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Motor resonance as a function of narrative time: Further tests of the linguistic focus hypothesis

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ABSTRACT

Neuroimaging and behavioral studies have revealed involvement of the brain's motor system in language comprehension. The Linguistic-Focus Hypothesis [Taylor, L. J., & Zwaan, R. A. (2008). Motor resonance and linguistic focus. *Quarterly Journal of Experimental Psychology, 61*, 869–904.] postulates that engagement of the motor system during language comprehension is controlled by the focus of the linguistic message. Two experiments were conducted to further test this hypothesis. They examined whether motor resonance, which has previously been found to occur on descriptions of actions occurring in the present, extends to descriptions of (1) actions potentially occurring in the future (action intentions) and (2) actions having occurred in the past. An additional goal was to examine if motor resonance occurs in a narrative context. Using the reading-by-rotation paradigm [Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135*, 1–11.], Experiment 1 found evidence for motor resonance occurring on current action descriptions embedded in a narrative, but not action intentions. Experiment 2 found evidence for motor resonance on both current and past actions. These results partly support the Linguistic-Focus Hypothesis and lead to further hypotheses about the modulation of motor activation during language comprehension.

1. Introduction

Language can be used to refer to the situation in which speaker and listener find themselves or to situations that are removed in time and/or space. For example, in the first case, the command *Start the car* refers to objects and an action to be performed (by the listener) in the actual situation. In contrast, the same command embedded in a narrative (*Start the car,*" *he said*) does not afford perception of the denoted objects and execution of the denoted actions on the part of the comprehender. The first form of language use has been termed "embedded" language use (Spivey & Richardson, 2008) and the second "displaced" language use (Zwaan & Kaschak, 2008). This article is concerned with displaced comprehension and specifically with the role of the brain's action system in it.

Various neuroimaging and behavioral studies have demonstrated the interaction between the brain's systems of language and action. For example, verbs describing actions activate areas of the motor cortex that are also active when the action is performed. Verbs referring to hand actions activate the hand area of the motor strip, verbs referring to leg actions the more dorsal leg area, and verbs denoting mouth actions the mouth area (Hauk, Johnsrude, & Pulvermüller, 2004; but see Kemmerer, Gonzalez Castillo, Talavage, Patterson, & Wiley, 2008, who found somatotopic activation for hand and leg verbs, but not for mouth verbs). Similar effects have been reported in neuroimaging studies of sentence comprehension (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Tettamanti et al., 2005). Consistent with these findings, behavioral evidence suggests motor involvement in language comprehension. For example, lexical stimuli have been shown to momentarily affect hand aperture in a reaching-to-grasp task (Gentilucci & Gangitano, 1998; Glover, Rosenbaum, Graham, & Dixon, 2004). Similarly, hand-arm actions are influenced by sensibility judgments about entire sentences (e.g., Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006, Experiment 3). More pertinent to the topic of this article, it has been shown that such activation occurs during the comprehension of sentences rather than only during their semantic evaluation (Glenberg et al., 2008; Kaschak & Borregine, 2008; Taylor, Lev-Ari, & Zwaan, 2008; Taylor & Zwaan, 2008; Zwaan & Taylor, 2006; for a review of this literature see Fischer & Zwaan, 2008).

At this stage of the research, it is important to ask how involvement of the motor system is modulated by the linguistic input. Taylor and Zwaan (2008) proposed the Linguistic-Focus Hypothesis (LFH), which postulates that motor involvement is controlled by the focus of the linguistic message. It occurs as soon as the nature

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of the described action can be inferred based on the input and the activated background knowledge and it subsides as soon as the focus of the message shifts from the action to a different aspect of the referential situation. Taylor and Zwaan (2008) recently obtained evidence that is consistent with the LFH. In their experiments, the onset of motor resonance coincided with the locus in the text at which the context was sufficiently constraining for the comprehension system to be able to identify the exact nature of the action performed by the protagonist, while the offset of motor resonance coincided with the point at which the focus of the text shifted from the action in question to a different aspect of the referential situation (e.g., the mental state of the protagonist). For example, in a sentence pair such as *He selected unleaded at the gas station. He placed his hand on the gas cap, which he opened slowly*, the onset of motor resonance occurred on the verb *opened*. At this point, sufficient information had accrued to infer that the action involved counterclockwise manual rotation—the protagonist's hand was on the gas cap after he had performed the necessary preparations to tank gas. Motor resonance was also found on the subsequent adverb, which maintained focus on the action (Taylor & Zwaan, 2008, Appendix A). However, with a virtually identical sentence pair, in which only the sentence-final adverb, an action-modifying adverb, was replaced by an agent-modifying adverb (e.g., it was changed from *slowly* to *carefully*; Taylor & Zwaan, 2008, Appendix B) a different pattern occurred. The onset of motor resonance still occurred on the verb, but the offset occurred immediately after the verb; there was no motor resonance on the adverb. Taylor and Zwaan hypothesized that this is due to the fact that the agent-modifying adverb shifted attention away from the action to the protagonist's state of mind. The current experiments were designed to further test the LFH.

An additional question motivating the present research is to what extent motor involvement in language comprehension generalizes to more naturalistic displaced language comprehension situations. Specifically, can motor resonance effects be obtained during the comprehension of narrative discourse? Narratives are about the goals and plans of protagonists (e.g., Schank & Abelson, 1977). Therefore, goal statements are common and play an important role in narrative comprehension (e.g., Graesser, Singer, & Trabasso, 1994). We asked whether a statement about a simple action goal would produce motor resonance. For example, if the sentence reads *He wanted to start the car* does this activate the program for clockwise manual rotation, just as the sentence describing the action actually being performed, e.g., *He started the car,* has been shown (Zwaan & Taylor, 2006) to do? In light of the LFH, it is plausible to expect that motor resonance will occur for the current action, even when it is embedded in a narrative. But how about an intended action? One view would be that motor resonance is necessary to understand any action, and therefore also action intention. In order to understand what someone wants, it is important to mentally simulate what it is they want. This view predicts that motor resonance occurs irrespective of the scope, in this case that of an intention as expressed by a modal verb, within which the action is embedded.[1] However, it is also possible that motor resonance is tightly controlled by the linguistic focus. Perhaps a sentence describing an intended action does not engage the motor program for that action *per se*. Perhaps it involves activation of motor programs for the preparation of that action. Experiment 1 was designed to adjudicate between these hypotheses.

In language, tense markers are used to situate events on a timeline with regard to the moment of utterance and with regard to each other (Reichenbach, 1947). In narratives, the simple past tense is typically used to describe the narrative *now*, with the present tense functioning as the narrative *now* in genres such as diaries and play-by-play sportscasts (Stanzel, 1984). If the narrative *now* is indicated by the simple past, then actions that occurred in the narrative past are indicated by the past perfective. For example, in the sentence *He opened the door, which he had unlocked*, two actions are described, one of which (opening the door) occurs in the present and one of which (unlocking the door) has occurred in the past. A focus-independent view would predict that motor resonance is indiscriminate with regard to narrative time, given that it is triggered by the core event and that it should therefore occur for statements describing the narrative present as well as for sentences describing the narrative past. In contrast, a strict version of the LFH would predict for motor resonance to occur only when a current action is described, with the past action merely reflecting that which has brought about the current state of the world—for example, all that is needed is to represent the door as being in an unlocked state, but not how it got to be that way. Thus, this view predicts for motor resonance to occur on the current action but not on the past action because this action is not within the current focus. Experiment 2 was designed to adjudicate between these hypotheses.

Both experiments employed the paradigm developed by Zwaan and Taylor (2006). In this paradigm, subjects read text by rotating a knob, with each subsequent five-degree rotation leading to the presentation of a new segment. The experimental sentences describe actions that involve common goal-directed manual rotation actions such as starting a car, opening a bottle, locking a door, and turning up the volume on a radio. Zwaan and Taylor (2006, Experiment 4) found that rotation/reading times were shorter when subjects rotated the knob in the same direction as was implied by the sentence. For example, subjects read *He opened the bottle* more quickly when rotating counterclockwise than when rotating clockwise and vice versa for *He started the car*. In this and subsequent experiments (Taylor & Zwaan, 2008; Taylor, Lev-Ari, & Zwaan, 2008), the stimuli consisted of a set of unrelated sentences or sentence pairs. By embedding such sentences in a story, it is possible to use a much larger number of rotation sentences without drawing attention to the manipulation. This is an added benefit of the procedure used in the current experiments.

2. Experiment 1

The goal of this experiment was to examine whether motor resonance would occur in narrative comprehension during the understanding of simple actions (e.g., *He started the car*) and simple action goals (e.g., *He wanted to start the car*). It is important to note that statements that a character intended to perform an action which he or she then carries out are relatively rare in narratives. It typically suffices to state that the action was performed and it would be odd to do otherwise. For example, it would be strange to read *He wanted to lock the door, so he locked the door.* The intention is normally left unstated because the comprehender will readily infer that the protagonist intended the action in question. In fact, when an intention is stated, it is usually because the intended action was *not* (immediately) performed, for example because it was interrupted by an external event or because the protagonist changed his or her mind. An example is *He wanted to lock the door, but it was pulled open.* Because our aim was to use a naturalistic story, the goal statements in the story used in this experiment were of the latter type.

What can be predicted regarding motor resonance on an intended action? One position would be that motor resonance occurs, because comprehenders first have to simulate what the action is before they simulate that it was intended. In other

[1] Of course, one problem such a view would have to address is how the distinction between the two types of statements is made (see Zwaan, 2008, for a discussion of this issue).

words, they first simulate the action and then the scope within which it occurs. This would be analogous to what happens with sensory simulations and negation. The comprehender first simulates what is not the case. For example, when reading *The door was not open* comprehenders first simulate an open door (Kaup, Yaxley, Madden, Zwaan, & Luedtke, 2007) and then apply the negator. In contrast, the LFH predicts that there should be no simulation of the action during the comprehension of an action intention statement, because the message focuses on the preparation for the action, not on the action itself. This presupposes that comprehenders are able to simulate actions at different stages of completion. For instance, when they read *he was about to start the car* they simulate the first part of the starting the car scenario, which normally involves grasping the car key and inserting it into the ignition, but not manual rotation itself, which constitutes the action itself. Given that reading-by-rotation involves manual rotation, no match advantage should therefore occur on the intended action. Although the connection is somewhat tenuous, there is earlier research showing that motor resonance does not occur on abstract words that are made up of a prefix and an action word. For example, the German word *begreifen* (to comprehend) contains the word *greifen* (to grasp). However, the motor resonance that is found on *greifen* does not extend to *begreifen* (Rüschemeyer, Brass, & Friederici, 2007). However, the relation to the current research is tenuous given that preposing the prefix *be-* to *greifen* accesses a different item in the mental lexicon and thus brings about a concomitant change of meaning, whereas the meaning of *starting* does not appreciably change when preposed with *wanted to*, which is an operation at the grammatical level. Nevertheless, the Rüschemeyer et al. finding does suggest that scope can quickly override motor resonance. More direct evidence for his claim was recently reported by Raposo, Moss, Stamatakis, and Tyler (in press), who, in an fMRI experiment found that action words such as *kick* produced activation in corresponding motor areas of the brain when presented in isolation and to a lesser extent when presented in literal sentences, but not when presented in idiomatic phrases (e.g., *kick the bucket*). Also broadly consistent with the idea that comprehenders do not simulate intended but interrupted actions is that comprehenders have been shown to be sensitive to the stages of initiating, discontinuing, and resuming actions (e.g., Zwaan, Madden, & Whitten, 2000). In short, there are two competing hypotheses regarding motor resonance for intended actions. Experiment 1 was conducted to adjudicate between them.

2.1. Method

2.1.1. Participants

Forty-eight right-handed undergraduate students participated in the experiment, either for course credit or for a payment of €7.

2.1.2. Stimuli

Stimuli were 40 critical sentences, 20 of which described current and 20 intended manual rotation actions. Half of the sentences in each group described clockwise rotations and the other half counterclockwise rotations. The sentences were embedded in a 2,642 word story in about a bank robbery written by the first and third author. The story was in Dutch. In the story, two men and a woman try to rob a bank. They succeed in securing the money, but a fight erupts among them and one robber takes off with all the money. He is later apprehended by the police. The critical sentences—i.e., the sentences describing manual rotation—were distributed as evenly as possible though the story without compromising the "naturalness" of the story. They described actions or action intentions that could plausibly be part of a bank robbery scenario: starting a car, locking a door, changing license plates, opening a bottle, turning up the volume on the police radio, and opening a gas tank.

2.1.3. Procedure

The reading-by-rotation paradigm of Zwaan and Taylor (2006, Experiment 4)was used. Half the participants read the stories incrementally by rotating the knob in a clockwise fashion and the other half by rotating the knob in a counterclockwise fashion, such that the counterclockwise sentences were all matches and the clockwise sentences mismatches for half the participants and vice versa for the other half. Each 5-degrees of rotation resulted in the presentation of a new text segment. Segments varied between 1 and 10 words showing meaningful units, i.e., words and phrases (the longer segments were in noncritical parts of the story). The critical segment, which contained the main verb that denoted the rotation action sometimes along with the direct object, was always presented in the 8th frame. After a maximum of 10 segments, a red 'X' appeared on the screen which prompted participants to release the knob and press the spacebar, after which a spring mechanism returned the knob to its starting position and the next group of segments could be read.

2.1.4. Results

Reading/rotation times <150 and >2000 ms were removed, as were times more than 2 standard deviations from a participant's condition mean. This led to the removal of slightly less than 5% of the data. The reading/rotation times are shown in Fig. 1. For the current actions, in the upper panel, there was a match advantage on the critical region. However, for the intended actions, in the lower panel, there was no effect. Statistical analyses support these conclusions. Mixed analyses of variance (ANOVAs) with knob rotation direction as the between-subjects and match as the within-subjects variable were conducted on the three regions. For the

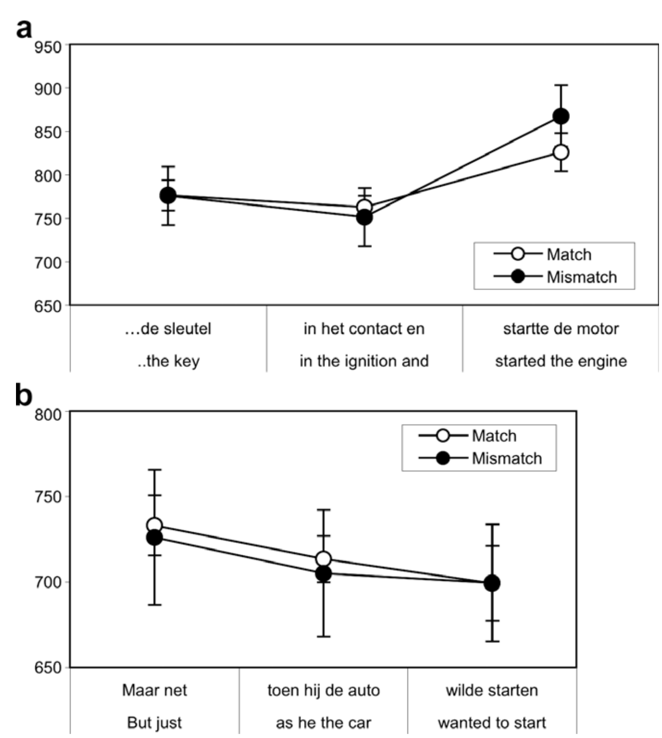

Fig. 1. Average reading-rotation times for (a) the critical region of the current action sentences and the two regions preceding it and (b) the critical region of the intended action sentences and the two regions preceding it. Error bars represent the 95% confidence interval based on the average condition differences with error variance due to rotation direction removed.

current actions, there was a significant match advantage on the verb region [$F1(1,46) = 6.15$, $p < 0.02$, $\eta_p^2 = 0.12$; $F2(1,18) = 3.70$, $p < 0.07$, $\eta_p^2 = 0.16$], whereas there was no effect on the preverbal region [$F1 < 1$, $\eta_p^2 = 0.00$; $F2 < 1$, $\eta_p^2 = 0.00$] nor on the region before it [$F1 < 1$, $\eta_p^2 = 0.00$; $F2 < 1$, $\eta_p^2 = 0.01$]. For the intended actions, there was no effect on any of the regions [all $Fs < 1$, all $\eta_p^2 < 0.02$].

2.2. Discussion

These results suggest that motor resonance occurs during the comprehension of connected discourse, specifically during the comprehension of simple action statements. However, motor resonance occurs when the focus is on the current action, but not when it is on an intended action. This finding is consistent with the LFH (Taylor & Zwaan, 2008) if one makes the assumption that with intended actions the focus is not on the action itself, but on the preparatory phase of it. For example, comprehending a sentence about wanting to lock a door involves in the motor domain simulating grasping a key and inserting it into the lock. It might involve a host of non-motoric processes as well (e.g., a visual representation of a key and a door, the desire to feel safe, and so on), but this is beyond the scope of this article.[2]

3. Experiment 2

The goal of this experiment was to examine whether motor resonance occurs (1) during the comprehension of connected discourse and (2) during the comprehension of sentences that refer to actions that were completed in the past. To test these hypotheses, the first and third author wrote a different version of the bank robbery story in which 20 current rotation sentences (10 match and 10 mismatch) and 20 past rotation sentences (10 match and 10 mismatch) were embedded. These sentences were distributed as evenly as possible throughout the story without compromising the "naturalness" of the story. As with the previous experiment, the manual rotation sentences described actions that could plausibly be part of a bank robbery scenario: starting a car, locking a door, changing license plates, opening a bottle (one bank robber had brought a flask of vodka to steady his nerves), turning up the volume on the police radio.

3.1. Method

3.1.1. Participants

Forty-eight right-handed undergraduate students participated in the experiment, either for course credit or for a payment of €7,-.

3.1.2. Stimuli

Stimuli were 40 sentences, 20 of which described current and 20 past manual rotation actions. Half of the sentences in each group described clockwise rotations and the other half counterclockwise rotations. The sentences were embedded in a 2,579 word story about a bank robbery. This story was a different version of the one used in Experiment 1, but with the same plot and also in Dutch.

3.1.3. Procedure

The reading-by-rotation paradigm of Zwaan and Taylor (2006, Experiment 4) was used. Half the participants read the stories by rotating the knob in a clockwise fashion and the other half by rotating the knob in a counterclockwise fashion, such that the counterclockwise sentences were all matches and the clockwise sentences mismatches for half the participants and vice versa for the other half.

3.1.4. Results

Reading/rotation times <150 and >2000 ms were removed, as were times more than two standard deviations from a participant's condition mean. This led to the removal of slightly less than 5% of the data. The reading/rotation times are shown in Fig. 2, with current actions in the upper panel and past actions in the lower panel. As the figure shows, there is a significant match advantage on the region right before the verb, but not on the verb itself. This is true for both current and past actions. Statistical analyses bear out these conclusions. Mixed ANOVAs with knob rotation direction as the between-subjects and match as the within-subjects variable were conducted on the three regions. The match advantage was significant in the preverbal region [$F1(1,46) = 7.17$, $p < 0.01$, $\eta_p^2 = 0.14$; $F2(1,18) = 5.17$, $p < 0.04$, $\eta_p^2 = 0.22$], but neither in the region preceding it [$F(1,46) = 3.1$, $p > .06$, $\eta_p^2 = .06$; $F2(1,18) = 1.65$, $p > 0.21$, $\eta_p^2 = 0.08$] nor in the verb region itself [$F1 < 1$, $\eta_p^2 = 0.00$; $F2 < 1$, $\eta_p^2 = 0.00$]. For the past actions, the pattern was remarkably similar. The only region for which the match advantage was significant was, again, the preverbal region [$F1(1,46) = 7.71$, $p < 0.01$, $\eta_p^2 = 0.14$; $F2(1,18) = 5.12$, $p < 0.04$, $\eta_p^2 = 0.22$], with the effect being nonsignificant on the region preceding it [$F(1,46) = 1.62$, $p > 0.21$, $\eta_p^2 = 0.03$; $F2 < 1$, $\eta_p^2 = 0.02$] as well as on the verb region itself [$F1(1,46) = 1.41$, $p > 0.23$, $\eta_p^2 = 0.03$; $F2 < 1$, $\eta_p^2 = 0.00$].

That the effect was significant on the pre-verb region but not on the verb region itself, warranted follow-up analyses. In re-examin-

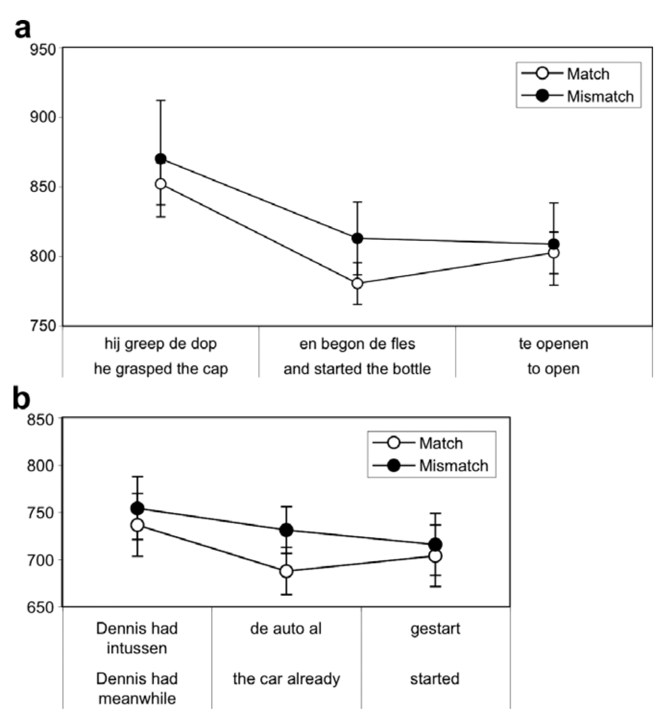

Fig. 2. Average reading-rotation times for (a) the critical region of the current action sentences and the two regions preceding it and (b) the critical region of the past action sentences and the two regions preceding it. Error bars represent the 95% confidence interval based on the average condition differences with error variance due to rotation direction removed.

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[2] One might argue that the fact that the intention statements were not followed by actual execution of the actions might have biased the subjects against activating the motor program for the actions in question (thanks to Art Glenberg for raising this issue). This is a possibility. Interestingly, it would still be consistent with a focus-based explanation if one takes the view that the focus of these statements is not on the execution of the action itself but on its (inconsequential) preparation.

ing the stimuli, we discovered a potential explanation for this finding. We had constructed the sentences such that the critical region was always the 8th region to be shown in a rotation cycle (i.e., it was reached after 35 degrees of rotation). The critical region always was the region in which the nature of the action—clockwise or counterclockwise manual rotation—was completely unambiguous. However, because we used the past perfect in one of the conditions, we necessarily had to include auxiliary verbs (e.g., *had*). In main clauses in Dutch the auxiliary verb always precedes the main verb and is separated from the main verb by a noun phrase. For example as in, *Had de auto gestart/Had the car started* (meaning *Had started the car*), and sometimes also by adverbial phrases (e.g., *Had de auto eindelijk gestart/Had the car finally started*). In subordinate phrases (which in Dutch have a subject–object–verb structure), the auxiliary and main verb are not separated (e.g., *...dat hij de auto had gestart/...that he the car had started*). In the simple past sentences that were embedded in the narrative, an auxiliary verb was sometimes used, as in *...begon de auto te starten/...began the car to start*. Due to these constraints, the auxiliary verb often occurred in a preverbal region rather than in the critical region itself. Because the story context provided sufficient constraints, the nature of the action could often be readily inferred in the preverbal region. If this region also contained an auxiliary verb, this could be a trigger for motor resonance. In order to address this hypothesis, we separated sentences with an auxiliary verb in the precritical region ($N = 23$) from the sentences in which no auxiliary verb was used, or in which it appeared together with the main verb in the critical region ($N = 17$), collapsing across tense. The average reading/rotation times for these two types of sentences are shown in Fig. 3.

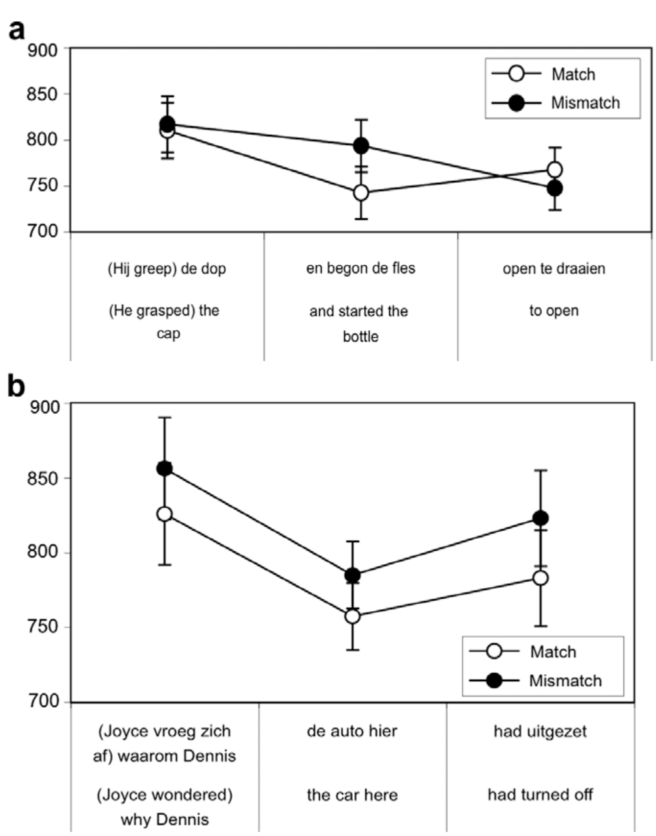

Fig. 3. Average reading-rotation times for the sentences (a) containing an auxiliary verb ($N = 23$) and (b) the sentences without an auxiliary verb ($N = 17$). Error bars represent the 95% confidence interval based on the average condition differences with error variance due to rotation direction removed.

As the figure shows, the patterns were very different for the two types of sentences. Statistical analyses confirm this conclusion. We performed a 3 (sentence type) $\times$ 2 (rotation direction) $\times$ 2 (match) $\times$ 3 (segment) mixed ANOVA with sentence type and rotation direction as between-items factor and match and segment as within-items factor. The key result was a significant three-way interaction involving sentence type, match and segment [$F(2,72) = 6.97$, $p < 0.0025$, $\eta_p^2 = 0.31$], indicating that the size of the match advantage was distributed differently across the two sentence types. For the sentences with auxiliary verbs, there was a significant two-way interaction between match and segment [$F(2,42) = 10.93$, $p < 0.0001$, $\eta_p^2 = 0.48$], which was due to a large match advantage on the region containing the auxiliary verb and the direct object [$F(1,21) = 15.10$, $p < 0.001$, $\eta_p^2 = 0.42$]; the apparent reversal on the critical region was not significant [$p > 0.13$]. For the sentences without auxiliary verbs, there was a marginally significant match advantage [$F(1,18) = 4.81$, $p = 0.051$, $\eta_p^2 = 0.23$], which was due in large part to a marginally significant match advantage on the region containing the main verb [$F(1,15) = 4.21$, $p < 0.06$, $\eta_p^2 = 0.22$].

3.2. Discussion

The results suggest that motor resonance occurs not only on sentences describing current actions, but also on sentences describing past actions. The finding that the effect occurred not on the critical region, but on the pre-critical region was at first sight surprising, but a post-hoc analysis revealed that this was due to the presence of auxiliary verbs in the precritical region in more than half of the sentences, which together with the preceding context and the immediately following direct object provided sufficient constraints for the comprehension system to identify the action in question. For such sentences, there was a highly significant match advantage in the pre-critical region, whereas there was no significant match advantage in this region for the remaining sentences. For those sentences, however, there was the predicted significant match advantage on the critical region.

These results are only partly consistent with the LFH. They are consistent with the LFH in that motor resonance occurred as soon as there were sufficient contextual constraints for the comprehension system to identify the nature of the action and the focus is on the action. In sentences that contained an auxiliary verb and a direct object that preceded the main verb, these conditions were met, even though the main verb had not yet been encountered. In sentences without auxiliary verbs, there was a marginally significant match advantage on the main verb, which is consistent with the original prediction. However, the results are inconsistent with the LFH in that there was no effect in the sentences with an auxiliary verb on the main verb. The LFH states that motor resonance should occur as long as the focus is on the action and it would *prima facie* stand to reason to assume that the main verb focuses attention on the action. One way to resolve this apparent contradiction is by noting that in the case of Taylor and Zwaan (2008), the post-verbal adverb provided additional information about the action, namely about the manner in which it was performed, whereas in the current stimuli, the main verb did not provide additional information about the action if the inference about the nature of the action had already been made in the previous region, which contains the auxiliary verb and the patient of the action. Admittedly, this account is post-hoc and warrants closer examination in future research.

4. General discussion

The current experiments were conducted to address questions regarding the role of the brain's action system in language comprehension. Central to these questions is the LFH (Taylor & Zwaan, 2008), according to which motor resonance occurs as soon as there are sufficient constraints for the comprehension system to access a specific motor simulation and as long as the focus remains on the action. In light of this hypothesis, we asked whether motor involvement only occurs during the comprehension of actions that are in the narrative present (i.e., that are ongoing) or also during the comprehension of actions that are intended to be performed in the near future or that have already been performed in the past. The answers to these questions are mixed. In both experiments, motor involvement was found for actions in the narrative present. This replicates and extends earlier findings with the same method (Taylor & Zwaan, 2008; Taylor et al., 2008; Zwaan & Taylor, 2006). The current research extends these findings because the sentences were embedded in naturalistic narratives rather than included on a list of unrelated sentences.

In Experiment 1, we found no evidence for motor resonance on sentences that described intended actions. A potential explanation for this is that comprehending an intended action does not involve simulating the action itself. It might, however, involve simulation of the preparatory phase of the action. However, direct evidence regarding this question is lacking. Obtaining it would require the creation of a whole new set of stimulus items and probably a different motor task. The commonality among the stimulus items in such an experiment would be that they describe intended actions whose preparatory phase involves a similar motor action.

In Experiment 2, we found evidence that motor resonance occurs also during the comprehension of sentences describing actions that were completed in the narrative past. A complication was that the effect did not materialize on the verb, which was the point at which the nature of the action was completely unambiguous, but on the region preceding the verb. A post-hoc analysis revealed that this pattern was true only for sentences containing an auxiliary verb (plus the noun phrase denoting the patient of the action) in the pre-critical region, such that the nature of the action could be readily inferred even before the verb was reached. Presumably because the verb did not add any information to this interpretation, it was not the locus of significant motor resonance.

It is obvious that the reading-by-rotation paradigm has its limitations. For one, it requires the participants to perform a motor action while reading and thus provides no insight into what would have happened to motor involvement had the motor system not been actively involved. However, as the neuroimaging literature concerning motor resonance and language reviewed in the introduction shows, the motor system is also activated through exposure to action language even during passive comprehension, although the evidence is not conclusive as yet, as Kemmerer and Castillo (submitted) demonstrate. Second, the rotation task is coupled with the reading task. In some ways, this is a strength—it is not difficult to conceive of a cover story for the rotation task, whereas making the rotation task a secondary task would be much more likely to draw unwanted attention to the correspondence between the rotation task and the contents of some of the sentences, which might yield unusual strategy use on the part of the participants. With the current paradigm, participants typically express extreme surprise afterwards when informed about the purpose of the experiment. However, the downside of this paradigm is that reading cannot readily be disentangled from rotation. Thus, is rotation speed modulated by comprehension or reading speed by rotation, or do both occur at the same time? Much of the research discussed in the introduction shows that motor planning is affected by semantic content. However, there is also research showing that relevant motor activation facilitates lexical access (Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005). We are planning to address this directionality-of-causation concern in future research. It should be noted, however, that in any case, the results show the motor system to be involved in language comprehension.

With these caveats in mind, the current results can be interpreted as providing further constraints on theories of motor resonance in language comprehension. The results indicate that motor resonance occurs in naturalistic comprehension, but in a more subtle way than might have been hypothesized. They are largely consistent with the LFH, although some additional assumptions have to be made. They also suggest a number of novel research questions. Apparently, the actual execution of the action, either in the narrative present or in the narrative past, is necessary for motor resonance to occur. The comprehension of intended actions does not seem to involve activating the motor programs that are used during execution of the actual action, but might involve activation of the motor processes involved in preparing the action rather than executing it. What might be the neural correlate for action preparation? Kilner, Vargas, Duval, Blakemore, and Sirigu (2004) used event-related potentials (ERPs) to show that the mere knowledge of an upcoming action is sufficient to excite subjects' motor system. Specifically, the rise of the readiness potential, an electrophysiological marker of motor preparation, occurred before the onset of the observed action.[3] Thus, it is plausible that sentences describing the preparation of predictable actions will elicit a similar increase in the readiness potential.

Meanwhile, along with earlier findings from our lab (Taylor & Zwaan, 2008; Taylor et al., 2008; Zwaan & Taylor, 2006) the current findings do show that the occurrence of motor resonance is not tied exclusively to (main) verbs, but rather to the interpretation of larger units of text (see Bergen, Lindsay, Matlock, & Narayanan, 2007 for a similar conclusion about sensory representations). It is important to consider these conclusions against the background of some neuroimaging studies, which find motor resonance elicited by individual verbs (see Pulvermüller, 2001, 2005 for reviews).

These results from single word studies are not inconsistent with the LFH. After all, when a single word denoting an action is presented, the linguistic focus is by definition on the action. However, the interesting question is what would happen to the neural activation elicited by an action word that is embedded in a sentence that also contains an auxiliary verb and a direct object like some of the sentences in Experiment 2. In such cases, the LFH, bolstered by the results of Experiment 2, would predict no or significantly diminished motor activation on the main verb compared to when the verb is presented in isolation, whereas a word-based activation view would predict context-independent motor activation elicited by the verb. However, given the above-mentioned limitations of the reading-by-rotation paradigm, there is no direct evidence as of yet whether these effects will extend to passive reading. Therefore, designing neuroimaging experiments that allow one to adjudicate between the LFH and word-based views is an important next step in the quest to examine the role of the brain's motor system in language comprehension (see Raposo et al., in press for an example).

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