) the

event introduced by *then* is expected to be interpreted as abutting the culmination. Following *long* adverbials the event was rather abstract and shifted the focus to higher order events. This was done to make it coherent with the habitual interpretation of the iterative accomplishment which situates the event at the level of life episodes like education, job, retirement. Crucially, the two continuations only differ after the first three words of the second clause whereas the region of interest is at the end of the first clause.

In addition, 20 sets of semelfactive sentences were constructed in two conditions. (3-a) is like the English example (1-c) and requires iterative coercion. (3-b) is a non-coercing control. The whole set of materials allows us to simultaneously test all predictions.

(3) a. Den ganzen Morgen nieste der Junge laut im Klassenzimmer, dann entschuldigte
The whole morning sneezed the boy loudly in-the classroom, then apologized
er sich bei seinen Mitschülern.
he himself at his classmates.

b. Heute Morgen nieste der Junge laut im Klassenzimmer, dann. . .
This morning sneezed the boy loudly in-the classroom, then. . .

2.2. Methods

The offline tests were two questionnaire studies that were administered over the internet using Webexp 2 (Mayo et al., 2006). For each sentence participants had to provide two judgments. First, they had to decide whether the sentence expressed that the (with accomplishments: culminating) event happened and if so, whether it happened only once or repeatedly.

- **Baseline:** The initial part of the target sentences (accomplishment: *the worker loaded the cart*; semelfactive: *the boy sneezed loudly*) were presented to 20 German native speakers to find out whether the chosen sentences were clear instances of accomplishments and semelfactives respectively. 20 fillers (10 non-complete events, 10 multiple events) were added resulting in a total of 80 items.

- **Coercion:** Only the first three conditions (2-a) to (2-c) of the accomplishments were included in the test because only these should receive a sensible interpretation. From the 40 accomplishment sentences and the 20 semelfactive sentences, six lists were created according to a latin square design. The set of 20 fillers from the Baseline test were added to each. 24 different native German speakers participated in the Coercion test.

2.3. Results and Discussion

Baseline Test: The accomplishments were interpreted as complete single events 89.4% of the time. Only 9.9% of all judgments were ”no, not completed”. Thus, the accomplishments were well chosen. Without adverbial modification they did not allow for an activity interpretation. The semelfactives received 100% ”yes” responses. Of these, 98.0% were single event judgments. This shows that the semelfactives denote single events and do not have a process interpretation.

Coercion Test: The results are depicted in Figure 1. Accomplishments modified by short *in*-adverbials and long *for*-adverbials overwhelmingly received ”yes, the culminating event happened” responses (short *in*: 76.6%; long *for*: 81.8%) but the short *for*-adverbials received ”yes” responses only 16.4% of the time. ANOVAs with the within-factor *adverbial* comparing the ”yes”-responses in the two constructions with short adverbials revealed a reliable difference between short *for* and short *in* ($F_1(1, 23) = 107.18$, $p < .01$; $F_2(1, 39) = 255.35$, $p < .01$). This shows that the short *for* condition lead to subtractive coercion.

The long *for* condition triggered the computation of iterative readings: 96.1% of the ”yes” answers were ”more than once”. In comparison, in the short *in* condition 95.1% of the ”yes” answers were ”only once”.

The semelfactives received 100% ”yes, the event happened” responses in both conditions. Semelfactives modified by *ago*-adverbials had ”only once” judgments 93.8% of the time, whereas semelfactives

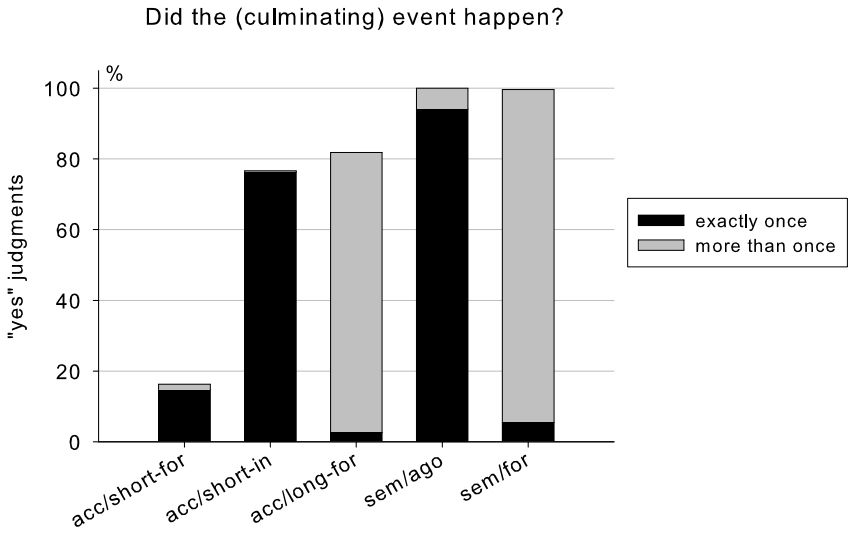

Figure 1: Mean judgments in the coercion test. *acc* = accomplishment, *sem* = semelfactive.

modified by *for* were 94.6% of the time judged to express repeated events indicating the computation of iterative readings. ANOVAs revealed that the latter difference was highly significant ($F_1(1, 23) = 2227.83$, $p < .01$; $F_2(1, 19) = 985.39$, $p < .01$).

To sum up, the findings of the two offline tests show that the materials have the intended meanings. In the accomplishments, short *for*-adverbials cause subtractive coercion and long *for*-adverbials trigger iterative readings. The semelfactives also show a strong coercion effect: with *ago*-adverbials they are unequivocally interpreted as punctual events but when modified by a *for*-adverbial they receive an iterative interpretation.

3. Reading Time Experiments

3.1. Methods

Experiments 1 and 2 were self-paced reading studies using non-cumulative moving window presentation. The segmentation of the experimental items is shown in Figures 3 and 4. The two experiments were run together in a single experimental session. After each sentence participants had to provide a judgment whether the sentence was sensible. Experiment 1 tested accomplishments in the four conditions (2-a) to (2-d). Experiment 2 tested semelfactives in the two conditions (3-a) and (3-b). The 60 experimental sentences were combined with 90 fillers of which 40 were nonsensical. The overall ratio of sensible to nonsensical sentences in the experiment was 2:1. Four lists were constructed according to a latin square design. These were randomized separately for each subject.

3.1.1. Participants

Forty students from Tübingen University (all native German speakers, 33 female, mean age = 22.6, min. 19, max. 29 years) participated in the experiment. They were naive to the purpose of the study and hadn't participated in any of the previous experiments. Each subject was paid 5€ for participation. The participants were randomly assigned to lists (ten subjects per list). An experimental session lasted about half an hour.

3.2. Results

3.2.1. Sensicality Judgments

The sensible distractors were judged sensible 90.1% of the time while nonsensical distractors were judged sensible 20.2% of the time. This shows that the participants read attentively. All judgments are

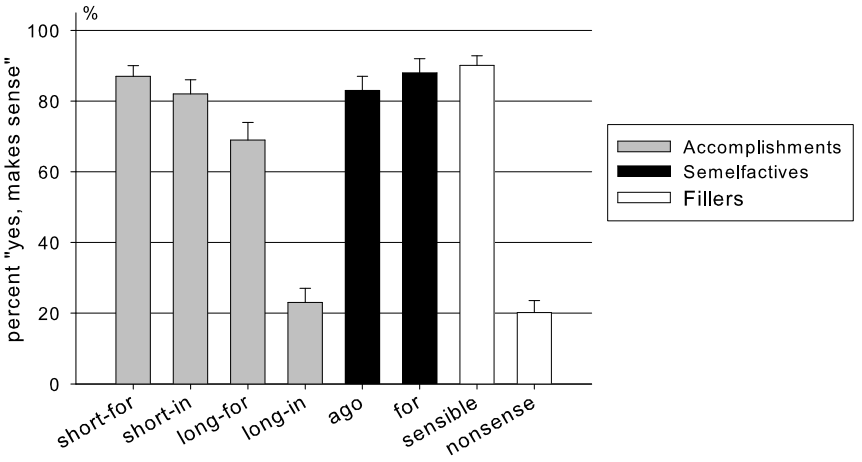

Figure 2: Mean sensicality judgments in Experiments 1 and 2 (+ 95% confidence intervals).

depicted in Figure 2.

Accomplishments: short *for*-adverbials were judged sensible 87.0% of the time and short *in*-adverbials were judged sensible in 82.3% of all cases. This difference didn't turn out to be significant in paired t-tests ($t_1(39) = 1.46$, $p = .15$; $t_2(39) = 1.54$, $p = .13$). Long *for*-adverbials were judged sensible 69.3% of the time and were significantly below the short *in*-adverbials ($t_1(39) = 2.65$, $p < .05$; $t_2(39) = 3.35$, $p < .01$). Long *in*-adverbials were judged sensible only 22.8% of the time and didn't differ from the nonsensical fillers ($t_1(39) = 0.58$, $p = .57$). In ANOVAs with *duration* (two levels: *short* vs. *long*) and *adverbial* (two levels: *for* vs. *in*) as within factors, the difference between the long *in* condition and the other conditions was reflected in a significant interaction ($F_1(1, 39) = 79.56$,, $p < .01$; $F_2(1, 39) = 87, 23$, $p < .01$) and in significant main effects both of *duration* ($F_1(1, 39) = 157.26$, $p < .01$; $F_2(1, 39) = 176.99$, $p < .01$) and of *adverbial* ($F_1(1, 39) = 84.59$, $p < .01$; $F_2(1, 39) = 125.54$, $p < .01$).

Semelfactives: Semelfactives modified by *for* were judged sensible 83.0% of the time compared to 87.5% "yes" for semelfactives modified by *ago*. In paired t-tests, this difference wasn't significant ($t_1(39) = 1.45$, $p = .16$; $t_2(19) = 1.54$, $p = .14$).

Analyses of answer times revealed no significant differences between conditions (all $Fs < 1.5$). The mean answer times ranged from 950 to 1000 ms.

3.2.2. Reading Times

Accomplishments: The reading times in the four accomplishment conditions are depicted in Figure 3. They were corrected for outliers by trimming data points that were below 200 ms or above 2500 ms.

At the adverbial, short *in* was read fastest with a mean of 904ms, short *for* had a mean RT of 936ms, long *for* 1000ms and long *in* was read with a mean RT of 1042ms. ANOVAs revealed a significant main effect of *duration* ($F_1(1, 39) = 18, 35$, $p < .01$; $F_2(1, 39) = 14.52$, $p < .01$) which is due to the fact that the long adverbials took longer to read than the short adverbials. The interaction between *duration* and *adverbial* was marginally significant in the subjects analysis but wasn't reliable by items ($F_1(1, 39) = 3.84$, $p = .06$; $F_2(1, 39) = 2.13$, $p = .15$). Also, there was no reliable main effect of *adverbial* ($F_{1/2} < 1$). Planned comparisons revealed that short *for*-adverbials didn't reliably differ from control ($t_1(39) = 1.25$, $p = .22$; $t_2(39) = .96$, $p = .34$) but that long *for*-adverbials took longer to read than control ($t_1(39) = 3.44$, $p < .01$; $t_2(39) = 2.92$, $p < .01$). Long *for*-adverbials didn't differ significantly from the implausible long *in*-adverbials ($t_1(39) = 1.73$, $p = .09$; $t_2(39) = 1.03$, $p = .31$).

At the following segment, the implausible long *in* condition had slower reading times (564ms) than the other conditions (short *for*: 485ms, short *in*: 472ms and long *for*: 509ms). This difference was reflected in a significant interaction between *duration* and *adverbial* ($F_1(1, 39) = 8.66$, $p < .01$; $F_2(1, 39) = 9.16$, $p < .01$), a significant main effect of *duration* ($F_1(1, 39) = 38.34$, $p < .01$;

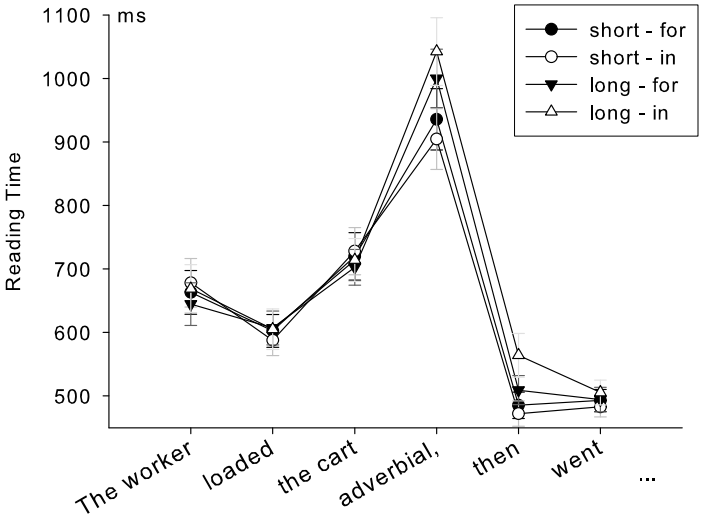

Figure 3: Mean reading times in Experiment 1 (+ 95% confidence intervals).

$F_2(1, 39) = 36.67$, $p < .01$) and a marginal effect of *adverbial* ($F_1(1, 39) = 3.36$, $p = .08$; $F_2(1, 39) = 3.21$, $p = .08$). Paired t-tests revealed that long *for* was slower than short *in* ($t_1(39) = 2.58$, $p < .05$; $t_2(39) = 2.39$, $p < .05$) and long *in* was slower than short *in* ($t_1(39) = 5.56$, $p < .01$; $t_2(39) = 6.87$, $p < .01$). The numerical difference between short *for* and short *in* wasn't reliable ($t_1(39) = 1.17$, $p = .25$; $t_2(39) = .92$, $p = .36$). At later segments there were no significant differences between conditions (all $Fs < 1$).

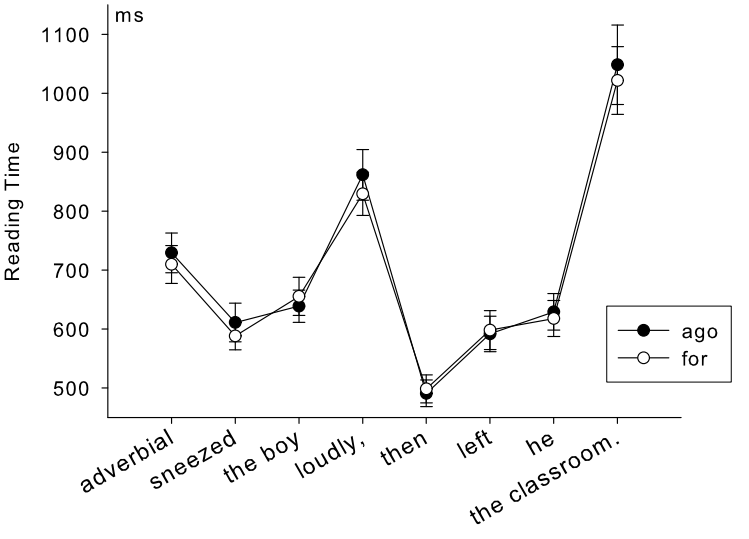

Figure 4: Mean reading times in Experiment 2 (+ 95% confidence intervals).

Semelfactives: The reading times of coerced and non-coerced semelfactives are depicted in Figure 4. Paired t-tests revealed that the two conditions didn't differ in reading time at any segment (all $t_{1/2} < .5$).

4. Discussion

In the reading time experiments, both subtractive coercion items and iterated semelfactives were read as fast as non-coercing controls indicating that they were not difficult to process. Iterated accomplishments, however, slowed down reading pace just like the aspectually implausible long *in* condition. In contrast to the latter condition, the slowdown in iterated accomplishments is due to local aspectual mismatch that can eventually be repaired as indicated by the sensicality ratings.

The findings provide evidence against operator-based accounts. Under this type of theory, aspectual mismatch is expected to occur in all three coercion types. However, neither subtractive coercion nor iterated semelfactives were harder to comprehend than their aspectual controls. This shows that some kinds of coercion do not cause processing difficulty at all. The lack of effect cannot be due to aspectual ambiguity of the accomplishments and semelfactives because in the baseline test the accomplishments were judged to unambiguously express perfective telic events and the semelfactives were judged to denote single events. Our findings are in line with the experimental results of Pickering et al. (2006) who also didn't find difficulty in iterated semelfactives either in self-paced reading or in eye-tracking.

Unlike the data from Pickering et al. (2006), the results of the present experiments are not compatible with underspecification accounts. Iterated accomplishments immediately slowed down reading pace. This indicates that this coercion type is taxing. According to underspecification accounts, both iteration types should be resolved by plugging an iterative operator into the underspecified representation. Since specification is carried out on pragmatic grounds the processor should never consider the implausible subtractive coercion reading in accomplishments modified by long *for*-adverbials. Instead, it should select the iterative reading right from the start. It is thus completely unexpected why one iterative coercion type should be harder to process than the other.

Our experimental findings fully support the predictions of the Event Calculus. Iterative accomplishments were much harder to coerce than subtractive coercion or iterative semelfactives. According to the Event Calculus, difficulty in the first coercion type stems from first computing an implausible subtractive coercion reading then revising it and giving it an iterative interpretation instead. Of these three steps the first and the last do not cause difficulty when they appear in isolation as was shown by the subtractive coercion condition and the iterative semelfactive condition. Only when a coerced meaning has to be reanalyzed, is difficulty enhanced. The situation is similar to syntactic garden path sentences where readers also have great difficulty recovering from local misinterpretation.

It is clear that much more work has to be done to substantiate these claims. The Event Calculus makes predictions about computational processes in coercion. To investigate these, we need a method that provides information about the functional correlates of the observed difficulty. It would be interesting to measure ERPs or MEG while readers are processing iterated accomplishments. If the predictions derived from Event Calculus are correct, we expect ERP correlates that are similar to those obtained in garden-path sentences.

In this paper, no distinction was made between different kinds of iterative interpretations. In particular, iterative processes were equated with habitual interpretations. This may, however, be oversimplistic. It is possible that the results reflect difficulty in processing habitual readings rather than revision of an implausible interpretation. I do not think that this alternative explanation is correct because habitual readings do not seem to be difficult in general (consider, for instance, *in the morning, John brushes his teeth*). Further research is needed to find out whether this intuition is correct. For this purpose, it would be important to compare coercion of an accomplishment into an iterated process as in (4-a) with coercion into a habitual reading as in (4-b).

(4) a. John dived through the pool for two hours.
b. John dived through the pool for twenty years.

The present study illustrates the relevance of psycholinguistic data in evaluating semantic theories. In order to design informative experiments it is essential to formulate semantic analyses in an algorithmic fashion. We can then experimentally compare semantic phenomena involving similar or related computational steps. This will lead to a better understanding of the interpretation process as well as to cognitively relevant semantic theories.

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