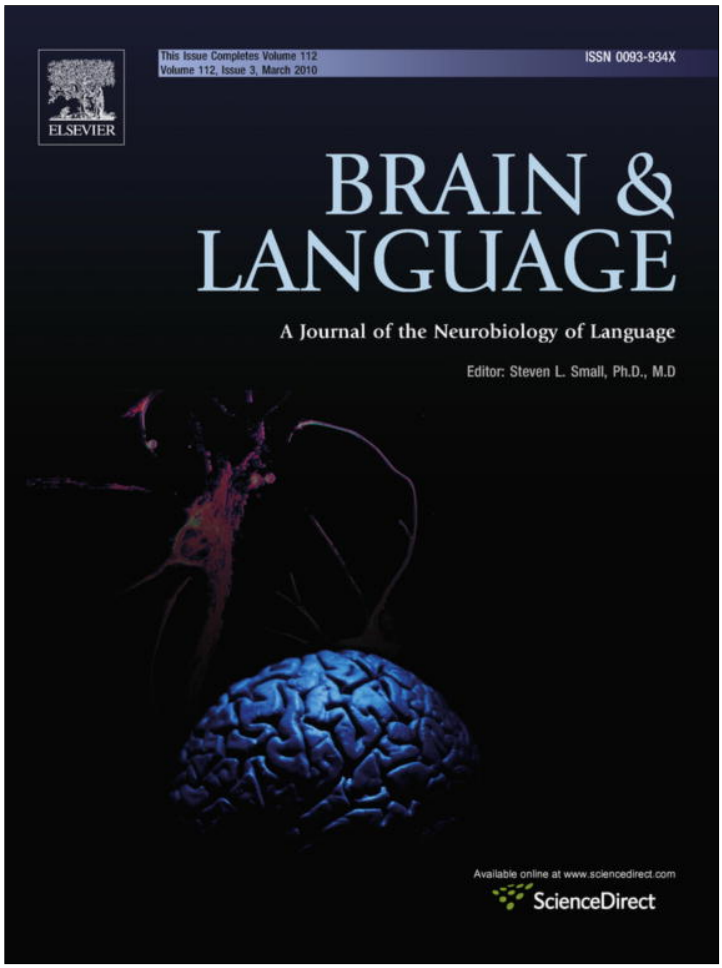

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"The drawer is still closed": Simulating past and future actions when processing sentences that describe a state

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ABSTRACT

In two experiments using the action–sentence–compatibility paradigm we investigated the simulation processes that readers undertake when processing state descriptions with adjectives (e.g., *Die Schublade ist offen/zu.* [*The drawer is open/shut*]) or adjectival passives (e.g., *Die Schublade ist geöffnet/geschlossen.* [*The drawer is opened/closed*]). In Experiment 1 we did not find evidence for action simulation, not even in sentences with adjectival passives. The results were different in Experiment 2, where the temporal particle *noch* (*still*/*yet*) was inserted into the sentences (e.g., *The drawer is still closed*). Under these circumstances readers mentally simulated the action that brought about the current state for sentences with adjectival passives, but the action that would change the current state for sentences with adjectives. Thus, comprehenders are in principle sensitive to the subtle differences between adjectives and adjectival passives but highlighting the temporal dimension of the described states of affairs seems a necessary precondition for obtaining evidence for action simulation with sentences that describe a state. We discuss implications for future studies employing neuro-psychological methods.

1. Introduction

In language comprehension research it is nowadays commonly assumed that understanding a sentence or text is tantamount to representing the state of affairs that the sentence or text describes rather than the sentence or text itself (Glenberg, Meyer, & Lindem, 1987; Johnson-Laird, 1989; Kelter, 2003; van Dijk & Kintsch, 1983). A growing number of authors additionally assume that the representations of the described states of affairs are experiential in nature, as they are grounded in perception and action. Comprehenders presumably mentally simulate experiencing or re-experiencing the described states of affairs to the effect that the meaning representations utilized in language comprehension are in principle of the same type as those utilized in non-linguistic cognition such as perception, imagery or action planning. According to this representational view, there is a common representational platform for both linguistic and non-linguistic cognition (Barsalou, 2008; Glenberg, 1997; Zwaan, 2004).

Strong evidence for this experiential-simulations account of language processing comes from neuroscience studies, in particular with respect to action simulation. For instance, studies using brain imaging techniques, have shown that the processing of linguistic materials referring to actions that are typically performed with certain effectors activates those sections of the premotor and motor cortex that are specific for actions with the respective effector (Hauk, Johnsrude, & Pulvermüller, 2004; Tettamanti et al., 2005). Similarly, studies using transcranial magnetic stimulation (TMS) have found that motor evoked potentials (MEPs) recorded from hand and foot muscles are specifically modulated by listening to hand-action-related vs. foot-action-related sentences, respectively (Buccino et al., 2005; Glenberg et al., 2008; see also Aziz-Zadeh, Wison, Rizzolatti, & Iacoboni, 2006; de Vega, Robertson, Glenberg, Kaschak, & Rinck, 2004; for a review, see Fischer & Zwaan (2008)).

In addition to neuroscience studies of this sort, numerous behavioral studies have provided evidence for motor resonance during language comprehension. One particularly elegant behavioral paradigm was first introduced by Glenberg and Kaschak (2002). In a sentence–sensibility–judgement task, participants were presented with sentences such as: (1) that described an action involving an arm movement either towards or away from the protagonist (e.g., *opened* vs. *closed*, respectively).

(1) You opened/closed the drawer.

The critical manipulation concerned the movement that was required for correctly responding to the sensibility-judgement task: for half of the participants, pressing the 'yes' button required a movement towards their body and for the other half, a move-

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ment away from the body. Thus, the movement implied by the action described in the sentence either matched or mismatched the required response movement. In line with the hypothesis that participants experientially simulate the described actions, sentence-reading times were significantly faster in the match than in the mismatch condition. This *action–sentence–compatibility effect (ACE)* is very robust. It has been replicated in different experimental settings (e.g., Taylor & Zwaan, 2008; Zwaan & Taylor, 2006; for an overview see, Fischer & Zwaan (2008)), and is observed even if the movement implied in the sentence is not concrete as in (1) but more abstract as in (2) (Glenberg & Kaschak, 2002, see also Glenberg et al., 2008).

(2) He told you the story.

To conclude, there is considerable evidence that the processing of linguistic material describing particular actions indeed activates the mental system that is responsible for action representation in non-linguistic cognition.

In the present experimental work we asked whether action simulation during language comprehension only takes place when processing sentences that describe an action, or whether it is possible to obtain action-simulation effects even with sentences that describe a state. Research concerned with the human visual system has demonstrated that humans can and regularly do extrapolate dynamic information from static pictures that imply motion. For instance, in a recent TMS-study by Urgesi, Moro, Candidi, and Aglioti (2006). It was found that the mere observation of static snapshots of hands suggesting a pincer-grip action induced an increase in corticospinal excitability specific for the muscle that would be activated during actual execution of the action. This increase was only observed for pictures implying ongoing action but not for snapshots of hands suggesting a completed action. Based on the notion that a snapshot of an ongoing action conveys dynamic information about forward and backward action paths, whereas a snapshot of a completed action only conveys information about backward action paths, this finding is interpreted as suggesting that the motor system is maximally activated by the extrapolation of the future trajectory of body actions. Presumably, anticipation of the future position is of special relevance as it allows the future position of moving entities to be anticipated, which helps to bridge discontinuities in visual inputs, and thus enables humans to optimally interact with the external world (cf. Urgesi et al., 2006). The idea that the human system is tuned to the extrapolation of the future trajectory of body actions is also in accordance with the finding that the action system is activated when humans observe objects that afford certain manipulations (e.g., tools; Chao & Martin, 2006; see also Richardson, Spivey, & Cheung, 2001).

On the basis of these findings, one could predict that linguistic state descriptions give rise to action simulation only if they suggest that a future action will cause a change of state but not if they imply a certain past action that has brought about the current state. That is, action simulation for state descriptions would always be future-oriented. However, we also consider it possible that language deviates from the processing of visual scenes in this respect. Language is a powerful tool that allows many different perspectives on one and the same state of affairs to be conveyed. For instance, if a sentence describes a state but in addition unequivocally conveys that this state is the result of a certain past action then it would be conceivable that this past action is being simulated during comprehension even for stative sentences.

For our study we exploited the fact that German (as many other languages) displays two kinds of passives: an eventive, or verbal, passive, and a so-called "stative" or "adjectival", passive; cf. Emonds, 2005. English does not mark this difference overtly – both verbal and adjectival passives are expressed by an *-en/-ed* participle in combination with a form of *to be*. Thus a sentence such as (3) is ambiguous between an eventive and a stative reading and can be disambiguated by linguistic or extra-linguistic context (cf. (3a) and (3b)). The manner adverbial *quickly* and the agent phrase *by the mother* in (3a) highlight the verbal passives's eventive reading whereas the conjunction with the adjective *short* in (3b) selects for the adjectival passive's stative reading.

(3) The child's hair was dyed.

a. The child's hair was quickly dyed by the mother.	eventive reading (verbal passive)
b. The child's hair was short and dyed.	stative reading (adjectival passive)

That is, in English the same form *to be* is used for both the verbal and the adjectival passive, which makes it difficult to tease them apart. In a language like German the situation is more transparent, because verbal and adjectival passives are expressed by different means. The verbal passive is formed by combining an *-en/-t* participle with the passive auxiliary *werden* ('become'); cf. (4). The adjectival passive is formed using the copula *sein* ('be'); cf. (5).

(4) Das Haar wurde gefärbt.	
The hair became dyed	only eventive reading
'The hair was dyed.'	(verbal passive)
(5) Das Haar war gefärbt.	
The hair was dyed	only stative reading
'The hair was dyed.'	(adjectival passive)

Thus, in (5) the verb phrase (VP) of the sentence (i.e., *war gefärbt*) unambiguously expresses a stative property: it refers to an attribute that is ascribed to the entity referred to by the subject noun phrase (NP), not to an event, as is evidenced by the fact that it cannot be combined with a manner adverbial such as *langsam* [*slowly*] (**Das Haar war langsam gefärbt* [*The hair was slowly dyed*]).

Nevertheless an adjectival passive clearly differs from a corresponding adjectival sentence. Take, e.g., the pair in (6)[1]:

(6) a. Die Schublade ist leer.
'The drawer is empty.'
b. Die Schublade ist geleert.
'The drawer is emptied.'

Both sentences in (6) describe a state of being empty but only (6b) implies that this state is the result of a past event of emptying the drawer. Sentence (6a), on the other hand, remains neutral as to whether the current state of being empty has been brought about by some past emptying event or whether the drawer never had anything in it (see Gese, Maienborn, & Stolterfoht, submitted for publication; Kratzer, 2000; Maienborn, 2007; Rapp, 1998, for linguistic analyses of the German adjectival passive). Thus, German is particularly suitable for empirically investigating the question of whether state descriptions give rise to action simulation when the sentence, despite describing a state, unequivocally implies that this action took place in the past and brought about the current state. If the answer to this question is "yes", then two sentences such as (6a) und (6b), both describing a state (i.e., being empty), should give rise to very different simulations. Only sentence (6b) should lead to the simulation of emptying the drawer.

[1] Note that the adjectival passive formation is highly productive in German, whereas in English the possibility of building adjectival passives seems to be blocked if there is an alternative primary adjective as in (6a), in German adjectival passives are systematically available for almost any verb; cf. Gese et al., submitted for publication; Maienborn, 2009.

In the present study, we tested this hypothesis in an action–sentence–compatibility study à la Glenberg and Kaschak (2002). Participants were presented with sentences that mentioned a particular target entity (e.g., the drawer of a desk) and described it to be in one of two states (closed or open). The two different states for each sentence were always such that the action that (possibly) brought about the current state involved for the agent either an arm movement towards the body (for a drawer to become open, the agent needs to pull it towards the body) or an arm movement away from the body (for a drawer to become closed, the agent needs to push it away from the body). The state was expressed either by means of an adjectival passive (8) or by means of an adjective (7). As stated above, whereas (7) remains silent about whether the described state has been brought about by a corresponding event of opening (closing) the drawer, sentence (8) unequivocally implies that such an action has taken place.

(7) Die Schreibtischschublade ist offen/zu. adjective
The desk drawer is open/shut
'The drawer of the desk is open/shut.'

(8) Die Schreibtischschublade ist geöffnet/geschlossen. adjectival passive
The desk drawer is opened/closed
'The drawer of the desk is open/closed.'

The participants' task was to judge the sensibility of the sentences. For half of the participants a 'yes'-response required an arm movement towards the body, for the other half an arm movement away from the body. Thus, the response movement either matched or mismatched the movement that (possibly) brought about the current state (henceforth "inducing movement").

If a state description implying a certain past action that has brought about the current state leads to a mental simulation of this action, then we should observe an ACE with respect to the inducing movement for sentences with adjectival passives (e.g. (8)). Response times should be shorter if the response movement matches rather than mismatches the inducing movement. For sentences with adjectives (e.g. (7)) we do not expect such an effect, as the sentence does not imply a past action that has brought about the current state. Thus, we expect an interaction between the match/mismatch manipulation and the form of the sentence (adjectival passive vs. adjective). Such a finding would be interesting in at least three respects. First, it would indicate that action-simulation effects can also be obtained with sentences describing states, rather than actions. Second, it would suggest that linguistically implied actions are being simulated even if they happened in the past, that is, even if they already lie behind the actual reference time that is established by the sentence. Third, such a result would show that readers are sensitive to the subtle differences in meaning between adjectives and adjectival passives and, moreover, that this difference is reflected in the mental simulations constructed during comprehension.

We also included two versions that described the same states of affairs but by means of a negative sentence (e.g. (9)).

(9) Die Schreibtischschublade ist nicht zu/geschlossen.
The desk drawer is not shut/closed
'The drawer of the desk is not shut/closed.'

It is well known that negation may be used to communicate deviations from expected or desired states of affairs (Givón, 1978; Horn, 1989; Lüdtke & Kaup, 2006; Schindele, Lüdtke, & Kaup, 2008; Wason, 1965). A sentence such as (9) may therefore be interpreted as an indirect request to the recipient to close the drawer (for the notion of indirect request, see e.g., Levinson, 1983; Noveck & Sperber, 2004). If so, the recipient can be expected to anticipate the required movement by mentally simulating it. This in turn should result in an ACE for the negative sentences, not with respect to the inducing movement but with respect to the movement that changes the current state into the expected/desired state (for the example above, the movement required to close the drawer; in the following, "modifying movement"). It should be noted that the modifying movement is a future-oriented movement. Thus, if implied movements are only simulated if they are about to occur but not if they have already taken place, then we should not obtain the effects predicted above with respect to the inducing movement. Nevertheless, the potential ACEs predicted for the negative sentences (with respect to the modifying movement) should still be observed.

2. Experiment 1

2.1. Method

2.1.1. Participants

Forty students at the Berlin University of Technology participated for course credit or a payment of 8 €/h. All participants were native speakers of German.

2.1.2. Materials

There were 64 sensible sentences and 64 non-sensical sentences. Thirty-two of the sensible sentences acted as experimental items. They appeared in eight versions, realizing a 2 (polarity: affirmative/negative) × 2 (form: adjective/adjectival passive) × 2 (state: open/closed) design (see Table 1 for an overview; see Appendix for a complete list of the stimuli).

2.1.3. Design and procedure

The 32 experimental items were assigned to eight sets, the 40 participants to eight groups, and the assignment of versions to sets and groups was according to a 8 × 8 × 8 Latin square. Each participant read all 32 experimental items intermixed with all 96 filler items. 'Yes' and 'No'-response buttons were arranged on the keyboard such that for half of the participants, a 'yes'-response required a movement away from their body, and for the other half a movement towards their body.

For the analyses we collapsed across the two states of each sentence (open vs. closed), as well as across the two button-arrangements (yes = away vs. yes = towards), and analyzed the data depending on whether the response movement matched the

Table 1
Sample materials employed in Experiment 1.

Sentence	Polarity	Form	State	$Match_{induce}$	$Match_{modify}$
Die Schublade ist offen. (the drawer is open)	Aff	Adj	Open	yes = towards	yes = away
Die Schublade ist geöffnet. (the drawer is opened)	Aff	AdjP	Open	yes = towards	yes = away
Die Schublade ist zu. (the drawer is shut)	Aff	Adj	Closed	yes = away	yes = towards
Die Schublade ist geschlossen. (the drawer is closed)	Aff	AdjP	Closed	yes = away	yes = towards
Die Schublade ist nicht offen. (the drawer is not open)	Neg	Adj	Closed	yes = away	yes = towards
Die Schublade ist nicht geöffnet. (the drawer is not opened)	Neg	AdjP	Closed	yes = away	yes = towards
Die Schublade ist nicht zu. (the drawer is not shut)	Neg	Adj	Open	yes = towards	yes = away
Die Schublade ist nicht geschlossen. (the drawer is not closed)	Neg	AdjP	Open	yes = towards	yes = away

movement that (possibly) brought about the current state (inducing movement) or the movement that would change the current state (modifying movement). Thus we employed a 2 (polarity: affirmative vs. negative) × 2 (form: adjective vs. adjectival passive) × 2 (match: inducing movement vs. modifying movement) × 8 group/set design with repeated measurement on the first three variables in both analyses.

Sentence presentation was self-paced by the participants. Each trial began with the participant pressing the "presentation-key" that displayed the sentence on the computer screen. When the key was released, the sentence disappeared and the participant responded with either the 'yes' or the 'no' key to the sentence-sensibility judgement task. We measured the time that participants pressed the presentation key (reading time). Each experimental session lasted approximately 20 min.

2.2. Results and discussion

We analyzed the reading times of experimental sentences which were correctly identified as sensible. Reading times longer than 10,000 ms or shorter than 200 ms were omitted. In determining outliers within the remaining reading times, we took not only differences among the participants into account, but also differences among the items. We employed a two-step procedure: First, the reading times of each participant were converted to *z*-scores. Second, these *z*-scores were again converted to *z*-scores per item and condition. Reading times with a *z*-score deviating more than 2.5 standard deviations from the mean *z*-score of that item in the respective condition were discarded. This eliminated less than 4.0% of the data.

We submitted the remaining reading times to two analyses of variance, one based on participant variability ($F1$), the other based on item variability ($F2$). We will not report the effects of the counterbalancing factors 'group' (analysis by participants) and 'set' (analyses by items) as these were only included in the analyses in order to reduce error-variance (cf. Pollatsek & Well, 1995) but lack theoretical relevancy.

The mean reading times in the eight different conditions are displayed in Fig. 1 (error bars represent confidence intervals for mixed designs determined according to Masson & Loftus (2003)). Reading times were significantly shorter in the affirmative than in the negative conditions ($F1(1,32) = 41.6,\ p < .001,\ \eta^2 = .57$; $F2(1,24) = 25.5,\ p < .001,\ \eta^2 = .52$), which is hardly surprising as negative sentences were always one syllable longer than the corresponding affirmative sentences. Other than that there were no significant effects (form: $F1(1,32) = 1.1,\ p = .30,\ \eta^2 = .03$; $F2(1,24) < 1$); match: both Fs < 1; polarity-by-match: $F1(1,32) = 2.4,\ p = .13,\ \eta^2 = .07$; $F2(1,24) < 1$; form-by-match: $F1(1,32) < 1$; $F2(1,24) = 1.1,\ p = .30,\ \eta^2 = .05$; polarity-by-form: $F1(1,32) = 1.3,\ p = .26,\ \eta^2 = .04$; $F2(1,24) = 1.6,\ p = .21,\ \eta^2 = .06$; polarity-by-form-by-match: both Fs < 1.

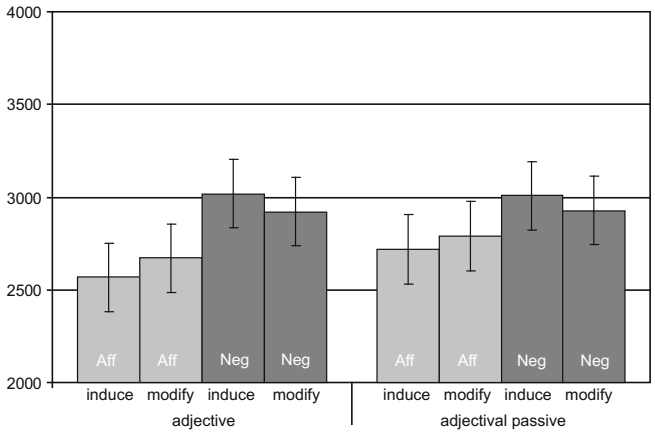

Fig. 1. Mean sentence reading times as a function of sentence polarity (affirmative vs. negative), response movement required for correct response (inducing movement vs. modifying movement), and sentence form (adjective vs. adjectival passive) in Experiment 1.

The results do not provide conclusive evidence for the hypothesis that readers simulate inducing movements that are implied by sentences describing states. Nor do they provide evidence that negative state descriptions are interpreted as indirect requests and lead readers to anticipate and mentally simulate the requested action. Numerically, the observed reading time pattern is in line with the prediction that readers simulate the movement that (possibly) brought about the current state for affirmative sentences, and the movement that would change the current state for negative sentences, but the relevant differences were not significant. Moreover, there was no qualitative difference between sentences with adjectives and adjectival passives. In fact, the results obtained with adjectival passives looked remarkably similar to the results obtained with adjectives.

It is always difficult to draw conclusions from null effects. In this case, one reason for the null result may be that although readers did simulate the inducing and/or the modifying movements, our experimental design was simply not powerful enough to unearth the effects. Another possibility is that readers of sentences describing a state indeed focus on the described state, even if the sentence implies that a particular movement has taken place in the past that brought about the current state. This possibility would be in accord with the hypothesis that the motor system is mainly activated by the extrapolation of the *future* trajectory of body actions (cf. Urgesi et al., 2006). The fact that no effect was observed with respect to the modifying movement for negative sentences may indicate that the negative sentences were not interpreted as indirect requests and thus did not give rise to action simulation.

A third possibility is that readers simulate movements that are implied by the linguistic stimuli only under special circumstances. For instance, it is conceivable that readers only simulate inducing or modifying movements when their attention is drawn towards the temporal dynamics of the described states of affairs – in our case, towards the fact that the target object may have been in a different state in the past and/or may be in a different state in the future.

An interpretation, according to which the hypothesized effect is dependent on whether or not the reader's attention is being drawn toward the relevant aspects of the described situation, would be in line with the results of a recent study by Ulrich and Maienborn (submitted for publication) that investigated the hypothesis of a left–right coding of past and future events in language comprehension. Participants read sentences that either described a past or a future event. If their task was to decide whether the event took place in the past or the future, response times were affected by whether or not the 'past' and 'future'-responses were mapped onto the matching hand (match: past = left, future = right; mismatch: past = right, future = left). By contrast, if their task was a sentence–sensibility judgment task (for which the question of whether events happened in the past or will happen in the future is irrelevant), no match/mismatch effect emerged: there was no interaction between the content of the sentence (past vs. future event) and the hand that was required for responding to a sensible sentence. There are different explanations for this finding. One possibility is that readers locate described events in time only if the experimental task draws attention towards this aspect of the described states of affairs. Applied to our study, we consider it possible that readers simulate the inducing and/or modifying

movements only if the experimental setting highlights the changeability of the described states.

Experiment 2 was designed to test this hypothesis. Instead of directly manipulating the experimental task (as in the Ulrich and Maienborn study), we changed the linguistic materials employed in the experiment in such a way that the relevant information would be highlighted. In this experiment, participants were presented with the same materials as in Experiment 1, except that we inserted the temporal particle *noch* (*still*/*yet*) into the sentences (cf. (10) and (11)).

(10) Die Schublade ist noch zu/geschlossen. 'The drawer of the desk is still shut/closed.'
(11) Die Schublade ist noch nicht zu/geschlossen. 'The drawer of the desk is not yet shut/closed.'

We reasoned that this would highlight the temporal dynamics of the described situation, in particular the changeability of the target entity's state. In other words it would draw attention to the fact that the target entity may have been in a different state in the past and/or may be in a different state in the future. If so, we might find evidence for simulations of inducing and/or modifying movements in this experiment.

It should be noted that in addition to highlighting the dynamics of the described situation, the temporal particle *noch* may increase the probability that the negative sentences are being interpreted as indirect requests (i.e., to close the drawer for *The drawer is not yet closed*), and may even suggest such an interpretation for the affirmative sentences as well (i.e., to close the drawer for *The drawer is still open*). Thus, although we may not find any effects reflecting simulations of the inducing movement (for instance because only future implied movements are being simulated; see above), we should still observe action-simulation effects in the present experiment, namely ACEs with respect to the modifying movement. Even if readers do not adopt an indirect-request interpretation, they may still anticipate a future movement that changes the current state, because the temporal particle *noch* indicates that a change of state is to be expected.

One could argue that if readers anticipate the modifying movement not only for the negative but also for the affirmative sentences, then they should do so for sentences with adjectives as well as for sentences with adjectival passives. However, even if both are interpreted as implying a modifying movement and therefore eventually lead to simulations of this movement, we should still observe differences between the two types of sentences if readers in the present experiment simulate the inducing movement for sentences with adjectival passives but not for sentences with adjectives, as our hypothesis predicts. At the very least, potential ACEs with respect to the modifying movement should be smaller for the adjectival passive versions, as here the effects should be counteracted by the effects of simulating the inducing movement.

3. Experiment 2

3.1. Method

3.1.1. Participants

Forty students of the Berlin University of Technology participated for course credit or a payment of 8 €/h. All participants were native speakers of German.

3.1.2. Materials

The materials were the same as in Experiment 1, except that the temporal particle *noch* (*still*) was included in the sentences after the copular verb *ist* (e.g., *Die Schublade ist noch (nicht) offen/zu/geöffnet/geschlossen*).

3.1.3. Design and procedure

The design and procedure were the same as in Experiment 1.

3.2. Results and discussion

Reading times were analyzed as in Experiment 1. Outlier elimination reduced the data set by less than 3.5%. The data of one participant were eliminated, as there had been technical problems during sentence presentation in the respective experimental session. The means of the remaining reading times in the eight different conditions are displayed in Fig. 2 (error bars represent confidence intervals for mixed designs determined according to Masson & Loftus (2003)). The results look quite different from those obtained in Experiment 1: for sentences with adjectival passives, sentence-reading times were shorter when the response movement matched the inducing movement. For sentences with adjectives, sentence-reading times were shorter when the response movement matched the modifying movement. This difference was reflected in the statistical analyses. In addition to main effects of polarity ($F1(1,31) = 15.9,\ p < .001,\ \eta^2 = .34$; $F2(1,24) = 6.3,\ p < .05,\ \eta^2 = .21$) (probably being due to sentence length) and form ($F1(1,31) = 5.8,\ p < .05,\ \eta^2 = .16$; $F2(1, 24) = 3.4,\ p = .08,\ \eta^2 = .12$), there also was a significant form-by-match interaction ($F1(1,31) = 9.7,\ p < .01,\ \eta^2 = .24$; $F2(1, 24) = 4.4,\ p < .05,\ \eta^2 = .16$). All other effects were not significant (match: both Fs < 1; form-by-polarity: both Fs < 1; polarity-by-match: both Fs < 1; match-by-form-by-polarity: both Fs < 1).

To further investigate the significant form-by-match interaction, adjectives and adjectival passives were analyzed in separate analyses. For adjectives, reading times were significantly shorter in the match$_{modify}$-condition than in the match$_{induce}$-condition ($F1(1,31) = 6.4,\ p < .02,\ \eta^2 = .17$; $F2(1,24) = 4.5,\ p < .05,\ \eta^2 = .16$). There also was a significant polarity effect in the analysis by participants ($F1(1,31) = 7.4,\ p < .05,\ \eta^2 = .19$; $F2(1,24) = 2.3,\ p < .15,\ \eta^2 = .09$) but no polarity-by-match interaction (both Fs < 1). By contrast, for adjectival passives, reading times were significantly shorter in the match$_{induce}$-condition than in the match$_{modify}$-condition in the by-participant analysis ($F1(1,31) = 4.1,\ p = .05,\ \eta^2 = .12$; $F2(1,24) = 1.1,\ p = .31,\ \eta^2 = .04$). There was a significant polarity effect in the analysis by items

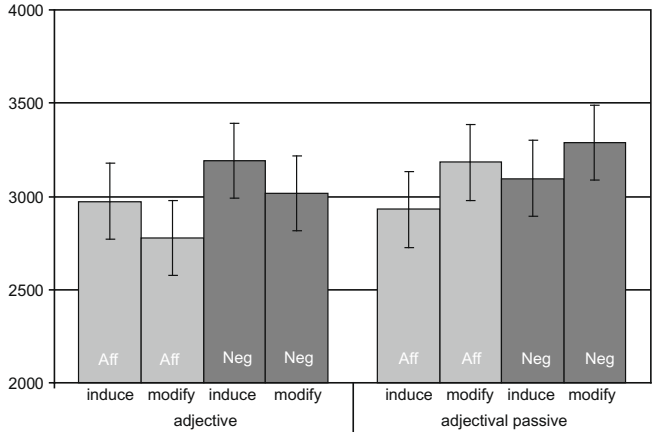

Fig. 2. Mean sentence reading times as a function of sentence polarity (affirmative vs. negative), response movement required for correct response (inducing movement vs. modifying movement), and sentence form (adjective vs. adjectival passive) in Experiment 2.

($F1(1,31) = 2.4,\ p < .15,\ \eta^2 = .07;\ F2(1,24) = 4.7,\ p < .05,\ \eta^2 = .16$) but no polarity-by-match interaction (both Fs < 1).

The results of this experiment are in line with the view that readers are in principle sensitive to the subtle differences between adjectives and adjectival passives. As hypothesized, ACEs were observed with respect to the inducing movement in the adjectival-passive conditions but not in the adjective conditions. This suggests that readers simulated the inducing movement when reading state descriptions with adjectival passives but not when reading state descriptions with adjectives. This is plausible as the inducing movement is unequivocally implied by the adjectival-passive sentences but not by the adjective sentences.

The finding that the inducing movement is simulated for sentences with adjectival passives but not for sentences with adjectives is in line with a recent study in which sentences with adjectives and adjectival passives were presented in different contexts (cf. Stolterfoth & Gese, 2008). In a moving windows paradigm with a word-by-word presentation, participants read sentences such as (12)–(14). The sentences described a particular state, either by means of an adjective (i.e. *tame*) or by means of an adjectival passive (i.e., *tamed*). The preceding linguistic material was available in three versions, and differed with respect to whether or not the target entity had previously been in a different state (i.e., (12) and (13) vs. (14)), and whether or not a particular action had taken place in the past that had brought about the change (i.e., (12) vs. (13)).

(12) Wenn Gabi ein Eichhörnchen regelmäßig gefüttert hat, bis das Tier keinerlei Scheu mehr vor ihr hat, dann ist das Eichhörnchen zahm/ gezähmt.
'If Gabi has fed the squirrel regularly until the animal isn't shy at her anymore then the squirrel is tame/tamed.'

(13) Wenn sich das Eichhörnchen in Gabis Garten ohne Gabis Zutun an sie gewöhnt hat, dann ist das Eichhörnchen zahm/ gezähmt.
'If the squirrel in Gabi's garden has got used to her without Gabi doing anything, then the squirrel is tame/tamed.'

(14) Wenn ein Eichhörnchen schon von Geburt an keinerlei Scheu vor Menschen gezeigt hat, dann ist das Eichhörnchen zahm/ gezähmt.
'If a squirrel has shown no shyness of people from birth, then the squirrel is tame/tamed.'

Self-paced reading times measured for the last word of the passages showed no context-effect for adjectives (i.e., *tame*). By contrast, for adjectival passives (i.e., *tamed*) reading times were significantly shorter in the condition in which the current state was brought about by a particular past action compared to the other two conditions in which no such action had taken place in the past. Acceptability judgements showed the same trend. Acceptability ratings were better for (12) than for (13) and (14) only in the adjectival-passive versions, not in the adjective versions. Taken together, these results indicate that readers indeed distinguish between adjectives and adjectival passives: they consider a past event that brought about the current state a necessary pre-condition for the validity of an adjectival-passive sentence but not for a sentence with an adjective. This finding supports the interpretation of our results according to which readers of state descriptions mentally simulate the movement that brought about the current state for sentences with adjectival passives but not for sentences with adjectives.

However, let us return to the results in the present experiment, in particular to the results for sentences with adjectives. For these, we did not obtain a null effect but rather effects in the opposite direction: for sentences with adjectives, reading times were shorter if the response movement matched the modifying rather than the inducing movement. This is in line with the view that the temporal particle *noch* not only highlighted the changeability of the described states but also led readers to anticipate and mentally simulate the movement that would change the current state. A possible reason may be that the sentences were interpreted as indirect request to change the current state (see above). Alternatively, *noch* may be interpreted as expressing the expectation that the current state is about to change. No evidence was obtained for the prediction that this tendency should be stronger for negative than for affirmative sentences.

One might of course wonder why the tendency to anticipate a modifying movement should only affect reading times for sentences with an adjective and not for sentences with adjectival passives. Indeed, in our view this tendency should be the same for both constructions. That no ACE with respect to the modifying movement was observed for the adjectival-passive sentences is probably due to the fact that *noch* not only led readers to anticipate a future movement but also highlighted the possibility that the target entity may have been in a different state in the past. For the adjectival-passive conditions this may have pushed the implied inducing movement into the focus of attention, thus leading to an ACE with respect to the inducing movement. It is of course conceivable that readers simulate both movements when processing sentences with adjectival passives, one after the other. In this case movements matching the modifying movement should be facilitated in the adjectival-passive conditions with a certain delay.

It should be noted that a negative sentence with an adjectival passive (e.g., *The drawer is not yet closed*) strictly speaking does not imply the inducing movement. It is therefore not quite clear why readers seem to simulate the inducing movement in the negative-adjectival-passive conditions. One possibility is that readers employ a verbal-recoding strategy when processing the negative sentences, that is, they transform the negative sentences into affirmative ones describing a similar state of affairs (i.e., *noch nicht geöffnet* $\Rightarrow$ *noch geschlossen*). Positive evidence for such a processing strategy was obtained in several studies for sentences with binary predicates (such as *open/closed*; *even/odd*, etc.; cf Trabasso, Rollins, & Shaughnessy, 1971). As the materials in the present study also employed binary predicates, such a verbal-recoding strategy appears possible. More work is necessary to clarify this aspect of the results.

4. General discussion

In two experiments, we investigated the simulation processes that readers undertake when reading sentences that describe a state (e.g., *The drawer is closed*). In particular, we asked whether readers are sensitive to the subtle differences in meaning between adjectives and adjectival passives in state descriptions. Whereas sentences with an adjectival passive imply that a certain movement has taken place in the past that brought about the current state, sentences with an adjective do not imply such a movement. In Experiment 1 we investigated whether this difference between the two constructions is reflected in the simulation processes during comprehension. The results of Experiment 1 suggest an answer in the negative. The results looked remarkably similar for adjectives and adjectival passives. No evidence for action simulation was obtained.

In Experiment 2 the same materials were employed as in Experiment 1 except that the temporal particle *noch* (*still*/*yet*) was inserted into the sentences. We argued that this would highlight the temporal dimension of the described states of affairs, in particular the fact that the target entity may have been in a different state in the past and/or may be in a different state in the future. Indeed, with this modification we did find clear differences between adjectival passives and adjectives. As predicted, an ACE was observed with respect to the inducing movement for adjectival

passives but not for adjectives. This suggests that readers indeed simulated the movement that brought about the current state when processing the sentences with an adjectival passive. We also observed ACEs for sentences with adjectives, but for the modifying movement. We argued that this is probably due to the temporal particle *noch* (*still*/*yet*) not only highlighting the temporal dimension of the described states of affairs but also leading readers to anticipate a future movement that changes the current state. Apparently readers mentally simulate this movement when processing the sentences. Future research is necessary to find out whether similar effects can be observed with adjectival passives after a certain delay. May be readers in this case first simulate the inducing movement and then the modifying movement.

Overall, the results of the two experiments are in line with findings from research concerned with picture processing that indicate that humans extrapolate motion information from static pictures. The present results go beyond these findings in showing that with linguistic materials, action simulation is not confined to future actions but may also be performed for past actions, if these are implied and highlighted by the specific wording used in the sentences. An interesting question for future research would be to investigate whether static pictures of completed actions also give rise to action simulation if the relevancy of potential past actions is highlighted by the experimental task.

In addition to the affirmative sentences discussed up to now, the experimental materials also included negative sentences. The results of the experiments suggest that with respect to the simulated movements it does not make much of a difference whether a state is being described by means of an affirmative or a negative sentence. This is surprising, considering the evidence in the literature that suggests that simulation processes differ between affirmative and negative sentences describing the same states of affairs (e.g., Kaup, Lüdtke, & Zwaan, 2005, 2006). As was argued above, we consider it possible that participants in this experiment employed a verbal-recoding strategy when processing the negative sentences (cf. Carpenter & Just, 1975; Trabasso et al., 1971). Future studies are necessary to find out whether affirmative and negative sentences describing a particular state also lead to the same simulation processes if readers are prevented from employing a verbal-recoding strategy during comprehension.

An interesting question for future research is whether the null results obtained in Experiment 1 reflect the fact that readers do not simulate the inducing movement when the sentences do not include the temporal particle *noch* or some other way of highlighting the changeability of the described events. An alternative hypothesis is that the effects were simply smaller under these conditions and were therefore not picked up in the experiment. If so, then a more sensitive experimental paradigm might display differences in the simulation processes associated with adjectives and adjectival passives even when the sentences do not highlight the temporal dimension. The action–compatibility paradigm that was employed in the present study has the disadvantage that movement simulation cannot be detected directly but must be inferred from a behavioral effect, namely the ACE. A neuro-psychological method with which movement simulation can be detected without the detour via a behavioral effect may constitute a more sensitive method for the present purpose. For instance, it would be interesting to investigate the adjectival passive in a TMS study (see above). Does a sentence such as (15) lead to muscle activity in the hands when presented in the context of a basket-ball game but to muscle activity in the feet when presented in the context of a soccer game? If so, this would indicate that readers do simulate the past event that brought about the current state described by an adjectival passive.

(15) Der Ball war bereits ins Tor katapultiert, als Simon aus seinem Sekundenschlaf erwachte.
'The ball was already slingshot into the goal when Simon awoke from his mikrosleep.'

Furthermore, do sentences with an adjectival passive (i.e., (17)) lead to more muscle activity than equivalent sentences with an adjective (i.e., (16)) but to less muscle activity than sentences with a verbal passive (i.e., (18))?

(16) Die Tür war fest zu. 'The door was firmly shut.'
(17) Die Tür war fest geschlossen. 'The door was firmly closed.'
(18) Die Tür wurde schnell geschlossen. 'The door was quickly closed.'

If they do, this would nicely match with the notion that a sentence with an adjectival passive is sort of an in-between case with respect to the state/event distinction: an adjective clearly describes a state and a verbal passive (of an eventive verb) clearly describes an event, whereas an adjectival passive (of an eventive verb) describes a state and implies that this state was brought about by an event.

5. Conclusion

The present research was concerned with three interrelated questions. First, can evidence for action simulation during sentence comprehension be obtained with sentences that do not describe an action but a state? Second, is action simulation in processing state descriptions confined to future actions, as implied by research concerned with picture processing, or is it possible to observe simulation effects for implied past actions during comprehension? Third, are comprehenders sensitive to the differences between adjectives and adjectival passives when processing state descriptions? All three questions can be answered with 'yes' but a qualification is needed. Evidence for the simulation of past and future movements during the processing of sentences that describe a state, and differences between adjectives and adjectival passives were observed only when the sentences contained the particle *noch* that highlights the temporal dimension, and in particular draws attention to the changeability of the described states of affairs. On the basis of the present data, we cannot decide whether bare adjectival passives are like adjectives in that they focus the reader's attention on the described state, or whether the mental simulations of the inducing movement are simply not as pronounced in this case. We argued that future studies using neuro-psychological methods may help to provide relevant information with respect to this issue.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.bandl.2009.08.009.

References

Aziz-Zadeh, L., Wison, S.-M., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing actions. *Current Biology, 16*, 1818–1823.

Barsalou, L.-W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645.

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gailese, V., & Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: A combined TMS and behavioral study. *Cognitive Brain Research, 24*, 355–363.

Carpenter, P. A., & Just, M. A. (1975). Sentence comprehension: A psycholinguistic processing model of verification. *Psychological Review, 82*, 45–73.

Chao, L. L., & Martin, A. (2006). Representation of manipulable man-made objects in the dorsal stream. *NeuroImage, 12*, 478–484.

de Vega, M., Robertson, D. A., Glenberg, A. M., Kaschak, M. P., & Rinck, M. (2004). On doing two things at once: Temporal constraints on actions in language comprehension. *Memory & Cognition, 32*, 1033–1043.

Emonds, J. (2005). Adjectival passives: The construction in the iron mask. In M. Everaert, H. V. Riemsdijk, & B. Hollebrandse (Eds.), *The blackwell companion to syntax* (pp. 16–60). Malden, Mass: Blackwell.

Fischer, M., & Zwaan, R. A. (2008). Embodied language – A review of the role of the motor system in language comprehension. *The Quarterly Journal of Experimental Psychology, 61*, 825–850.

Gese, H., Maienborn, C., & Stolterfoht, B. (submitted for publication). On the formation of adjectival passives: The case of unaccusatives.

Givón, T. (1978). Negation in language: Pragmatics, functions, ontology. In P. Cole (Ed.). *Syntax and semantics* (Vol. 9, pp. 66–112). New York: Academic Press.

Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences, 20*, 1–55.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9*, 558–565.

Glenberg, A. M., Meyer, M., & Lindem, K. (1987). Mental models contribute to foregrounding during text comprehension. *Journal of Memory and Language, 26*, 69–83.

Glenberg, A. M., Sato, M., Cattaneo, L., Riggio, L., Palumbo, D., & Buccino, G. (2008). Processing abstract language modulates motor system activity. *The Quarterly Journal of Experimental Psychology, 61*, 905–919.

Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron, 41*, 301–307.

Horn, L. R. (1989). *A natural history of negation*. Chicago: Chicago University Press.

Johnson-Laird, P. N. (1989). Mental models. In M. I. Posner (Ed.), *Foundations of cognitive science* (pp. 469–497). Cambridge, MA: MIT Press.

Kaup, B., Lüdtke, J., & Zwaan, R. A. (2005). Effects of negation, truth value, and delay on picture recognition after reading affirmative and negative sentences. In B. G. Bara, L. Barsalou, & M. Bucciarelli (Eds.), *Proceedings of the 27th annual conference of the cognitive science society* (pp. 1114–1119). Mahwah, NJ: Lawrence Erlbaum.

Kaup, B., Lüdtke, J., & Zwaan, R. A. (2006). Processing negated sentences with contradictory predicates: Is a door that is not open mentally closed? *Journal of Pragmatics, 38*, 1033–1050.

Kelter, S. (2003). Mentale Modelle. In G. Rickheit, T. Herrmann, & W. Deutsch (Eds.), *Psycholinguistik – Ein Internationales Handbuch* (pp. 505–517). Berlin: Walter de Gruyter.

Kratzer, A. (2000). Building statives. In L. Conathan, J. Good, D. Kavitskaya, & A. Wulf, et al. (Eds.), *Proceedings of the 26th annual meeting of the berkeley linguistics society* (pp. 385–399). Cambridge, UK: Cambridge University Press.

Levinson, S. (1983). *Pragmatics*. Cambridge, UK: Cambridge University Press.

Lüdtke, J., & Kaup, B. (2006). Context effects when reading negative and affirmative sentences. In R. Sun (Ed.), *Proceedings of the 28th annual conference of the cognitive science society* (pp. 1735–1740). Mahwah, NJ: Lawrence Erlbaum.

Maienborn, C. (2007). Das Zustandspassiv: Grammatische Einordnung – Bildungsbeschränkungen – Interpretationsspielraum. *Zeitschrift für germanistische Linguistik, 35*, 83–114.

Maienborn, C. (2009). Building event-based ad hoc properties: On the interpretation of adjectival passives. In A. Riester & T. Solstad (Eds.). *Proceedings of Sinn und Bedeutung* (Vol. 13, pp. 35–49). Stuttgart: Universität Stuttgart.

Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology, 57*, 203–220.

Noveck, I. A., & Sperber, D. (2004). *Experimental pragmatics*. Houndmills, UK: Palgrave.

Pollatsek, A., & Well, A. D. (1995). On the use of counterbalanced designs in cognitive research: A suggestion for a better and more powerful analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 785–794.

Rapp, I. (1998). Zustand? Passiv? – Überlegungen zum sogenannten "Zustandspassiv". *Zeitschrift für Sprachwissenschaft, 15*, 231–265.

Richardson, D. C., Spivey, M. J., & Cheung, J. (2001). Motor representations in memory and mental models: The embodied zork. In *Proceedings of the twenty-third annual meeting of the cognitive science society* (pp. 867–872). Mahwah, NJ: Erlbaum.

Schindele, R., Lüdtke, J., & Kaup, B. (2008). Comprehending negation: A study with high functioning adults with autism or aspergers syndrome. *Intercultural Pragmatics, 5*, 421–444.

Stolterfoth, B., & Gese, H. (2008). Events in the processing of adjectival passives. In Talk presented at the 9. Fachtagung der Gesellschaft für Kognitionswissenschaft, Dresden University.

Taylor, L. J., & Zwaan, R. A. (2008). Motor resonance and linguistic focus. *The Quarterly Journal of Experimental Psychology, 61*, 896–904.

Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., et al. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience, 17*, 273–281.

Trabasso, T., Rollins, H., & Shaughnessy, E. (1971). Storage and verification stages in processing concepts. *Cognitive Psychology, 2*, 239–289.

Ulrich, R., & Maienborn, C. (2008). Online sentence processing suggests the use of a mental time line: On the left–right coding of past and future in language.

Urgesi, C., Moro, V., Candidi, M., & Aglioti, S. M. (2006). Mapping implied body actions in the human motor system. *The Journal of Neuroscience, 26*, 7942–7949.

van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic Press.

Wason, P. C. (1965). The contexts of plausible denial. *Journal of Verbal Learning and Verbal Behavior, 4*, 7–11.

Zwaan, R. A. (2004). The immersed experiencer: Toward an embodied theory of language comprehension. In B. H. Ross (Ed.). *The psychology of learning and motivation* (Vol. 44, pp. 35–62). New York: Academic Press.

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135*, 1–11.