Christiane Diefenbach: Interactions between Sentence Comprehension and Concurrent Action: The Role of Movement Effects and Timing.
Leipzig: Max Planck Institute for Human Cognitive and Brain Sciences, 2010 (MPI Series in Human Cognitive and Brain Sciences; 124)

Impressum

Max Planck Institute for Human Cognitive and Brain Sciences, 2010

Druck: Sächsisches Druck- und Verlagshaus Direct World, Dresden

ISBN 978-3-941504-08-0

Interactions between sentence comprehension and concurrent action:

The role of movement effects and timing

Von der Fakultät für
Biowissenschaften, Pharmazie und Psychologie
der Universität Leipzig
genehmigte

DISSERTATION

zur Erlangung des akademischen Grades
doctor rerum naturalium
Dr. rer. nat.

vorgelegt
von Dipl.-Psych. Christiane Diefenbach, geb. Hauser
geboren am 21. März 1980 in Halle (Saale)

Dekan:	Prof. Dr. Matthias M. Müller
Gutachter:	Prof. Dr. Wolfgang Prinz
	Prof. Dr. Günther Knoblich

Tag der Verteidigung: 18. November 2010

Danksagung

Bei der Entstehung dieser Arbeit habe ich auf vielfältige Art und Weise Unterstützung erfahren, für die ich mich hier ganz herzlich bedanken möchte.

An erster Stelle richtet sich mein Dank an Cristina Massen und Martina Rieger. Sie haben mir bei all den Schwierigkeiten und Unwägbarkeiten, die sich mir auf der Suche nach dem ACE entgegenstellten, stets zur Seite gestanden. Ihre anhaltende Unterstützung, Diskussionsbereitschaft, Geduld und Aufmunterung haben erheblich zum glücklichen Abschluss dieser Arbeit beigetragen.

Ebenso gilt mein Dank Wolfgang Prinz – nicht nur für die hervorragende Forschungsumgebung, die er in seiner Arbeitsgruppe gewährleistete, sondern vor allem für die enorme Zeit und Energie, die er meinen immer wieder unerwarteten Ergebnissen gewidmet hat, und für wertvolle Vorschläge und Ideen, mit denen er half diese Ergebnisse zu erklären.

Bei Arthur Glenberg bedanke ich mich für seine Ratschläge und den Gedankenaustausch insbesondere in der Anfangsphase meiner Arbeit.

Danken möchte ich auch meinen Kolleginnen und Kollegen aus dem Max-Planck-Institut und aus meinem Graduiertenkolleg für die vielen Diskussionen und Anregungen, aber auch für Erheiterung und Ablenkung bei gemeinsamen Mittagessen und Freizeitaktivitäten. Besonders dankbar bin ich meinen Bürogefährtinnen Sandra Dietrich und Christina Jäger für wertvollen Austausch, Denkanstöße und Diskussionen sowie Miriam Beisert für das Korrekturlesen und viele hilfreiche Hinweise und Ratschläge.

Weiterhin danke ich Henrik Grunert für die Konstruktion der Versuchsapparaturen. Gudrun Henze, Anne Herbik, Katharina Horstkotte, Ramona Kaiser, Silke Meißner und Sascha Weis danke ich für die zuverlässige Unterstützung bei der Datenerhebung.

Zum Schluss möchte ich meiner Familie und meinen Freunden Dank sagen dafür, dass sie mich stets unterstützt und ermutigt und mir viele schöne und erholsame Stunden außerhalb der Arbeit bereitet haben.

Contents

1 Introduction

Imagine that you are meeting a friend and the friend tells you how he spent the day. You hear that he helped someone with moving and carried heavy boxes up the stairs, that his arms and back started to hurt after some time, and that he was rewarded with a tasty pizza in the end. While listening to his report, you vicariously experience all the described events. You “see” the scene in your mind’s eye, you “feel” the tension of your muscles, the exertion under the weight of the boxes, the pain and fatigue of your limbs, and you “smell” and “taste” the hot pizza. We all know such a vicarious experience of a described situation not only from conversations, but also from reading stories where we feel with the characters as if the events occurring in the story happened to ourselves.

This kind of vicarious experience is what the embodied approach to language comprehension (Barsalou, 1999b; Glenberg & Kaschak, 2002; Zwaan, 2004) calls mental simulation of the described situation and what is regarded as essential for capturing the meaning of an utterance. According to the embodied view, words reactivate traces from actual experiences with their referents in the comprehender’s brain, that is, they activate among others perceptual and action representations which then enter into the simulation constructed during language comprehension. So, language comprehension draws on the same neural systems used for perception and action. This use of common codes is reflected in priming effects between the understanding of a verbally described situation and congruent actions and perceptions or in interference effects with incongruent actions and perceptions.

In this dissertation, such an interaction between sentence comprehension and action is investigated more closely. First of all, I will present theories that are related to the embodied cognition approach, namely the common coding approach (Prinz, 1990, 1997), the mirror neuron theory (Rizzolatti & Craighero, 2004), and theories representing the view of situated action, such as the theory of perceptual symbol systems (Barsalou, 1999b) and the indexical hypothesis (Glenberg & Robertson, 1999, 2000). The first two theories argue for shared representations of perceptual and action events, which is in line with the idea of embodied cognition that cognitive processes are grounded in the body’s interactions with the world (Wilson, 2002). The view of situated action is also compatible with this idea as it assumes that the proposed tight coupling between cognition and action exists because cognition has developed to enable humans to act effectively in their environment. In this context, it will be discussed that language probably has developed to guide behavior and therefore, sensory-motor simulations in language processing may serve to prepare the understander for situated action (Glenberg & Kaschak, 2003). These theories differ in whether they suggest the underlying representations to reside on a high level of abstraction (e.g., common coding approach) or on a lower level that for instance involves motor structures (e.g., theories of situated action). This unresolved issue motivated the experiments of this thesis. So, the main research question was whether an interaction between the understanding of action-related sentences and to-be-performed actions occurs on a higher representational level where intended action effects are coded, or whether it occurs on a lower level where motor programs are represented that are used to produce these action effects. From this, conclusions can be drawn on the abstractness of the representations activated during language comprehension. In addition to this question of abstractness, temporal properties of the interaction were investigated. Pilot experiments will be presented in the end of the introduction. In the empirical part of this thesis, two series of three experiments each will be reported which are followed by the discussion of the results in the light of the existing theories.

1.1 Common coding approach

Traditional views of information processing assume that codes representing perceptual and action events are completely distinct because the former refer to sensory codes resulting from patterns of stimulation in the sense organs while the latter refer to motor codes which stand for patterns of muscle activity. Yet according to the common coding approach (Prinz, 1990, 1997), there is a more abstract, high-level representational domain on top of the separate coding in which perceptual and action information is coded in the same format.

This notion is based on the ideomotor principle (James, 1890) which states that the mental image of the perceptual consequences of an action has the power to evoke the execution of this action. Perceivable action consequences or action effects are regarded as being sensations of carrying out the movement itself (resident effects, e.g., the kinesthetic sensation of flexing a finger) or changes in the agent’s environment (remote effects, e.g., illumination after switching on a light). For actions to be triggered by imagined action effects, associations between them are required. James (1890) proposed that such associations are formed by learning which consequences are caused by a certain movement. These associations allow to anticipate action outcomes of given movements and, in the reverse direction, to select appropriate movements for achieving intended effects. Greenwald (1970) extended the ideomotor principle by arguing that when the imagination of an action or its remote consequences is sufficient to evoke that action, the same should hold for perceiving an action or its outcomes.

The assumptions of the ideomotor principle were examined by Elsner and Hommel (2001). Their participants first underwent an acquisition phase in which they repeatedly chose between executing a left and a right key press, each of which was associated with an irrelevant tone of a certain pitch (the action effect). In the subsequent test phase, the tones that previously had followed the actions were now presented as stimuli and required key press responses either in the same assignment as in the acquisition phase or in the reverse assignment. Responses were faster for congruent assignments compared to incongruent ones confirming that action-effect associations are bidirectional and that learned action effects hence gain the power to activate the associated actions. Similar results were obtained by Rieger (2004) who demonstrated that in typewriting experts the perception of letters, which can be considered remote action effects of typing, automatically activates key presses corresponding to the learned ten-finger typing system (for further evidence for the ideomotor principle see, e.g., Koch & Kunde, 2002; Kunde, 2001).

Concerning the basis for how perceiving actions or action effects can activate corresponding actions in the observer, the common coding approach assumes that actions are represented in terms of their perceivable effects (Prinz, 1990). Thus, they are represented in the same format, using the same codes, as every other perceivable event. These common codes of perception and action refer only to “late” afferent representations and “early” efferent representations (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, Aschersleben, & Koch, 2009): Activating the representations of perceptual events in the environment is related to end products of perceptual processing, and activating the representations of action effects is assumed to be the initial step in action planning and prerequisite for selecting the appropriate motor codes. In contrast, “early” sensory processes and “late” motor processes are still incommensurate.

The coding of perception and action in a common representational format implies that their representations overlap on some dimensions when perceived events and planned actions share some features (Prinz, 1990, 1997). By virtue of their similarity, perception and action may interact with each other, e.g., activated stimulus features can prime actions with similar features, as shown in stimulus-response compatibility paradigms. In these tasks, a set of responses is mapped onto a set of stimuli either with a compatible assignment in which stimuli and responses possess a common feature (e.g., responding to a stimulus on the left-hand side with a left key press) or with an incompatible assignment in which stimuli and responses differ in their features (e.g., responding to a stimulus on the left-hand side with a right key press) (Fitts & Seeger, 1953). It is a frequent finding that responses are faster for compatible assignments relative to incompatible ones. This even applies to tasks in which the shared feature is irrelevant for response selection as it is the case in the Simon task. Here stimuli and responses again exhibit corresponding or non-corresponding features for example on the spatial dimension (left vs. right), but the task requires responding to the pitch (high vs. low) of the presented tones (Simon & Small, 1969). In terms of common coding, such compatibility effects arise because, for compatible assignments, stimulus codes prespecify response codes, i.e., corresponding response codes are automatically activated which facilitates performance, whereas for incompatible assignments, stimulus codes prime the wrong response codes which results in impaired performance (Prinz et al., 2009).

In this kind of stimulus-response compatibility paradigm, the perceivable action effect resides in the action itself. A more direct support for the claims that actions are selected by activating representations of the intended action effects and that perception and action share a common representational domain on a higher cognitive level would be provided by separating action effects from actions and obtaining stimulus-effect compatibility effects (Prinz et al., 2009). Since it is assumed that an action can be represented in terms of either more resident or more remote effects, depending on the intended action goal, compatibility should be effective between stimulus features and the intended action effect. This exactly was the rationale behind Hommel's (1993) study in which he used the Simon task described above, but introduced additional visual action effects. High- and low-pitched tones were presented via a loudspeaker on the left- or right-hand side and participants had to respond to the pitch by pressing a left or a right key. Each of the two response keys was connected to a light on the left- or right-hand side lighting up when the key was pressed. For one group of participants, keys and lights were connected in parallel and the action goal was defined in terms of pressing keys in response to the pitch while ignoring the lights. A second group was also instructed to pursue the goal of pressing keys, but with the reverse mapping of lights to keys, i.e., a right-hand key press turned on the light on the left-hand side and vice versa (see Figure 1.1 for an illustration of the reverse mapping). A third group received the reverse key-light mapping like the second group, but was instructed to define the action goal as illuminating the lights in response to the tones, i.e., actions should be represented in terms of their remote effects. While the first two groups showed a regular Simon effect with faster responses when the stimulus and key press shared the same location than when they appeared in different locations, the Simon effect was reversed in the third group. In this group, responses were facilitated by corresponding locations of stimulus and remote effect, despite the fact that the response itself was always located on the opposite side. The existence of stimulus-effect compatibility effects supports the assumptions of the common coding approach.

Shared high-level representations of perception and action were also demonstrated by Massen and Prinz (2007). In this study, participants observed and executed complex tool-use actions in turns. Priming effects from the perceived to the executed action were compared for different components of tool-use actions, namely for the movement, the goal or target of the movement, and the target-to-movement mapping. Results revealed that action execution was facilitated when its target-to-movement mapping matched the mapping of the previously observed action compared to conditions with congruent movements or action goals. Thus, observing complex actions activated abstract action representations – no specific movement parameters were activated and even the action target played a subordinate role.

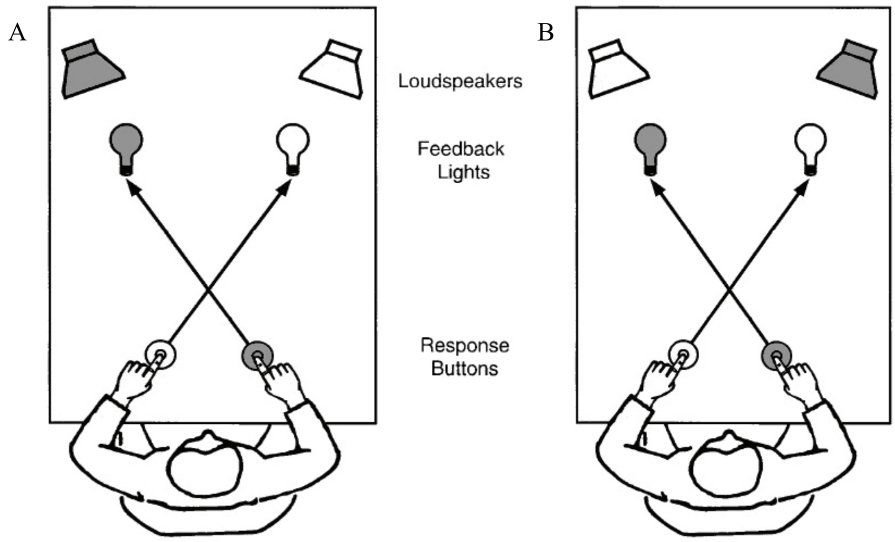

Figure 1.1. Paradigm of Hommel (1993). The reverse key-light mapping is illustrated by the example of a stimulus-effect compatible trial (A) and of a stimulus-effect incompatible trial (B). Adapted from Prinz (1997).

Common coding is also in line with the claim that linguistic meaning engages perceptual and action representations. Perception- and action-related language contents might be represented by the same common codes as perceptual contents and action plans because actions are not only activated by imagining or perceiving actions or action effects, but also by language: Verbalizations of actions as in verbal instructions or in inner speech support task selection (e.g., Emerson & Miyake, 2003; Kray, Eber, & Karbach, 2008), action selection, and action control (e.g., Tubau, Hommel, & López-Moliner, 2007). Therefore, also on-line interactions between language and action should occur on the higher-order level of representation on which action effects are coded.

On the neurophysiological level, evidence for the idea of shared representational resources for perception and action is provided by "mirror neurons", which will be discussed in the next section. Mirror neurons are not only interesting as potential neural substrate of the common codes, but also because they are assumed to underlie simulations in language comprehension (Rizzolatti & Arbib, 1998).

1.2 Mirror neuron theory

1.2.1 General properties and possible functions of the mirror neuron system

Mirror neurons were discovered in the ventral premotor cortex and inferior parietal cortex of macaque monkeys and received this name because they seem to show that observed actions are mirrored in the motor representations of the perceiver (Buccino, Binkofski, & Riggio, 2004) (Rizzolatti & Craighero, 2004): These neurons discharge both when the monkey performs a specific action and when it observes a similar action performed by another individual. Mirror neurons code goal-directed actions, i.e., they only become active during performed or observed interactions between a biological effector and an object, but do not respond to observations of mimicked actions, intransitive gestures (movements that are not directed to an object), or the object alone. For some of the mirror neurons, the congruence between the observed and executed actions is very strict, i.e., they code both the action goal and the means of achieving it, but most of the neurons are broadly congruent and code only the goal of the action – they respond to observed actions as long as they share the same goal with the effective executed action, regardless of the involved movements (Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi, & Gallese, 2001). Especially these broadly congruent mirror neurons seem to correspond with the idea of common codes representing actions in terms of their goals or meanings on a higher, more abstract level. Such considerations led to the assumption that mirror neurons play a functional role in action understanding.

Accordingly, the direct-matching hypothesis (Buccino et al., 2004; Rizzolatti et al., 2001) posits that action understanding is based on motor resonance: While observing another person's action, its visual representation activates directly and automatically the same neural structures (the mirror neurons) which would be involved in the own performance of the observed action, i.e., it activates the own motor representation of this action. Since the observer knows the result of activating these neural structures during action execution, she or he is able to understand the perceived action. This hypothesis has been tested by measuring the activity of mirror neurons in conditions in which the monkey does not perceive the visual features of an occurring action that usually activate mirror neurons, but can infer the goal of the action and hence understand its meaning. In a study by Umiltà et al. (2001), object-directed actions were presented which were either completely visible to the monkey or whose final part of the hand-object interaction was hidden. When the monkey knew about the presence of the object although it was hidden, the majority of mirror neurons discharged as in the full vision condition. In contrast, when the object was not shown to the monkey before presenting the partly hidden action, mirror neurons failed to respond (as for fully visible mimicked actions without an object) although the observed actions were identical from a physical point of view. This result seems to support the claim that the activity of mirror neurons is related to action understanding. Furthermore, mirror neurons have been found to respond to actions even in complete absence of visual stimuli when the action can be understood on another basis. As demonstrated by Kohler et al. (2002), there is a type of mirror neurons which not only responds to performing and observing a specific action, but also to the mere perception of the action-related sound. Apparently, these audio-visual mirror neurons code actions independently of whether they are executed, heard or seen, i.e., they code the abstract meaning of actions. Again, this provides support for the common coding approach and suggests that this type of mirror neurons could be used for planning actions by evoking the action goal.

However, instead of interpreting goal representation in mirror neuron activity as support for the assumption that it serves to recognize and understand observed actions, an alternative explanation might be that mirror neurons come into play after the meaning of the observed action has been understood, forming high-level, abstract action concepts (Csibra, 2004). Moreover, the mechanism of how the visual information of the observed action can be directly and automatically mapped onto the motor system of the observer remains unclear; in fact, selecting the appropriate motor representation for an observed action requires the physical and semantic features of the action to be already identified (Csibra, 2004; Prinz, 2006).

A prerequisite for relating the mirror neuron system to the common coding principle and for arguing for its role in language comprehension is that such a system exists in humans as well. Evidence for a mirror neuron system in humans is provided by neurophysiological and brain imaging studies demonstrating mirror properties in brain regions which are supposed to be the homologues of the monkey mirror regions, namely the rostral part of the inferior parietal lobule, the lower part of the precentral gyrus, and the posterior part of the inferior frontal gyrus – the latter being part of Broca’s area (BA 44) (Gentilucci & Dalla Volta, 2008; Rizzolatti & Craighero, 2004). Similar to the strictly congruent and broadly congruent mirror neurons found in monkeys, certain parts of the putative human mirror neuron system seem to code the action kinematics while other parts rather represent the action goal (Hamilton & Grafton, 2006). Regarding kinematics, mirror regions responding to perceived and executed actions with hand, mouth, and foot appear to be somatotopically organized (Buccino et al., 2001; Gazzola, Aziz-Zadeh, & Keysers, 2006). Goal matching and effector matching in humans were also demonstrated in a functional magnetic resonance imaging (fMRI) study by Gazzola et al. (2007). In this study, effector-unspecific mirror areas were activated during the observation of actions the observer was not able to perform in the same way because the body parts used by the observed agent were lacking. Additionally, activation was found in mirror regions specific for the effector the observer would use for achieving the perceived action goal. So, action observation recruited effector-specific motor programs which either matched those of the observed agent if possible or referred to different effectors the observer would use instead.

Research on the putative mirror neuron system in humans has also revealed properties that differ from those found in monkeys, e.g., motor resonance is observed not only for object-directed actions, but for intransitive movements as well (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). Furthermore, the match between the observed action and the activated motor representation is not only related to the goal and the involved effector, but can include even more detailed movement features such as temporal characteristics of the movement (Gangitano, Mottaghy, & Pascual-Leone, 2001).

These changes in the human mirror neuron system towards responding to intransitive gestures are assumed to be related to the development of imitation and may have opened the way for gestural communication and finally for the evolution of language (Arbib, 2008; Rizzolatti & Buccino, 2005). It seems to suggest itself that motor resonance in action observation and motor resonance in the comprehension of verbal descriptions of actions are both based on the mirror neuron system. Since there is evidence for mirror areas representing the generalized goal of actions and for mirror areas representing more specific features of the involved movements, action representations activated during language processing may reside on a more abstract level as well as on a lower motor level. Empirical research has focused primarily on the latter case and will be presented in the following section after the mirror system hypothesis for the basis of language has been explained.

1.2.2 Mirror neuron system as possible basis of language comprehension

Starting point of the mirror system hypothesis of language comprehension (Arbib, 2008; Rizzolatti & Arbib, 1998) is the requirement for mutual understanding in a conversation, i.e., for the activation of similar representations in the sender and the receiver of a message, in order to achieve successful communication. This link between sender and receiver is assumed to be based on the same mechanism that links actor and observer – the mirror neuron system, and especially Broca's area which is regarded as being part of the putative human mirror neuron system. Since Broca's area is involved in perception and production of speech as well as in movements of hand and mouth, it is speculated that human language evolved from hand gestures (Iacoboni, 2005; Rizzolatti & Arbib, 1998).

According to the mirror system hypothesis, the initially object-related mirror neuron system later became capable of responding also to intransitive actions and pantomimes because the development of imitation for the purpose of transferring novel skills required not only the action goal to be represented, but also the precise movements leading to this goal (Arbib, 2008; Rizzolatti & Buccino, 2005). Once incorporated into the mirror neuron system, gestures and pantomimes may have been increasingly used for communication between individuals. These actions probably were accompanied by vocalizations because both individuals share the same communication system (Broca's area), and articulation organs may have unconsciously followed the gestural movements (Gentilucci & Dalla Volta, 2008; Rizzolatti & Buccino, 2005). Support for this notion comes for instance from experiments by Gentilucci (2003; Gentilucci, Benuzzi, Gangitano, & Grimaldi, 2001) which show that the execution and observation of grasping objects of different sizes influence the simultaneous pronunciation of syllables: Grasping larger objects increased lip aperture and maximal voice power relative to grasping smaller objects.

Vocalizations could have been understood by means of audio-visual mirror neurons which were discovered in the putative precursor region of Broca's area in monkeys and allowed auditory access to action representation; thus, hearing the vocal sounds would have activated the associated gestures (Rizzolatti & Buccino, 2005). In the course of time, vocalizations probably acquired autonomy and were generated without performing gestures. At this point, echo mirror neurons should have evolved which code perceived and produced vocal sounds (Rizzolatti & Buccino, 2005; Rizzolatti & Craighero, 2004). The existence of such a resonance mechanism in humans is confirmed by the finding that during listening to words whose production requires tongue movements, motor centers controlling tongue muscles were stronger activated than during listening to words not involving tongue movements (Fadiga, Craighero, Buccino, & Rizzolatti, 2002). Since echo mirror neurons should still be connected with the representation of the corresponding manual gesture, the meaning of the heard verbal material can be recognized by activating the associated action representation (Rizzolatti & Buccino, 2005). Finally, the vocalizations could have expanded to words and sentences and language evolved.

Evidence for the hypothesis that language processing is based on the mirror neuron system is provided by neurophysiological and brain imaging studies showing that motor representations are activated during comprehension of action-related words and sentences. As one of these, Tettamanti et al. (2005) found in an fMRI study that the comprehension of sentences describing actions performed with mouth, hand, or leg engaged motor circuits which largely overlapped with those activated during execution and observation of the described actions, i.e., they observed somatotopic activations in Broca's area and in the premotor cortex. Buccino et al. (2005) conducted a similar study using transcranial magnetic stimulation (TMS). While subjects listened to sentences expressing hand or foot actions, either their hand or their foot/leg motor area was stimulated and motor evoked potentials (MEPs) were recorded from hand and foot muscles. In line with the fMRI results, changes in motor excitability were specific for the effector involved in the described action. Pulvermüller, Hauk, Nikulin, and Ilmoniemi (2005) demonstrated in another TMS study that activation in motor and premotor areas is not only epiphenomenal, but really contributes to word processing. When the arm motor area was stimulated, words referring to arm actions were recognized faster than words referring to leg actions, and the opposite pattern appeared for stimulation of the leg motor area.

A stronger indication of a functional role of motor areas in language processing would be the finding of impaired language processing due to lesioned motor regions or movement disorders. There are indeed some studies pointing in this direction. Bak and Hodges (2004) for instance reported a selective deficit in verb production and understanding for patients with motor neuron disease whose motor system is affected by neurodegeneration. This deficit was not limited to the lexical level, but included abstract representations of actions. The processing of action verbs was also shown to be impaired in patients with Parkinson’s disease in which regions supporting motor preparation are underactivated (Boulenger, Mechtouff et al., 2008).

In all of these studies, only the meaning of words referring to actions (which are in most cases action verbs) appears to be represented in motor regions, whereas words which are not related to actions (e.g., nouns referring to non-manipulable objects) seem to engage partly different brain regions. Furthermore, many authors doubt that the meaning of abstract words can be derived from motor representations (e.g., Toni, de Lange, Noordzij, & Hagoort, 2008; Mahon & Caramazza, 2008), and some results seem to support these doubts. For instance, Rüschemeyer, Brass, and Friederici (2007) found motor circuits to be activated only by comprehension of verbs denoting motor actions (e.g., “greifen” - to grasp) in contrast to verbs denoting abstract actions (e.g., “denken” - to think) or even abstract verbs built on stems with motor meanings (e.g., “begreifen” - to comprehend). Despite extensive evidence especially for the involvement of low-level motor representations in language comprehension, it remains unclear how the mirror system hypothesis could account for the finding that language without a clear reference to action is understood through different processes. This qualifies the claim of the very special and fundamental importance of motor areas for language processing.

1.2.3 Mirror neurons, Hebbian associations, and distributed semantic representations

Perhaps the presented findings are more compatible with the view of distributed semantic representations in the brain (Jeannerod, 2008; Martin, Ungerleider, & Haxby, 2000; Pulvermüller, 2005). In this view, word meanings draw on many different cortical areas. They are represented in distributed networks binding together word forms and aspects of their referential semantics (Pulvermüller, 2008). Since different lobes and distant cortical areas are connected anatomically via long-distance links, widely distributed sets of neurons can develop strong associations when they fire together frequently, based on the Hebbian learning rule ("neurons that fire together wire together"; Hebb, 1949). During language acquisition, infants frequently hear the caretaker use a word while they are perceiving a certain visual object or event or while they are performing a certain action. This may strengthen the synaptic connections between the simultaneously activated neurons in the classical language areas of Broca and Wernicke processing the linguistic properties of the word and neurons in visual areas and in motor and premotor areas processing the visual and action event, respectively. After having learned such associations, the processing of action-related words (e.g., action verbs, tool names) would automatically activate areas involved in action control and execution, and the processing of object-related words would activate areas mediating perception of object features (e.g., shape, color) (Pulvermüller, 2005, 2008). The findings reported in favor of the mirror system hypothesis fit well with this prediction about action-related words.

Further support for the assumption that semantic representations are stored in sensory and motor systems comes from research on conceptual knowledge. Although concepts are non-linguistic mental representations of objects, events, actions etc., experiments on concepts may provide insights into the representation of word meanings because for understanding words conceptual information has to be activated (Vigliocco & Vinson, 2007). In a study of that kind, Martin, Wiggs, Ungerleider, and Haxby (1996) contrasted concepts semantically linked to visual information with concepts semantically linked to actions. They asked participants to silently name drawings of animals and tools and found the identification of animals to be associated with activation of medial occipital cortex which is involved in visual processing, whereas naming of tools resulted in activation in the left premotor cortex and middle temporal gyrus which are active during object use and motion perception. Similarly, in a property verification task in which participants determined whether a given property was true of a named object, the retrieval of tactile, gustatory, auditory, and visual knowledge activated regions engaged in processing sensory experiences in each of these modalities (Goldberg, Perfetti, & Schneider, 2006).

Despite apparent differences, the notion of distributed semantic representations does not necessarily conflict with the mirror system hypothesis because both may be based on Hebbian associations. According to Keysers and Perrett (2004), mirror neurons could acquire their mirror properties by Hebbian learning in the following way: When human and monkey infants observe their own actions, brain regions responding to visually perceived actions and regions engaged in action control and execution become activated at the same time. The Hebbian associations which are formed that way become stronger over time until the observation of another individual performing an action will automatically activate neurons involved in the own performance of this action. At this point, mirror properties will have emerged. Audio-visual mirror neurons could have developed in the same way by observing own actions and hearing their sound which leads to associations between the simultaneously activated auditory, visual, and motor representations of these actions. Subsequently, own motor representations become activated when hearing the sound of others' actions. This mechanism could furthermore explain that perceiving someone else being touched activates own somatosensory areas supporting the sensation of touch (Keysers et al., 2004), or that observing another person's emotions activates regions active in the own experience of similar emotions (Jabbi, Swart, & Keysers, 2007). In this way, the concept of mirror neurons can be extended beyond the domain of action (Keysers & Fadiga, 2008).

Thus, the view of distributed semantic representations can account for the contribution of mirror neuron activity to action-related language processing without speculating about the role of the mirror neuron system in the evolution of language. Word meanings are represented by reactivating stored experiences with the referents of the words, that is, by reactivating the states of the neural systems during action or during perception of their referential entities. This also explains how language carries meaning that is not directly related to action. Because the processing of such experiences involves not only primary sensory-motor areas, but also secondary association areas which means forming representations with increasing abstraction, language comprehension might call upon low-level as well as upon higher-level semantic representations.

There is another line of research that shares the notion of distributed semantic representations, but proposes that this kind of representation has the function of preparing the language comprehender for situated action. These theories of situated action will be described in the following section.

1.3 Theories of situated action

1.3.1 Object concepts and affordances

From the perspective of situated action, cognitive mechanisms have been shaped to support situation-appropriate, effective actions for adapting to rapidly changing environmental conditions, thereby enhancing survival and reproductive success (Glenberg & Robertson, 2000; Prinz, Roth, & Maasen, 1996). Probably, the perceptual system evolved to extract action information from visual input that could be relevant for the current situation. In doing so, for example, the agent's body morphology has to be taken into account because actions that prove to be effective in a certain situation differ for agents with different bodily constraints such as members of different species or humans in different stages of development (Borghi, 2005; Glenberg, 2008; Glenberg, Jaworski, Rischal, & Levin, 2007).

The close coupling of perception and action resulting from this has provided the basis for the common coding approach described above as well as for Gibson's (1979) notion of affordances which has been adopted in a modified version to account for motor activation during object perception and during language processing. According to this notion, the visual scene provides information which is used by the motor system to compute actions that are possible for the observer in the present situation. In this sense, stimulus-response compatibility effects, which were used to demonstrate common coding, can be interpreted as reflecting the automatic activation of response codes by perceived stimulus attributes that are relevant to potential actions, i.e., they can be interpreted as reflecting the activation of affordances (Tucker & Ellis, 1998).

In the original use of the term by Gibson (1979), affordances are information about potential uses of an object which are directly registered based on the perceived physical characteristics of the object. This may be possible for actions like grasping and picking up an object and may play a role for interactions with novel objects for which no previously acquired action information is accessible (Borghi, 2005). However, for using an object according to its specific function, most likely, semantic knowledge about the object has to be retrieved from memory (Creem & Proffitt, 2001). Thus, as research on affordances indicates, they are better regarded as activated motor representations of actions which are associated with a perceived object based on the observer's physical capabilities, his current state, and his history of past interactions with this object (Tucker & Ellis, 1998, 2004). The automatic activation of affordances was nicely shown in experiments conducted by Tucker and Ellis (1998). Participants had to make judgments about pictured household objects which (as a task-irrelevant dimension) afforded grasping with the left or right hand. Consistent with the idea that perception of an object results in the activation of possible manual interactions with it, responses were facilitated when they required button presses with the same hand that would be used for the afforded action compared to button presses with the opposite hand. Concerning the role of the history of past interactions, Ross, Wang, Kramer, Simons, and Crowell (2007) were able to demonstrate that actions that were arbitrarily associated with new objects during learning were incorporated into the object representations. When the object was perceived again later, these acquired affordances became automatically activated.

Within the view of situated action, such activations of affordances are also applied to linguistic stimuli: If motor representations are part of the conceptual representation of an object, processing words denoting objects would activate the associated object concept and hence result in the activation of potential motor interactions. In other words, motor activation during language comprehension might reflect the activation of affordances that belong to the meaning of the words. Empirical support for actions as part of object concepts was provided for instance by Tucker and Ellis (2004) who revealed that on-line visual input about an object is not necessary to derive affordances – activation of object representations seems to be sufficient. Even when only object-related words were presented, afforded responses were faster than non-afforded responses. Similarly, Richardson, Spivey, and Cheung (2001) found motor responses to be affected by their compatibility with actions afforded by objects when object representations were recalled from memory or generated from linguistic descriptions. There are numerous reports of affordance effects produced by language processing (Borghi, Glenberg, & Kaschak, 2004; Glover, Rosenbaum, Graham, & Dixon, 2004). A correspondingly important role for sentence understanding is ascribed to affordances by the indexical hypothesis which will be presented in section 1.3.3.

The perspective of situated action is akin to the earlier mentioned view of distributed semantic representations with regard to the nature of concepts and the involvement of motor representations. However, the assumptions that not only the modal representation of a concept's referential entity is activated, but also its associated actions, and that this activation of motor representations is a kind of preparation to act are special about the perspective of situated action. In the following, the last-named aspect will be explained in more detail, with the focus lying on the domain of language.

1.3.2 Language as preparation for situated action

There is a broad consensus among evolutionary theorists that humans increased their fitness, i.e., their probability of survival, by coordinating their actions and that social coordination, in turn, was promoted by evolving linguistic abilities (Barsalou, 1999a). If language serves the function of coordinating situated action, it is central to index the meaning of words, that is, to associate words with perceived referents in the physical environment. Thus, language is conceived of as cues which are used by speakers or writers to direct the listener's or reader's attention to components of the immediate or displaced situation (Tomasello, 2003; Zwaan & Madden, 2005).

Experiments confirming that language comprehenders try to establish reference to the non-linguistic context with respect to their behavioral goals mainly focus on how physical objects are indexed by verbal instructions to perform a task. In the study by Tanenhaus, Spivey-Knowlton, Eberhard, and Sedivy (1995), recordings of eye movements during the comprehension of instructions revealed that information provided by the visual context was used for interpreting sentences with temporarily ambiguous syntax. Depending on whether the visual context contained two possible reference objects or only one, adverbial phrases of location were interpreted either as specification of the object that had to be picked up or as target location where the object had to be put. The importance of indexing for language comprehension and resulting actions was further demonstrated by Glenberg and Robertson (1999). Participants who got the opportunity to index words to objects and this way learned perceptual information while acquiring knowledge were able to read and understand subsequent instructions more quickly and to better apply the acquired knowledge to an associated task compared to participants without opportunity of indexing.

According to Barsalou (1999a), the underlying mechanism of words indexing objects and events in the world is perceptual simulation, which is part of his framework of perceptual symbol systems (Barsalou, 1999b). In this framework, conceptual representations are again regarded as patterns of activation distributed across sensory-motor systems. It is claimed that perceived experiences are represented by modality-specific states – by the patterns of neural activation which arise during perception of external (sensory) or internal (proprioceptive and introspective) events and which lay down traces of these experiences in the brain. Reactivating the original states at a later point in time creates a perceptual simulation of the experienced events. When, for example, retrieving a visual property of an object, the visual system becomes active in much the same way as during its perception, and when retrieving an action, the motor system partially reenacts the motor state that produced it (Barsalou, 2003). The patterns of activation in the distributed modality-specific areas are assumed to be stored via Hebbian associations between active neurons or via association areas adjacent to the neural systems involved (Barsalou, 1999b). In the same way, words can be viewed as represented by perceptual traces of hearing or seeing linguistic information. Links between these linguistic representations and concept representations can be established depending on their co-occurrence, and as a result, words become able to activate perceptual simulations of possible referents.

These simulations in turn could form the basis of indexing objects and events as follows. While talking about a present situation, the linguistic descriptions evoke associated simulations in the listener. Since perceptual simulations are represented in the same neural systems and hence in the same format as perception and action, the simulation of a previously experienced referent can be readily compared to the current perceptions, and as a result, the described referent can be determined (Barsalou, 1999a). Perceptual simulations also support indexing of absent situations – by reactivating earlier perceptual experiences, humans are, for instance, able to jointly construct simulations of planned actions and interactions and to coordinate and adjust their plans according to common goals (Barsalou, 1999a). In order to serve situated action, the representation of a word or concept has to be tailored to the present situation, and this is what characterizes perceptual simulations – they are specific conceptualizations which represent the meaning of a word or concept in a context-dependent manner (Barsalou, 2003). Depending on the current conditions and goals, the most accessible subset (i.e., a particular conceptualization) of the extensive amount of stored information which a concept includes is assumed to become activated. And because perceptual simulations share representations with perception and action, the neural systems involved in a simulation are prepared for perceptions and actions that are likely to occur in the current situation (Barsalou, 2003). In sum, since simulations are conceived of as multimodal reenactments of stored experiences, this framework argues for low-level representations underlying language comprehension.

There is considerable evidence for sensory-motor simulations and their situatedness in language processing. A large part of it comes from behavioral studies using basically the following procedure: While or shortly after processing words or sentences, participants are asked to perform a perceptual or motor task which matches the meaning of the linguistic description or not. If the matching has an effect on performance in the perceptual or motor task, this would suggest common cognitive mechanisms underlying these processes. Zwaan, Stanfield, and Yaxley (2002) demonstrated that perceptual simulations are situation-specific or adjusted to the sentential context by presenting subjects with sentences which described objects in varying contexts (e.g., eagle in the sky vs. eagle in its nest) and therefore implied different object shapes (e.g., outstretched wings vs. folded wings). Pictured objects presented after each sentence were identified more quickly when their visual shape matched the shape implied by the sentence. A similar match effect was obtained by Zwaan, Madden, Yaxley, and Aveyard (2004) who used sentences describing the movement of an object toward or away from the observer. The subsequent judgment of whether two successively presented pictures displayed the same object or not was facilitated in cases where the pictures implied a movement direction that corresponded with the direction expressed in the sentence. In line with the assumption that perceptual simulations make neural systems ready for corresponding perceptions, Meteyard, Bahrami, and Vigliocco (2007) found that verbs referring to upward or downward movements influence related sensory perceptions. Participants were more sensitive to detect a coherent movement of a subset of dots in a random-dot kinematogram when its direction was congruent with the movement direction associated with a concurrently presented verb.

All the studies reviewed so far provided examples of simulations involving the visual system, but there is also evidence for motor simulations of linguistic meaning, such as the action-sentence compatibility effect (ACE) reported by Glenberg and Kaschak (2002). In their study, participants judged whether sentences describing actions toward or away from the body, such as "Courtney handed you the notebook" or "You handed Courtney the notebook", were sensible or not. When the judgment required to move the hand to a button in a direction that was compatible with the movement direction expressed by the sentence, response times were faster than when movement directions were incompatible (see Figure 1.2). Zwaan and Taylor (2006) showed a similar compatibility effect for verbally described directions of manual rotation (e.g., opening a water bottle) and rotation directions that were produced as a response by turning a knob. Although the ACE and related phenomena are regarded as speaking for low-level modal representations, it cannot be excluded that they may be based on higher-order representations of actions because they do not differentiate between the representations of movement and movement effect. Therefore, the ACE will play an important role in the experiments of this thesis investigating this question.

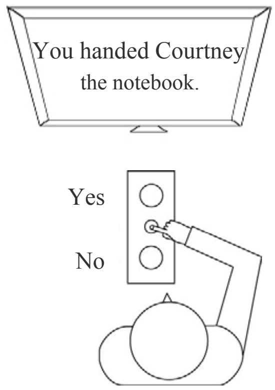

Figure 1.2. Paradigm of Glenberg and Kaschak (2002). In the example shown, the direction of action described in the sentence is compatible with the response direction (both are directed away from the body).

Another question that arises from the assumption that simulations serve the purpose of preparing situated action is whether they are only a redundant by-product of language processing or whether they directly contribute to word recognition and comprehension and reflect functional links between the cortical systems processing language, perception, and action (Pulvermüller, 2008). It could be concluded from the situated action view that these sensory-motor activations are only used for the planning of action execution after words or sentences are understood. Research on this issue has mainly focused on the role of the motor system in language processing – in part, this was already touched on in section 1.2.2, but in the following it will be discussed in more detail.

According to Pulvermüller (2008), the assumption that motor system activation is involved in semantic access to the meaning of action words can be supported by studies showing that this activation arises automatically and early in word processing and has a specific influence on the processing of action words. Early lexico-semantic processes are known to occur about 100-200 milliseconds after word onset (Sereno, Rayner, & Posner, 1998). Thus, a result in favor of semantic access was reported by Boulenger et al. (2006) who found that processing action verbs at the onset of reaching movements affected the kinematics of the movements already 160-180 milliseconds after word onset. Pulvermüller, Shtyrov, and Ilmoniemi (2005) also observed in an MEG study that action words related to different body parts elicited somatotopic motor activation within 200 milliseconds after the respective recognition points of the spoken words. Since, moreover, participants' attention was not directed to the language stimuli, but to a distractor task, the activation of motor areas in action word recognition appears to be automatic. Another study suggesting automatic motor activation was presented by Boulenger, Silber et al. (2008). Even though action verbs were displayed only subliminally while subjects were preparing a reaching movement, they affected motor preparation and subsequent movement kinematics. Some evidence for modifications of the motor system influencing language comprehension processes was already cited in section 1.2.2, but two further relevant studies are worth mentioning – a patient study and a behavioral experiment. Neininger and Pulvermüller (2003) examined language understanding in patients who were suffering from lesions in areas responsible for action or vision. In a speeded lexical decision task, patients with lesions in areas controlling action showed greater impairment in processing action verbs than in processing nouns with strong visual associations whereas patients with lesions in visual areas exhibited the reverse pattern. Glenberg, Sato, and Cattaneo (2008) did not work with patients, but manipulated subjects' motor system activity by requiring them to move 600 beans either toward the body or away from the body according to the location of the target container. After having performed this task which probably caused automatization of the movement or fatigue, both resulting in reduced activity of the respective neurons, participants were slower to understand sentences which described actions in a direction compatible with the direction of the previous bean movement. Together, these findings speak in favor of the view that motor area activation reflects comprehension of the meaning of action words instead of reflecting post-comprehension processes.

Thus, it seems as if perceptual and motor simulations played a functional role both for situated action and for language comprehension. These two functions are not conflicting given the view mentioned at several points that perceptual and motor representations are part of the core meaning of words and that word meanings are context-dependent just as the meaning of their referents (Barsalou, 2003; Feldman & Narayanan, 2004). In line with this, Glenberg (Glenberg et al., 2007; Glenberg & Robertson, 1999) claims that the meaning of language, objects, or events to an individual consists of those of their associated actions that are possible for the individual in a given situation. That is, when individuals differ in the affordances they derive, the meanings of the referents also differ between them. This action-based account of meaning in combination with Barsalou's (1999b) notion of perceptual symbols constitutes the core of the indexical hypothesis developed by Glenberg and Robertson (1999, 2000) which will be subject of the next section.

1.3.3 Indexical hypothesis

The linguistic approaches presented so far primarily focused on the embodied meaning of words. Now, an approach to the embodied understanding of whole sentences will be addressed which is offered by the indexical hypothesis (Glenberg & Robertson, 1999, 2000). According to this hypothesis, constructing the meaning of a sentence requires three processes. The first process consists in indexing the words and phrases in the sentence to their referents. More precisely, noun phrases either index objects in the immediate environment they refer to or – in case of displaced reference – they retrieve mental representations of the associated objects from memory while verbs activate corresponding motor representations. Evidence for the indexing process has already been reviewed in section 1.3.2. In the second process, affordances are derived from the indexed objects or representations, i.e., the comprehender gains access to potential motor interactions with the referents. As discussed previously, this action information is part of the object representation and becomes activated along with it. As a third process, the indexical hypothesis proposes that the affordances are combined or meshed into a coherent, executable, and imaginable set of actions guided by the syntax of the sentence and taking into account biological and physical constraints on combinations. A sentence is understood when the mental simulation of the described situation is successful (Glenberg & Robertson, 2000; Kaschak & Glenberg, 2000).

Concerning the role of syntax in the meshing process, the identification of the grammatical subject, object etc. indicates how to correctly relate the persons and objects with each other – for example, how the roles of agent and patient are assigned – (Kaschak & Glenberg, 2000), and the meaning of temporal adverbs (e.g., “while” and “after”) directs the temporal order of combining the affordances (de Vega, Robertson, Glenberg, Kaschak, & Rinck, 2004). The goal of the meshing process is specified by the meaning of the syntactic construction. This idea is based on the construction grammar approach in which every linguistic unit, ranging from morphemes and words to clause-level patterns, is considered to be a pairing of form and meaning, called construction (Goldberg, 1995, 2003). Thus, even syntactic structures have a semantic function – they convey their own meaning independently of the specific lexical items contained in the construction.

The way of how the links between constructions and certain meanings are established is imagined as follows. When sets of words often co-occur in language, they (or rather their experiential traces in the brain) become associated, and hence, these sequences of words are treated as constructions. Again by means of coincidence, connections are formed between experiential traces for linguistic constructions and those for their referential perceptions, actions, and events, thereby providing constructions with embodied meaning (Zwaan & Madden, 2005). Initially, children associate lexical-specific constructions with concrete experiences, but as more and more relevant exemplars of a construction are encountered, a more general notion that is common across these different exemplars emerges, and thus, schematic representations of constructions and meanings are derived (Goldberg, 1995; Tomasello, 2003). As suggested by the embodied construction grammar view (Bergen, Chang, & Narayan, 2004), these generalized construction schemas as well activate perceptual and motor structures according to their meaning, but the simulations are rather coarse-grained as they, for instance in case of action schemas, merely involve certain shared movement features instead of specific motor programs. An example of a syntactic structure we will encounter later in some of the cited studies is the double-object construction with the form Subject-Verb-Object1-Object2 as in the sentences "He gave me a book" or "He told me a story". Double-object constructions evoke the notion that an agent (Subject) transfers an object or something more abstract (Object2) to a recipient (Object1), that is, it activates a schema for giving (Goldberg, 2003). But schemas are only frames with open roles that have to be filled by the meaning of the particular words involved in order to obtain a semantic specification of the linguistic input on which the simulation of the described situation is based (Bergen et al., 2004; Feldman & Narayanan, 2004).

Syntactic constructions in turn supply the verbs they contain with different shades of meaning by indicating the nature of the described scene or event (such as transfer). Not only the interpretation of verbs is constrained by the general meaning of the construction, but also the selection and combination of affordances as demonstrated in a series of experiments by Kaschak and Glenberg (2000). Using innovative denominal verbs in their experiments, i.e., verbs created from nouns that have no defined meaning (e.g., to crutch), the authors found that depending on the syntactic construction (double-object form or transitive form), participants interpreted these verbs as conveying either a transfer meaning or a meaning of acting on someone or something. It was also shown that regarding the nouns underlying the denominal verbs, affordances which were very important for the understanding of the critical sentences were stronger activated compared to affordances that were not important for understanding and even compared to affordances that are most frequently associated with these nouns. Furthermore, Kaschak and Glenberg (2000) observed that subjects had difficulties in understanding a sentence in the double-object form containing an innovative denominal verb, when the verb was derived from an object whose affordances cannot support transfer. Thus, if affordances cannot be meshed into a doable simulation of action according to the basic scene specified by the construction, sentence comprehension suffers and the sentence is regarded as nonsensical (Glenberg et al., 2007).

The claim of the indexical hypothesis that sentence comprehension requires the underlying actions to be simulated is not restricted to sentences describing concrete situations, but holds as well for abstract sentences implying non-physical entities. In fact, several experiments which were conducted against the background of the indexical hypothesis confirm that understanding abstract sentences engages neural systems for perception and action. For instance in the study by Glenberg and Kaschak (2002) mentioned earlier, the ACE (compatibility effect for directions of verbally described actions and motor responses) appeared not only for sentences implying transfer of physical objects, but also for sentences conveying abstract transfer, such as the transfer of information. Comprehension of the same abstract transfer sentences was found to be affected by manipulations of motor system activity resulting from prior movements of beans in the direction of the described transfer (Glenberg, Sato, & Cattaneo, 2008). Moreover, a TMS study revealed that processing abstract transfer sentences modulates the activity of the motor system in the same way as processing concrete transfer sentences (Glenberg, Sato, Cattaneo et al., 2008). MEPs which were elicited by TMS pulses delivered to the hand motor cortex during the processing of the verb and which were recorded from a muscle involved in grasping actions turned out to be larger for both types of transfer sentences compared to sentences expressing no transfer.

One possibility of how abstract sentences could evoke action simulations is the following: While motor simulation in concrete sentences probably reflects the more general motor activation evoked by the meaning of the syntactic construction combined with specific motor representations that are activated by concrete verbs and nouns, motor activation in abstract sentences presumably arises solely from the general meaning of the syntactic construction (Fischer & Zwaan, 2008). As mentioned above, over the course of learning constructions, they become associated with action schemas which generalize over specific motor programs and include only relevant parameters, and finally, these schemas can be applied even to non-physical events with a similar structure (Feldman & Narayanan, 2004; Glenberg, Sato, Cattaneo et al., 2008). In the case of the reviewed experiments by Glenberg and colleagues, the used double-object construction activates the transfer action schema and hence the corresponding directional parameter of motion also for sentences describing abstract transfer of non-physical objects. This would imply differences in the specificity of action representations underlying concrete and abstract sentences. Since action schemas are usually considered higher-order action representations, it remains unclear how the processing of abstract sentences can cause low-level muscle activity as observed in the above studies. Either it has to be assumed that action schemas also use motor codes and hence include muscle-related information (Bergen et al., 2004; Glenberg, Sato, Cattaneo et al., 2008), or another possibility for action simulations in abstract sentences has to be taken into account.

Such an alternative explanation for low-level representations of abstract linguistic contents is suggested by Barsalou (1999b; Barsalou & Wiemer-Hastings, 2005): Not the meaning of the syntactic construction involves codes on the level of muscle control, but the meaning of the abstract words themselves. Abstract concepts or words are represented in modality-specific areas just like concrete concepts – their contents are perceived in specific situations and the states of processing these contents and situations can be simulated later.

In contrast to this notion, studies which explicitly investigated the neural correlates of processing single abstract words (e.g., Rüschemeyer et al., 2007) or which used abstract words as a control condition in determining the involvement of the motor system in processing action words (e.g., Borghi & Scorolli, 2009; Lo Gerfo et al., 2008) usually found no motor basis for abstract words. A possible reason for this might be that the meanings of abstract words are more complex and heterogeneous than those of concrete words. Abstract concepts represent more complex configurations of external and internal events that are extended over time, for example event sequences or comparisons between situations, and that they consist of information about introspective states (e.g., cognitive operations and emotions) to a larger extent than concrete concepts (Barsalou, 1999b). While abstract words are associated with multiple exemplars of specific experiences and actions which is reflected in greater variability of activation patterns within and across individuals, concrete words refer to well-specified entities or events in the world and thus are associated with consistent sensory or motor information, that is, they activate a more homogeneous set of experiential traces (Barsalou & Wiemer-Hastings, 2005; Kaschak & Glenberg, 2000; Zwaan, 2008). Probably, such homogeneous meanings are retrieved for abstract words as well when they are embedded in sentences providing a context that specifies which of their various perceptual or motor traces should be activated. Therefore, abstract sentences exhibit similar involvement of corresponding neural structures as concrete sentences, whereas abstract words examined in isolation lack the specifying context which results in interference between competing situations and experiences (Barsalou & Wiemer-Hastings, 2005; de Vega, Graesser, & Glenberg, 2008). Supporting evidence is cited by de Vega et al. (2008) showing that differences between concrete and abstract words disappear when contexts are presented or actively generated by the participants.

To summarize, the indexical hypothesis implies that sentence understanding calls upon mental simulations on different levels of abstraction. For one thing, the words in a sentence are assumed to activate low-level modal representations such as specific motor programs, for another thing, syntactic constructions are assumed to activate more generalized action schemas, i.e., higher-order action representations. However, there is still disagreement about the level of abstraction on which the meanings of syntactic constructions and of abstract words are represented. Our experiments could shed some light on whether concrete and abstract sentences differ in the abstractness of their semantic representations as the linguistic material used contained concrete as well as abstract sentences.

1.4 Aims of this dissertation

There is a considerable body of evidence showing that low-level motor programs are engaged in the comprehension of action-related sentences. Nevertheless, some of the presented theories assume that also more abstract, higher-level action representations might play an important role for sentence comprehension. Possibly, the abstractness of the activated action simulations depends on the specificity of the linguistic description (de Vega, 2008): When descriptions of actions reside on a lower level including specifications of the basic physical features of the movements (e.g., “He closed his fist around the glass”), action simulations can be more fine-grained recruiting low-level motor programs. In contrast, when linguistic descriptions reside on a higher level where information about the way in which an action is performed is omitted and lots of details remain unspecified (e.g., “He moved the glass from here to there”), action simulations might be more coarse-grained drawing on higher-order action representations.

So far, these higher-order representations of action descriptions have not been further investigated – it is still unclear how they could look like and how abstract they really are. Therefore, the present thesis focused on sentences with a rather unspecific level of description and addressed the nature of the action representations activated during the comprehension of these sentences. Based on assumptions of the common coding approach, high-level representations of described actions could be coded in terms of action goals. A similar suggestion is made by Pulvermüller (2008), a proponent of the view of distributed semantic representations: Abstraction might be implemented by structures where alternative concrete action representations converge that could be performed to achieve a certain goal. The idea that described actions could be represented on the level of action goals or action effects formed the basis for the experiments presented in this thesis.

As mentioned in section 1.1, Hommel (1993) provided evidence that action representations refer to the intended action effect by dissociating actions from action effects and showing that performance of actions is facilitated when stimuli share some features with the action effects. The fact that stimulus-response compatibility effects can rely on action effects supports the notion of shared codes for perception and action in a high-level representational domain as proposed by the common coding approach. In the same way, semantic meaning of words and sentences uses common codes with perception and action, and therefore, these codes as well could have the same high-level representational format. Sensory-motor simulations in language processing which imply this kind of common codes are frequently demonstrated using behavioral paradigms with a similar structure as stimulus-response compatibility paradigms. For instance, the ACE (Glenberg & Kaschak, 2002) is a compatibility effect which arises because action sentences (which are the stimuli) and motor responses share a feature, namely the direction of action. Both the action simulation during sentence understanding and the response include as a feature either the direction toward the body or the direction away from the body, and when these directions correspond, the response is primed because both in succession activate the same code.

Since it was a main aim of the present work to determine the level of representation on which the interaction between language and action takes place, this aim could be pursued by dissociating action and action effect in the ACE, following Hommel's (1993) paradigm. The ACE appears suitable for investigating this issue because for understanding the sentences which produce the effect, activating a relatively abstract, coarse-grained representation of the described action toward or away from the body seems to be sufficient. Higher-order representations in the ACE are also suggested by the fact that the sentences imply actions with quite different motor programs which in turn differ from the motor program of the response and that their representations interact in spite of these differences (de Vega, 2008). Combining Hommel's and the ACE paradigm means that participants have to produce an action effect at a location near the body or far from the body for indicating whether sentences describing actions toward or away from the body are sensible or not. The intended action effect can be separated from the action carried out to achieve this effect by means of transformation between action and action effect. That is, making an arm movement in a certain direction causes an effect in the opposite direction – a near action effect results from moving to a far location and a far action effect results from moving to a near location.

Thus, the first research question was which of the two components that are part of the movement preparation process enters into the ACE: the "early", more abstract premotor component including activation of distal features of the to-be-produced action event, i.e., of features of the intended movement effect, or the "late" motor component including activation of motor neurons and specific muscles involved in the movement. The rationale behind the first experiment investigating this question was as follows: When movement and movement effect are dissociated and differ in whether they are directed toward or away from the body, this difference in the directional feature is reflected in the low-level motor codes and high-level feature codes forming these two components of the response representation. Therefore, different patterns of interactions are expected between response representation and sentence representation depending on whether the latter is based on motor codes or feature codes. If the representation of the described action consisted of motor codes, the activation of these codes during sentence comprehension would prime codes of the motor component of the response and hence facilitate responding when both are characterized by the same directional feature, whereas different directional features would cause interference (see Table 1.1, rows 1 and 2). In this case, a compatibility effect would be observed between sentence direction and movement direction, in other words, a movement-related ACE would appear. Yet if the described action was represented by more abstract distal feature codes and shared the directional feature with the movement effect, feature codes representing the movement effect would be primed and the response would be facilitated, whereas there would be interference when directional feature codes differed (see Table 1.1, rows 3 and 4). In this case, a compatibility effect would occur between sentence direction and direction of the movement effect, that is, an effect-related ACE would be found.[1]

In order to provide further and stronger evidence for whether the ACE emerges on the motor level or on the abstract level of action planning, parameters of the movement and of the movement effect were manipulated in two subsequent experiments. For one thing, the amplitude of the movement was varied, i.e., the extent of the required arm movement to the near and far response locations, and for another thing, the amplitude of the movement effect, i.e., the distance between the locations of the near and far movement effect. Manipulating the amplitude of the movement effect should modify the feature codes which represent the response on the abstract level, and accordingly, the ACE should be modulated when arising on the higher level of movement effects. Yet if the ACE emerged on the lower level of movements, varying the amplitude of the movement effect should have no effect. Instead, manipulating the amplitude of the movement itself and thereby changing the motor codes which represent the response on the low level should affect the ACE.

Since results of these first three experiments in part showed a negative ACE and suggested that the sign of the ACE is influenced by response timing, a second series of experiments addressed the role of relative timing between sentence comprehension and response selection in the ACE. In the first experiment of this series, the point in time was controlled at which participants were able to prepare the required response direction. This point in time was determined to be the onset of the sentence as this allows the maximal temporal overlap between sentence processing and movement preparation and thus should enable priming (i.e., a positive ACE) when the same directional codes are used in the sentence and response representation. Two subsequent experiments then manipulated the point in time at which participants were informed of which response direction to prepare: The information was provided either before sentence onset, at sentence onset, within the

[1] As mentioned in section 1.1, the high-level component of the response representation can not only refer to features of remote movement effects (to-be-produced environmental events), but also to features of resident movement effects (kinesthetic or proprioceptive sensations of the movement). Thus, in principle, there is a third possibility besides the movement-related and the remote effect-related ACE, namely the resident effect-related ACE. If the response was coded in terms of its resident instead of its remote effects, the direction represented in high-level feature codes would be the same as the direction represented in low-level motor codes. Therefore, a resident effect-related ACE would have the same appearance as a movement-related ACE and hence could not be differentiated from it, although arising from an interaction between high-level sentence and response representations using abstract feature codes. So, the present work only aimed at differentiating between a movement-related and a remote effect-related ACE; a more precise differentiation would require further investigations.

sentence presentation, or at the end of the sentence. In this way, different orders and degrees of temporal overlap were created concerning the activation of the directional codes during sentence comprehension and response preparation, and this should influence the sign of the resulting ACE.

1.5 Pilot experiments

The question which formed the starting point for the first experiments was whether action-sentence compatibility is effective between sentence direction and movement direction (movement-related ACE) or between sentence direction and direction of the movement effect (effect-related ACE). In order to investigate this issue, movements and their effects were dissociated using a special response device (see Figure 1.3) which differed from the one used in Glenberg and Kaschak's (2002) study. So, these pilot experiments also served the purpose of testing whether the ACE can be produced by responding on that device. Furthermore, while Glenberg and Kaschak (2002) presented sentences visually, the new response device necessitated to present sentences auditorily instead – reading sentences on a screen would have hindered subjects from focusing on the visual movement effect.

Table 1.1

Predicted compatibility effects depending on the level on which the sentence content is represented. The coded direction of action is symbolized by arrows, with corresponding arrows indicating that the directional feature that is part of the semantic representation of the sentence is compatible with the directional feature of the respective response component. Codes of sentence and response representations that are able to interact with each other due to a common format are marked by grey background

Sentence		Response		Interaction due to common representational format	ACE is related to
represented by motor codes	represented by feature codes	Movement represented by motor codes	Movement effect represented by feature codes		
↑		↑	↓	priming	movement
↑		↓	↑	interference	
	↑	↑	↓	interference	movement effect
	↑	↓	↑	priming	

Figure 1.3. Illustration of the response device. The left figure shows the device in the condition with regular action-effect relation and the right figure in the condition with transformed action-effect relation.

In all other respects, the experiments followed closely those of Glenberg and Kaschak (2002). Participants were asked to judge whether the sentences they hear are sensible or not. The sentences described transfer actions directed either toward the body (e.g., “Jakob reicht dir das Buch” - Jacob hands you the book) or away from the body (e.g., “Du reichst Jakob das Buch” - You hand Jacob the book), or they described no transfer, but contained the same character names and objects as the transfer sentences (e.g., “Du liest mit Jakob das Buch” - You read the book with Jacob). Half the sentences of each category mentioned concrete objects (as in the examples above) and half abstract objects such as information (e.g., “Julia erzählt dir eine Geschichte” - Julia tells you the story). Responding that the sentence made sense (“yes” response) or not (“no” response) required getting a rod that was mounted on the top of the response device either toward or away from the body, always starting from a position in the middle. For shifting the rod, participants had to move a covered handle at the bottom of the device either in the same direction in which they wanted to get the rod (regular action-effect relation) or in the opposite direction (transformed action-effect relation) (see Figure 1.3). Thus, in the transformed condition, movement (moving the handle) and movement effect (shifting the rod) were dissociated so that the direction of action described in the sentence corresponded either with the direction of the arm movement or with the direction of the movement effect.

If the ACE relies on movement effect, response times should be faster in cases where sentence direction is compatible with effect direction, i.e., where both are directed toward the body or away from the body, compared to cases where both are incompatible – irrespective of the direction of the arm movement itself. Yet if the ACE relies on movement, response times should be faster in cases where sentence direction is compatible with movement direction, irrespective of the effect direction. Possibly, there might be a difference between concrete and abstract transfer sentences. Since they by definition describe actions on different levels of abstraction, these actions might be simulated on different levels. Understanding concrete sentences might involve activation of motor programs and hence give rise to a movement-related ACE, whereas understanding abstract sentences might involve activation of representations on the higher level of movement effects and therefore lead to an effect-related ACE.

Four pilot experiments were carried out. For one thing, these experiments differed in the type of movement effect that was caused by moving the handle. Either the continuous effect described above was applied with the rod running from the middle position to the near or far response position, or a discrete effect was used where moving the handle turned on a light at one of the response positions. Since Glenberg and Kaschak (2002) had demonstrated that the ACE only occurs when the response requires a movement – solely pressing buttons at the respective spatial locations was insufficient to evoke the ACE –, one could suspect that in contrast to using a continuously moving response effect, a stationary discrete effect at these locations could as well fail to produce an ACE or at least an effect-oriented ACE. For another thing, the pilot experiments differed in their designs concerning the interindividual or intraindividual variation of effect direction (whether a "yes" response for example requires shifting the rod to the near or to the far location) and action-effect relation (regular and transformed). Moreover, when action-effect relation was manipulated within subjects it either alternated blockwise within one session or varied between two sessions.

Details on the differences between the four pilot experiments are listed in Table 1.2. Apart from that, all experiments were identical in that variables like Sentence direction (toward, away, and neutral), Sentence type (concrete and abstract), and Sensibility (sensible and nonsensical) varied from trial to trial.

Response times (RTs) calculated from onset of the sentence presentation to movement onset showed no systematic effects. Results were mixed with respect to the question whether the ACE refers to movement or to movement effect. One experiment yielded an effect-related ACE (which was significant only in the first half of the experiment), another experiment showed a significant movement-related ACE, but attempts to replicate and further examine these patterns of results failed. Instead, in two further experiments no significant ACE was found at all. Regarding the influence of effect type (continuous or discrete), one experiment which directly compared both types found no difference, but a significant movement-related ACE for both of them. Again this could not be replicated.

Since producing a robust ACE turned out to be difficult with the response device used, and since producing a robust ACE is a prerequisite for investigating research questions related to the ACE, the experiments presented in the second part of this thesis more closely followed the setup described by Glenberg and Kaschak (2002) in using response buttons.

However, the question remains of why the ACE probably can be found when responding on buttons, but does not reliably appear when using a response device like the one described. At least three causes are conceivable. First, unlike buttons, the used response device required the presence of a second person (the experimenter) in the testing room. This person was sitting next to the participant in order to note down such trials in which the device did not work properly, which could happen if the participants did not move as smoothly as instructed. Possibly, the participant integrated the present person into the simulation of the sentence content and hence simulated the described action to the side and not toward the front. In such a case, no interaction with the response direction can take place. Second, moving the handle probably brings along more motor constraints regarding e.g. hand posture and trajectory than freely moving the hand from one button to another button. If the simulation of a described action recruits a specific motor program, its activated movement parameters may have interfered with the movement parameters involved in planning the response with the handle – these mismatches could have reduced the priming effect underlying the ACE. Third, in case of the used response device, the feature of movement direction probably is highlighted in the response representation, whereas in case of buttons, the response representation may reflect the more important role of movement goals. The latter matches the structure of the presented sentences in which the recipient of the transferred object constitutes a clearly defined goal as well, and this may lead to a larger ACE.

It has not been further investigated whether any of the explanations is correct (although they could be interesting starting points for future studies). These considerations only encouraged the decision to change the response device to buttons. So, the following experiments stuck to the initial question of whether the ACE is related to movement or movement effect, which should be easier to address when obtaining a more robust ACE using response buttons.

Table 1.2

Overview on specific characteristics and results of the pilot experiments

Pilot experiment	Effect type	Effect direction	Action-effect relation	Results
A	continuous	between subjects	within subjects (blocked)	effect-related ACE (first half)
B	continuous vs. discrete (between subjects)	within subjects (blocked)	within subjects (between sessions)	movement-related ACE
C	continuous	between subjects	within subjects (between sessions)	no ACE
D	discrete	within subjects (blocked)	between subjects	no ACE

2 The relative importance of movement and movement effect in the action-sentence compatibility effect

The following three experiments aimed at investigating which kind of interaction underlies the ACE: The ACE might result from priming between the direction of action described in the sentence and the direction of arm movement that is part of the response. Alternatively, the ACE might as well result from priming between sentence direction and direction of the effect that is intended by the arm movement and defines the response. The purpose of Experiment 1 was to test whether a more robust ACE (compared to the pilot experiments) can be obtained when using response buttons as in Glenberg and Kaschak (2002) and adding stationary movement effects. Yet most importantly, it was studied whether the ACE relies on movement or its effect under these conditions. In Experiments 2 and 3, amplitudes of movement and movement effect were manipulated in order to investigate whether one of these manipulations would affect the ACE. To put it more clearly, in Experiment 2, participants differed in the extent to which they had to move the arm to the near and far response location, but produced the same movement effect, whereas in Experiment 3, participants executed the same arm movements, but achieved movement effects with different distances between the near and far locations. If the interaction between language and action occurs on a low level in the hierarchy of action planning, then modifying parameters of the movement should influence the magnitude of the ACE. If the interaction occurs on a higher representational level, then modifying parameters of the intended movement effect should have an influence on the magnitude of the ACE.

2.1 Experiment 1

Experiment 1 addressed the contributions of movement and movement effect to the ACE by dissociating movements from their effects. To this end, an apparatus was introduced which combined movements to a near and a far button with visual movement effects at a near or far location on the screen. The mapping of movements to movement effects was either congruent or incongruent. Movements and movement effects had the same amplitudes, i.e., the distance between the near and the far button was identical to the distance between the near and the far location of the movement effect.

A B

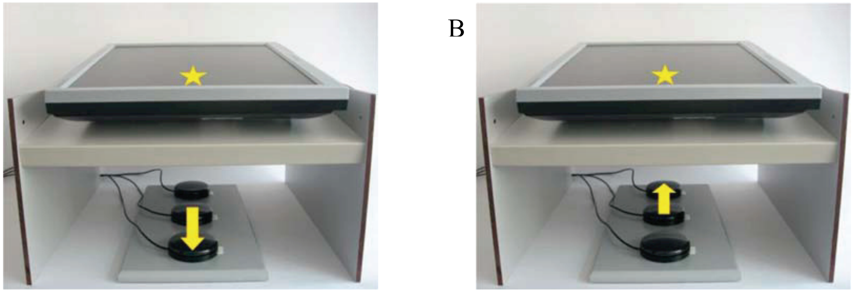

Figure 2.1. Illustration of movement and its effect by the example of a "yes" response in the yes-is-near condition with regular action-effect relation (A) and with transformed action-effect relation (B).

2.1.1 Method

Participants. Twenty-four adults (mean age = 24.4 years; 9 males, 15 females) participated in the experiment in exchange for 7 Euros per experimental session. As in the following experiments, all participants were native German speakers, right-handed, reported normal or corrected-to-normal vision and audition, and none of them had participated in another ACE experiment and heard the stimulus sentences before.

Materials. The linguistic material consisted of 80 triads of sentences that were adopted from Glenberg, Sato, Cattaneo et al. (2008) and translated into German. Half the sentences (40 triads) were sensible and half were nonsensical as required for the task to be done. The two critical sentences of each triad described the same transfer action in a toward version and in an away version, while the third sentence contained a different verb which expressed no transfer. Half of these neutral sentences began with the German word "Du" [you] as did the away sentences, and half began with a character name like the toward sentences. In addition, half of the triads described concrete transfer of objects and half abstract transfer, for example the transfer of information. Twenty additional sentences were created and served as practice items. All sentences were recorded by a female German speaker and played over headphones during the experiment. The mean length of the critical (sensible toward and away) sentences was 1751 ms (standard deviation SD = 235 ms). The experimental sentences are listed in the Appendix A.

The response device consisted of three buttons which were 6.3 cm in diameter and were arranged in a vertical line on a board. The board was laid on the table in front of the participant so that the buttons differed in distance from the participant's body (see the lower part of the response apparatus shown in Figure 2.1). There was a distance of 11.3 cm from the center of the middle button to the centers of the near and far button. Above the buttons, a 17'' flat screen monitor was mounted horizontally on which two grey response boxes were presented on a black background. One of the boxes appeared at a near and one at a far location, subtending a visual angle of 6.6° and 3.1°, respectively. To indicate whether a sentence made sense or not, participants had to activate the respective response box by pressing the near or far button. The distance between the centers of the boxes was identical to the distance between the centers of the outer response buttons (i.e., 22.6 cm), and so was also the distance between the yellow stars that flashed up at either location of the response boxes on the screen as an effect of the button press. The effect stars subtended a visual angle of 16.2° at the near location and of 7.7° at the far location. Because the screen was placed directly above the buttons, the moving hand was covered, and thus participants received no on-line visual feedback of their movement, but only perceived its effect on the screen. For increasing attention to the visual response effect, a sound ("twinkles") was played at the time at which the star appeared. The sound was composed of two successively presented tones that formed a fourth upward (with fundamental frequencies of 625 Hz and 834 Hz) and lasted 320 ms in total.

The experiment was controlled by an IBM-compatible computer running Presentation software (Neurobehavioral Systems, Albany, USA), and the response buttons were connected to it via the parallel port.

Procedure. Sessions were run individually in a dimly illuminated and sound-attenuated room. Each trial was initiated by pressing the middle button with the right hand, and participants were told not to release this button until they were able to make their response. A near and a far response box appeared on the screen 500 ms after the button press, and 1000 ms after their appearance, a sentence started to play. Participants were instructed to decide if the presented sentence was sensible or not and to activate the "yes" (i.e., sensible) or "no" (i.e., nonsensical) response box on the screen as soon as this decision could be made. There were two possible response assignments: Either the "yes" response was assigned to the near box and the "no" response to the far box (yes-is-near condition) or it was the other way round (yes-is-far condition). Activating the response boxes required moving one's arm from the middle button to the near or far button, i.e., toward the body or away from the body. As an effect of the button press, a star flashed up at the activated location on the screen and an accompanying sound was played. Figure 2.1 illustrates the two different mappings of action effects to buttons. In the condition with regular action-effect relation, the location of the activated response box and of the resulting action effect on the screen corresponded with the location of the button press as either both were near the body or both were far from the body. In contrast, action and its effect were dissociated in the condition with transformed action-effect relation where an action effect at a certain location on the screen resulted from moving one's arm in the opposite direction. That means, the near response box was activated by pressing the far button and vice versa. No time limit was imposed on the response, but participants were asked to respond as quickly and accurately as possible. Immediately after responding, participants had to return to the middle button and press it down in order to start the next trial. The experiment consisted of two sessions in which participants each time judged all the 240 sentences – once with regular and once with transformed action-effect relation. To prevent participants from making their judgments from memory when the sentences were presented for the second time, the second session took place approximately one week after the first session.

At the beginning of each session, participants received two blocks of practice trials. The first block consisted of 20 trials in which participants were familiarized with the response assignment. After instructing them about the assignment, the German words "Ja" [yes] or "Nein" [no] were presented auditorily and participants had to activate the corresponding response box on the screen by moving from the middle button to the response button associated with the respective box. Along with the visual response effect, feedback about the correctness of the response was provided by displaying the German words "Richtig" [right] colored in green or "Falsch" [wrong] colored in red on the screen. The visual feedback was accompanied by appropriate sounds: For correct responses the sound described in the Material section was played (ascending interval), and for incorrect responses a sound was played that was composed of two successively presented tones forming a descending interval (with fundamental frequencies of 625 Hz and 548 Hz, lasting 320 ms in total). In the second practice block, participants received 10 trials with practice sentences which corresponded with the experimental trials that followed. The experimental trials were divided into two blocks with the response assignment being reversed after the first block of trials. Therefore, the second experimental block again was preceded by two practice blocks resembling those at the beginning, but using the new response assignment. A whole session lasted approximately 30 minutes.

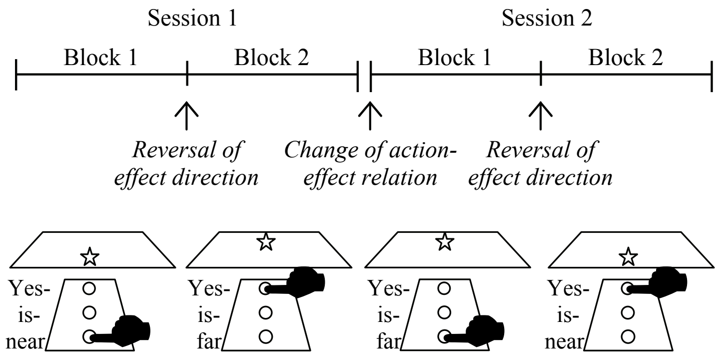

Figure 2.2. Structure of the experiment, illustrated by the example of one of the possible condition orders of effect direction and action-effect relation.

Design. All of the independent variables were manipulated within participants. While sentence direction (toward, away, and neutral), sentence type (concrete and abstract), and sensibility (sensible and nonsensical) varied from trial to trial, action-effect relation (regular, transformed) was changed between two sessions, and effect direction (yes-is-near, yes-is-far) was reversed from the first to the second block of each session (see Figure 2.2). To ensure that all sentences appeared equally often in every condition, the 240 stimulus sentences were split up into two material blocks which were presented as the first and second block of a session and as such were assigned to the respective conditions of effect direction and action-effect relation. These combinations and the order of their presentation in blocks and sessions were counterbalanced across participants (see Appendix B for the complete counterbalance scheme). Sentences were randomized in such a way that each material block was divided into five subblocks (24 sentences each) that contained an equal number of sentences of each category (sensibility, sentence type, sentence direction), but never included sentences that belonged to the same triad. For each participant, the order of sentences in each subblock as well as the order of the subblocks themselves were randomized.

Data analysis. In this and the following experiments, dependent variables included response time (RT), movement time (MT), and percentages of errors. RT was measured from the onset of the sentence presentation to movement onset, that is, to the release of the middle button, and MT was measured from releasing the middle button to pressing the near or far response button. In all of the to be presented experiments, participants were removed from the analysis and replaced when they missed the second session, when their error rates exceeded 15%, or when their way of executing the response differed from the instructed way in more than 15% of the analyzed trials. The last-named were cases in which participants had their hand resting on the middle button and only pressed the response buttons with fingers splayed out despite being instructed to move the whole hand from the middle button to the response button. These cases were identified through earlier registration of response button presses than of the release of the middle button. Response time data and movement time data were analyzed as follows: Incorrect trials were excluded from the analysis. To reduce the effect of outliers, first, 0.5% of the longest and shortest responses over participants were eliminated, and second, for each participant in each condition, responses were discarded that were more than 2.5 SD from the condition mean. This procedure was based on the trimming procedure used by Glenberg, Sato, Cattaneo et al. (2008).

The analysis of RTs, MTs, and error rates focused on the data from the sensible toward and away sentences. Means of the dependent variables were computed for each participant in each condition by averaging across items. For the purpose of simplifying the analysis, the variables Sentence direction and Effect direction were merged into the new variable Sentence-effect compatibility (compatible, incompatible). The compatible condition contained cases in which effect direction matched the sentence direction, i.e., when both the "yes" response on the screen and the described action were directed toward the body or when both were directed away from the body, irrespective of the direction of the arm movement required for the response. The incompatible condition included cases in which effect direction and sentence direction were opposed, i.e., when the "yes" response on the screen was directed toward the body, whereas the described action was directed away from the body, or the other way round.

It may be possible that the obtained compatibility effects are affected by carry-over effects from the action-effect relation experienced in the first session to the second session. In the second session, the previously learned action-effect association might conflict with the newly acquired association, and as this would influence the activation of the responses, it would have an effect on the ACE. In order to control for such carry-over effects, four-way mixed-factor analyses of variance (ANOVAs) were conducted on RTs, MTs, and error rates with Sentence-effect compatibility (compatible, incompatible), Sentence type (concrete, abstract), and Action-effect relation (regular, transformed) as within-subjects factors and with Order of action-effect relations (first session regular and second session transformed or reverse order) as a between-subjects factor. When there was some kind of interaction between Sentence-effect compatibility and Order of action-effect relations, further analysis focused on the first session only, because this session was free of such influences. This meant performing a three-way mixed-factor ANOVA with Sentence-effect compatibility and Sentence type as within-subjects factors and with Action-effect relation as a between-subjects factor. When no interaction with the factor Order of action-effect relations was found, the results of the initial ANOVA on the data of both sessions were interpreted.

An alpha level of .05 was adopted for all analyses. Whenever the sphericity assumption was violated, the Greenhouse-Geisser procedure was used to adjust the degrees of freedom for the F tests (for an easier reading, the uncorrected degrees of freedom are reported).

Predictions. The critical questions in this experiment were whether the ACE can be observed with the experimental setup used and whether it is related to the arm movement or to the movement effect. As was already hypothesized in section 1.5, the second question might be answered differently for concrete and abstract sentences – responses to the former might show a movement-related ACE, whereas responses to the latter might display an effect-related ACE. An effect-related ACE manifests itself as a significant main effect of Sentence-effect compatibility which consists in faster responses when sentence direction and effect direction are compatible than when they are incompatible – both for regular and for transformed action-effect relation. In contrast, a movement-related ACE manifests itself as a significant interaction between Sentence-effect compatibility and Action-effect relation. This interaction should result from the standard ACE pattern occurring for regular action-effect relation (faster responses when sentence direction and effect direction are compatible than when they are incompatible), while this pattern reverses for transformed action-effect relation. Since in the transformed condition, compatible directions of sentence and movement effect are equivalent to incompatible directions of sentence and arm movement and vice versa, the reversed ACE pattern means that responses are faster when sentence direction is compatible with movement direction than when they are incompatible. Even if the ACE only disappeared in the transformed condition, this would still speak for movement direction contributing to the ACE, because its opposite compatibility relation to the sentence must have counteracted and hence reduced the compatibility effect between sentence and movement effect.

Since these compatibility effects are the main interest of this work, only main effects of Sentence-effect compatibility or interactions between compatibility and other factors will be reported. For this and the following experiments, further main effects and interactions not involving the compatibility variable are listed in Appendix C.

2.1.2 Results

The removal of outliers from the RT and MT data resulted in a total percentage of discarded trials of 2.4% for RTs and of 4.4% for MTs.

RTs. Mean RTs are shown in Table 2.1. The ANOVA across sessions yielded neither significant interactions between Sentence-effect compatibility and Order of action-effect relations (all ps > .3) nor a significant main effect of Sentence-effect compatibility or other interactions involving this factor (all ps > .2). Thus, no ACE emerged in RTs.

MTs. The MT analysis across sessions revealed a significant interaction between Sentence-effect compatibility, Action-effect relation, and Order of action-effect relations ($F(1, 22) = 4.62$, $MSE = 304.45$, $p < .05$) as well as a significant interaction between Sentence-effect compatibility, Sentence type, and Order of action-effect relations ($F(1, 22) = 5.57$, $MSE = 386.28$, $p < .05$). However, when computing an ANOVA on the data of the first session only, there were no significant effects (all ps > .09). Mean MTs of the first session are listed in Table 2.1.

Error rates. As for RTs, the ANOVA across sessions on error rates showed no significant interaction between Sentence-effect compatibility and Order of action-effect relations (all ps > .09), but this time, there was a significant interaction between Sentence-effect compatibility, Action-effect relation, and Sentence type ($F(1, 22) = 5.29$, $MSE = 5.55$, $p < .05$). Mean error rates are depicted in Figure 2.3. When running separate ANOVAs on concrete and abstract sentences in order to interpret this interaction, only error rates for concrete sentences revealed a significant main effect of Sentence-effect compatibility ($F(1, 23) = 10.18$, $MSE = 4.4$, $p < .01$) as well as a significant interaction between Sentence-effect compatibility and Action-effect relation ($F(1, 23) = 8.16$, $MSE = 5.49$, $p < .01$), whereas there were no significant compatibility effects for abstract sentences (all ps > .3). Participants made fewer errors in responses to concrete sentences when sentence direction and effect direction were incompatible than when they were compatible, but this was true only for the condition with regular action-effect relation ($t(23) = 4.02$, $p < .01$, two-tailed), while there was no difference between errors in compatible and incompatible trials in the transformed condition ($t(23) = 0.0$, $p = 1.0$, two-tailed). Thus, there was a negative ACE in error rates for concrete sentences which disappeared for transformed action-effect relation.

2.1.3 Discussion

These results did not show the standard ACE. Usually, the ACE manifests itself as an RT advantage that arises when sentence direction and response direction are compatible compared to incompatible directions. In this experiment, an ACE was found in error rates instead of in RTs, and in contrast to the performance benefit expected for compatible directions, these cases produced more errors than incompatible directions when listening to concrete sentences. The vanishing of this negative ACE when the direction of the arm movement was opposite to the direction of the thereby produced movement effect may suggest that both directions interact with the direction of the verbally described action, their opposite effects cancelling each other out. However, this is not the only possible explanation. The vanishing of the negative ACE in the condition with transformed action-effect relation could also result from some unknown factors that give rise to the negative ACE in the regular condition and that are less present in the transformed condition. Because a negative ACE was not predicted in the condition with regular action-effect relation, it cannot be interpreted unambiguously what caused the negative ACE to disappear in the condition with transformed action-effect relation. The fact that this effect occurred only for concrete sentences and only in error rates additionally limits the conclusiveness of the results. So, these results are difficult to interpret and require further investigation.

In sum, responding on buttons per se did not result in a robust ACE, and adding stationary movement effects did not seem to be sufficient to obtain an effect-related compatibility effect.

Experiment 2 was carried out in order to replicate Experiment 1 and beyond that, to investigate the relevance of movement and its amplitude for the ACE.

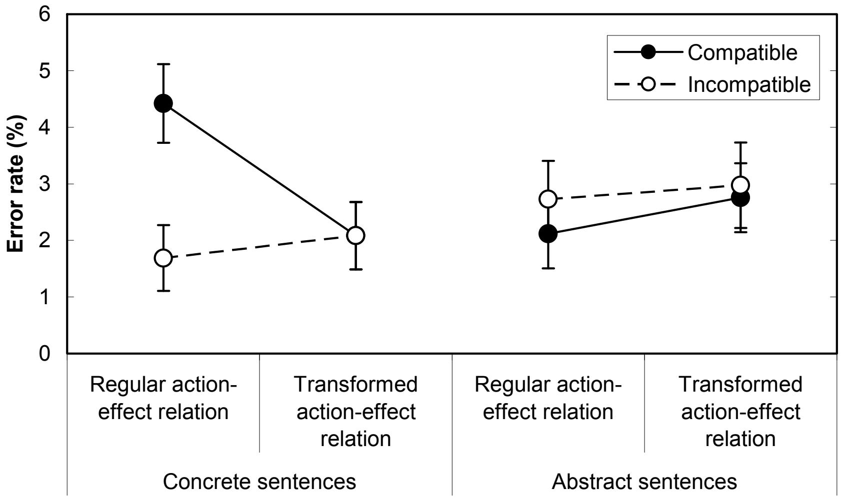

Figure 2.3. Mean error rates (in %) across the two sessions of Experiment 1 as a function of the factors Sentence-effect compatibility, Action-effect relation, and Sentence type. Error bars represent standard errors.

Table 2.1

Mean RTs and MTs (in ms) in Experiment 1, presented as a function of Sentence type, Sentence-effect compatibility, and Action-effect relation. The values in parentheses represent standard errors

	Concrete sentences				Abstract sentences			
	Compatible		Incompatible		Compatible		Incompatible	
RT (across sessions)								
Regular action-effect relation	1814	(22)	1836	(29)	1952	(26)	1961	(24)
Transformed action-effect relation	1820	(20)	1821	(22)	1981	(22)	1962	(25)
MT (first session)								
Regular action-effect relation	230	(18)	225	(17)	227	(17)	230	(16)
Transformed action-effect relation	267	(35)	279	(36)	255	(29)	276	(37)

2.2 Experiment 2

For one thing, Experiment 2 aimed at reinvestigating the questions posed in Experiment 1 and at examining whether the negative ACE could be replicated. For another thing, it was designed to test whether a movement-related manipulation such as the manipulation of movement amplitude modulates the magnitude of the ACE. Since modifying the movement amplitude means modifying the motor codes that represent the response on the lower level, an effect of such a manipulation on the ACE would indicate that the interaction between sentence direction and response direction occurs on the level of motor codes.

For this purpose, two experimental groups were set up which differed in the amplitude of the movement required for pressing the near or far response button, while the amplitude of the movement effect on the screen was kept constant. One group was identical to Experiment 1 in every respect, which means that amplitudes of movement and effect corresponded with each other. In a second group, a smaller movement amplitude was used than in the first group, whereas effect amplitude remained the same. While the first group alone is only a replication of Experiment 1, its comparison with the second group could provide insight into whether the ACE is modulated by movement amplitude.

2.2.1 Method

Participants. Thirty-two participants (mean age = 24.8 years; 15 males, 17 females) took part in the experiment. They were randomly assigned to two groups of 16 participants each. The data from four participants were excluded and replaced (details are provided in the Results section).

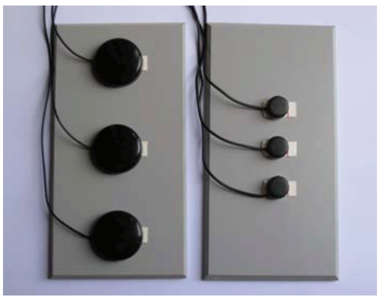

Figure 2.4. The response buttons used for the conditions with large movement amplitude (on the left) and with small movement amplitude (on the right).

Materials and procedure. Materials and procedure were identical to those used in Experiment 1, except that movement amplitude was additionally manipulated between participants. For responding, one group of participants got the same buttons arranged with the same distances as in Experiment 1, while a second group received smaller buttons that were 2.9 cm in diameter and had a smaller distance to each other. According to Fitts' law (Fitts, 1954), the difficulty of moving the hand to a target and thus the time required for the movement depends on the size of and the distance to the target. Because responses on the large and on the small response buttons had to be equivalent in difficulty (or in MT required), the distance from the center of the middle button to the centers of the outer buttons was set to 5.2 cm for the small button size (see Figure 2.4). This distance resulted in a constant index of difficulty. Independently of size and distance of the buttons, the distance between the response boxes on the screen as well as between the centers of the stars serving as action effects remained the same as in Experiment 1 for both groups.

Design and analysis. Experimental design and data analysis were the same as in Experiment 1, except that one independent variable was added, namely Movement amplitude (small, large) which was manipulated between participants. The counterbalance scheme from Experiment 1 was applied separately to each amplitude group. The performed ANOVAs included Movement amplitude as an additional between-subjects factor.

2.2.2 Results

The data from four participants had to be removed from analyses for the following reasons: One participant made errors in 18.8% of the trials, and another participant did not follow the instruction of moving the whole hand to the response buttons in 28.9% of the sensible trials. Through an oversight, a third participant was not given the intended version of the experiment, and a fourth participant had already taken part in one of the previous ACE experiments. The removal of outliers from the data from the remaining and replacing participants eliminated 2.4% of the RT data and 4.3% of the MT data.

RTs. The RT analysis across sessions yielded a significant interaction between Sentence-effect compatibility, Sentence type, and Order of action-effect relations ($F(1, 28) = 10.78$, $MSE = 1194.89$, $p < .01$). Regarding data of the first session, there was a significant interaction between Sentence-effect compatibility, Sentence type, and Action-effect relation ($F(1, 28) = 7.51$, $MSE = 2432.87$, $p < .05$). Separate ANOVAs for each sentence type revealed a significant interaction between Sentence-effect compatibility and Action-effect relation for both concrete sentences ($F(1, 28) = 4.61$, $MSE = 1664.37$, $p < .05$) and abstract sentences ($F(1, 28) = 4.7$, $MSE = 2281.36$, $p < .05$), but with an opposite direction of effects. The mean RTs are shown in Figure 2.5; as there was no effect of Movement amplitude, data are presented averaged over the two amplitude groups. Descriptively, responses to concrete sentences were faster in trials with compatible sentence and effect directions than in trials with incompatible directions when action-effect relation was regular, while the pattern was reversed for transformed action-effect relation. As concerns abstract sentences, RTs were faster in trials with incompatible sentence and effect directions than in trials with compatible directions when action-effect relation was regular, and again the reverse pattern appeared in the transformed condition. When computing separate analyses for conditions with regular and transformed action-effect relation, only the transformed condition yielded a significant interaction between Sentence-effect compatibility and Sentence type ($F(1, 14) = 4.7$, $MSE = 2456.47$, $p < .05$), whereas no effect was observed in the regular condition ($p > .1$).

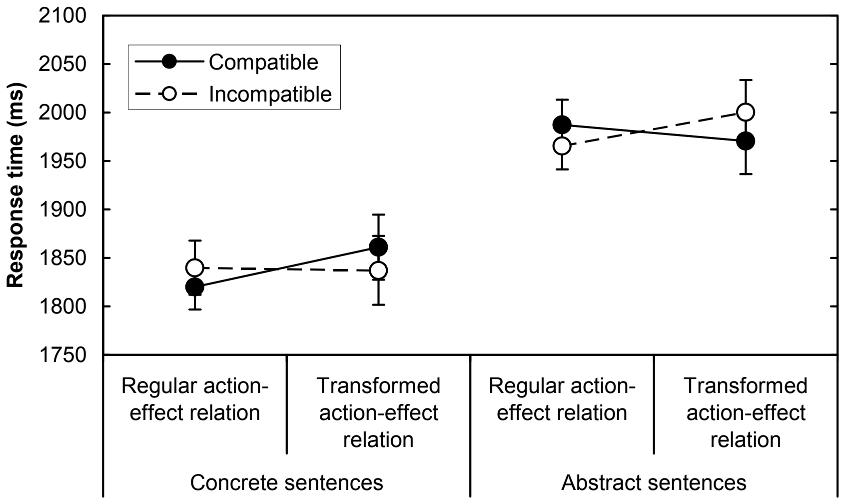

Figure 2.5. Mean RTs (in ms) in the first session of Experiment 2 as a function of the factors Sentence-effect compatibility, Action-effect relation, and Sentence type. Data are averaged over conditions with small and large movement amplitude. Error bars represent standard errors.

Thus, in RTs, a compatibility effect was obtained only for transformed action-effect relation, with the direction of the effect being modulated by the concreteness of the sentences.

MTs. MTs showed a significant interaction between Sentence-effect compatibility, Action-effect relation, Sentence type, Movement amplitude, and Order of action-effect relations ($F(1, 28) = 4.65$, $MSE = 146.94$, $p < .05$), but when looking at the first session only, no significant effects involving the compatibility variable were found (all *p*s > .1). Mean MTs of the first session are given in Table 2.2.

Error rates. The ANOVA across sessions yielded no significant interaction between Sentence-effect compatibility and Order of action-effect relations (all *p*s > .07). The same analysis showed a significant interaction between Sentence-effect compatibility and Action-effect relation ($F(1, 28) = 5.1$, $MSE = 5.5$, $p < .05$) as well as between Sentence-effect compatibility and Movement amplitude ($F(1, 28) = 4.46$, $MSE = 6.05$, $p < .05$). Mean error rates are listed in Table 2.2. In order to take a closer look at these interactions, ANOVAs were conducted separately for the two action-effect relation conditions (but across movement amplitudes) as well as for the two movement amplitude groups (but across action-effect relations). As the analyses for the regular and transformed conditions revealed, there were no significant effects of Sentence-effect compatibility for regular action-effect relation (*p*s > .05), but in the transformed condition a significant main effect of Sentence-effect compatibility occurred ($F(1, 28) = 4.84$, $MSE = 6.98$, $p < .05$). Across movement amplitudes and sentence types, participants made more errors in this condition when sentence direction and effect direction were compatible than when they were incompatible. The analyses for the two movement amplitude groups showed no significant effects in the group with small movement amplitude (all *p*s > .09), while there was a significant main effect of Sentence-effect compatibility in the large-amplitude group ($F(1, 15) = 7.79$, $MSE = 4.24$, $p < .05$). The latter reflected higher error rates in trials with compatible sentence and effect directions than in trials with incompatible directions across sentence types and action-effect relations. So, in the group with large movement amplitude, a negative ACE was found, but as the separate analyses of the action-effect relation conditions suggest, this effect resulted mainly from strong compatibility differences in the transformed condition.

Table 2.2

Mean MTs (in ms) and error rates (in %) in Experiment 2, presented as a function of Sentence type, Sentence-effect compatibility, Movement amplitude, and Action-effect relation. The values in parentheses represent standard errors

	Concrete sentences		Abstract sentences	
	Compatible	Incompatible	Compatible	Incompatible
MT (first session)				
Small movement amplitude				
Regular action-effect relation	274 (21)	272 (25)	271 (19)	271 (22)
Transformed action-effect relation	223 (24)	229 (26)	227 (25)	227 (25)
Large movement amplitude				
Regular action-effect relation	239 (24)	230 (23)	234 (24)	230 (27)
Transformed action-effect relation	250 (28)	242 (26)	238 (29)	237 (29)
Error rate (across sessions)				
Small movement amplitude				
Regular action-effect relation	2.3 (0.8)	2.8 (0.9)	1.0 (0.5)	2.5 (0.9)
Transformed action-effect relation	2.5 (0.8)	2.5 (0.8)	2.9 (1.2)	1.9 (0.6)
Large movement amplitude				
Regular action-effect relation	2.5 (0.8)	1.3 (0.6)	0.9 (0.5)	1.3 (0.6)
Transformed action-effect relation	2.8 (0.9)	0.9 (0.7)	1.9 (0.8)	0.6 (0.4)

2.2.3 Discussion

Unlike in Experiment 1, the ACE was found not only in error rates, but also in RTs. However, as concerns RTs, the ACE appeared solely in conditions with transformed action-effect relation. Because for one thing, the ACE was absent in the regular condition, and for another thing, a negative ACE seems to be as possible as a positive ACE, the question of whether the ACE in the transformed conditions refers to movement or to movement effect cannot be solved on the basis of these results. Faster responses in incompatible trials (as it was the case for concrete sentences) could reflect both a positive movement-related ACE and a negative effect-related ACE. Similarly, faster responses in compatible trials (which were observed for abstract sentences) could reflect a negative movement-related ACE as well as a positive effect-related ACE.

With regard to error rates, a compatibility effect occurred only in the group with large movement amplitude. Participants in this group produced performance costs when sentence direction matched effect direction, but like in RTs, this effect arose primarily under conditions in which action-effect relation was transformed. So, it cannot be determined with certainty whether they really exhibited a negative ACE that relied on the movement effect.

One purpose of implementing the large-amplitude group was to test whether results of Experiment 1 could be replicated, because of which conditions in this group were identical to Experiment 1 in every respect. Though the effects obtained in error rates were broadly similar to results of Experiment 1, they did not completely replicate them, as this time, the negative ACE occurred not only during responses to concrete sentences and not for regular action-effect relation, but across both sentence types and mainly for transformed action-effect relation. So, in both cases, it remains unclear whether the ACE resides on the motor level or on the higher level of action effects.

Beyond that, also the comparison of the two movement amplitude groups was expected to provide insight into whether the ACE emerged on the lower level of motor codes. If this was the case, the magnitude of ACE should have been influenced by movement amplitude. While RTs showed no differences in the ACE between small and large movement amplitude, the ACE found in error rates was more pronounced in the condition with large movement amplitude. However, in consideration of the uncertainties as to the direction of the effect mentioned above, the conclusion that the ACE is based on motor codes should be drawn very tentatively. Thus, it remains to be seen whether results of Experiment 3 would strengthen this view.

2.3 Experiment 3

Analogous to Experiment 2, this experiment investigated whether the ACE is affected by varying amplitudes of the movement effect on the screen. Such a modulation would indicate that the ACE emerges on the abstract representational level of movement effects. When manipulating the movement effect, but not the movement itself, only the high-level component of the response that is represented by abstract feature codes will be different, whereas the low-level component represented by motor codes will be unchanged. Thus, if the interaction between language and action reflected by the ACE takes place on the higher level of movement effects, different action representations on that level should lead to an altered ACE.

To test this assumption, the amplitude of the movement effect was manipulated between two experimental groups, while the amplitude of the movement from the middle button to the response buttons was kept constant. This movement amplitude was the same as the one used for the small-amplitude group in Experiment 2. In one group of participants, effect amplitude was just as small as movement amplitude, whereas in a second group, effect amplitude was considerably larger than movement amplitude. Thereby, the salience of the movement effect was increased in the second group which should result in a stronger effect-related ACE because features of the movement effect play a more important role in the response representation. However, if the ACE emerges on the motor level, it is irrelevant how the response is coded on the higher level, and thus the ACE should be movement-related in both amplitude groups.

2.3.1 Method

Participants. Thirty-two volunteers (mean age = 24.4 years; 17 males, 15 females) participated in the experiment. They were randomly assigned to two groups of 16 participants each. The data from three participants were discarded and replaced (details are provided in the Results section).

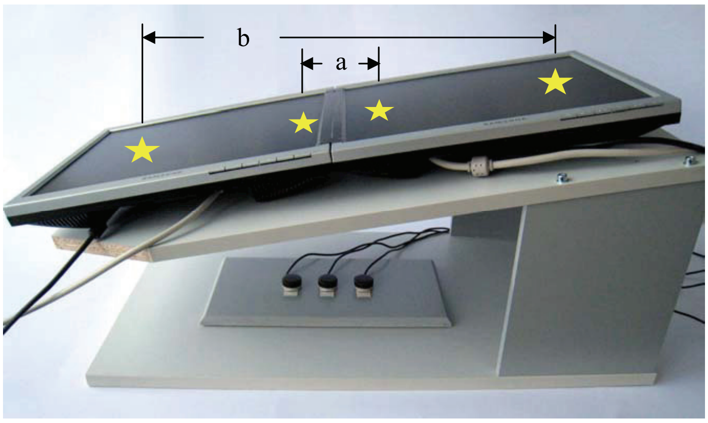

Figure 2.6. Apparatus used in Experiment 3 in side view, illustrating small amplitude (a) and large amplitude (b) of the movement effect.

Materials and procedure. Everything remained the same as in Experiment 2, apart from the following modifications: All participants responded on the small-distance buttons used for the group with small movement amplitude in Experiment 2. Pressing these buttons produced movement effects whose distance differed between two groups of participants. In the group with small effect amplitude, response boxes on the screen as well as the centers of the stars flashing up as movement effects had the same distance as the outer response buttons (10.4 cm). The near and far response boxes subtended a visual angle of 1.5° and 1.2°, the near and far effect stars subtended a visual angle of 3.1° and 2.5°. The distance between the response boxes and between the effect stars on the screen increased to 49.0 cm in the group with large effect amplitude. Thus, the ratio between amplitudes of movement and effect was twice the ratio of the group with small movement amplitude in Experiment 2. The size of the response boxes and effect stars also increased proportionally with the larger amplitude. So, the near and far boxes measured 10.8° and 3.8° of visual angle, the near and far effect stars measured 24.3° and 8.6° of visual angle. For implementing the large distance, two 17’’ flat screen monitors were mounted horizontally one behind the other and the screen frames separating both screens were pasted over with black adhesive tape to make them appear like one big screen. The response apparatus and the two effect amplitudes are illustrated in Figure 2.6.

Design and analysis. Experimental design and data analysis were identical to that of Experiment 2, except that the between-subjects variable Movement amplitude was substituted by the new between-subjects variable Effect amplitude (small, large).

2.3.2 Results

The data from three participants were dropped from analyses – one because of problems with the transformed action-effect relation which caused errors in 47.5% of the trials in this condition, one because of not moving the whole hand to the response buttons in 30.8% of the sensible trials, and one because of doing the second session with the wrong effect amplitude by mistake. The trimming procedure applied to the data from the final sample resulted in the elimination of 3.1% of the RT data and of 4.6% of the MT data.

RTs. In the RT analysis, a significant interaction between Sentence-effect compatibility, Effect amplitude, and Order of action-effect relations was found ($F(1, 28) = 7.06$, MSE = 4107.91, $p < .05$). When looking at the first session only, the ANOVA showed a significant interaction between Sentence-effect compatibility, Effect amplitude, and Action-effect relation ($F(1, 28) = 13.56$, $MSE = 4386.08$, $p < .01$). Mean RTs are listed in Table 2.3. As separate analyses for the two effect amplitude groups revealed, only the small-amplitude group exhibited a significant interaction between Sentence-effect compatibility and Action-effect relation ($F(1, 14) = 9.84$, $MSE = 5019.1$, $p < .01$), reflecting faster responses when sentence direction and effect direction were compatible than when they were incompatible, but only for regular action-effect relation, while the pattern was reversed in the transformed condition. Individually the compatibility advantage in the regular condition as well as the compatibility disadvantage in the transformed condition were at least marginally significant (regular action-effect relation: $F(1, 7) = 5.18$, $MSE = 3071.23$, $p = .057$; transformed action-effect relation: $F(1, 7) = 5.08$, $MSE = 6966.96$, $p = .059$). In contrast to the small-amplitude group, participants from the large-amplitude group took longer to respond in trials with compatible sentence and effect directions than in trials with incompatible directions when action-effect relation was regular, and again this pattern was reversed for transformed action-effect relation. However, this interaction was not reliable, but approached significance ($F(1, 14) = 4.01$, $MSE = 3753.06$, $p = .065$).

Thus, the group with small effect amplitude showed a tendency towards a positive ACE in the regular condition which was modulated by action-effect relation, whereas the group with large effect amplitude also tended towards such a modulation by action-effect relation, but with exactly opposite directions of compatibility differences.

MTs. The MT analysis across sessions yielded no significant interaction between Sentence-effect compatibility and Order of action-effect relations (ps > .06), but there was a significant interaction between Sentence-effect compatibility, Sentence type, and Effect amplitude ($F(1, 28) = 4.25$, $MSE = 396.69$, $p < .05$). Mean MTs are given in Table 2.3. In order to interpret the obtained interaction, MTs were separately analyzed for concrete and abstract sentences with both small and large effect amplitudes. The only significant effect was found for concrete sentences in the large-amplitude group, namely a main effect of Sentence-effect compatibility ($F(1, 14) = 5.08$, $MSE = 223.76$, $p < .05$), with movements being faster for incompatible sentence and effect directions than for compatible directions which held across regular and transformed action-effect relation. That is, the above interaction resulted from a disadvantage of compatibility between sentence direction and effect direction for concrete sentences in the large-amplitude group, while there were no significant effects for abstract sentences in this group as well as for both sentence types in the small-amplitude group (all *p*s > .1).

These results contradict those of the RT analysis with regard to the transformed condition. In principle, different results for RTs and MTs can emerge when participants do not always select the response before releasing the middle button, but instead decide to press the near or the far button only when they have already initiated the movement. A strategy like that would shift the compatibility effect from RTs to MTs, leading for instance to faster RTs and slower MTs in conditions in which an RT disadvantage would otherwise occur. But regardless of whether the compatibility effect manifested itself in RTs or in MTs, it would always be visible when adding them together. Therefore, total response time (TRT) was analyzed as an additional measure that comprises RT and MT, defined as the time interval between the onset of the sentence and the pressing of one of the response buttons.

TRTs. Results of the TRT analysis parallel those of the RTs: The ANOVA across sessions revealed an interaction between Sentence-effect compatibility, Effect amplitude, and Order of action-effect relations ($F(1, 28) = 8.84$, $MSE = 4476.45$, $p < .01$), and the ANOVA on the data of the first session an interaction between Sentence-effect compatibility, Effect amplitude, and Action-effect relation ($F(1, 28) = 17.28$, $MSE = 4775.58$, $p < .01$). Similar to RT data, this interaction reflected the modulation of the ACE by action-effect relation – this time, interactions between Sentence-effect compatibility and Action-effect relation were significant for both groups (small effect amplitude: $F(1, 14) = 11.12$, $MSE = 4636.68$, $p < .01$; large effect amplitude: $F(1, 14) = 6.54$, $MSE = 4914.47$, $p < .05$) – as well as opposite patterns of effects for the two effect amplitude groups. The mean TRTs are depicted in Figure 2.7; since no effect of sentence type was observed, data are presented averaged over concrete and abstract sentences. In the small-amplitude group, the direction of the compatibility effect was positive in the regular condition ($F(1, 7) = 6.79$, $MSE = 1990.15$, $p < .05$) and reversed in the transformed condition ($F(1, 7) = 5.76$, $MSE = 7283.2$, $p < .05$), whereas the large-amplitude group tended towards a negative compatibility effect that was also reversed in the transformed condition (*p*s > .07).

Error rates. The ANOVA across sessions yielded neither significant interactions between Sentence-effect compatibility and Order of action-effect relations (all *p*s > .08) nor a significant main effect of Sentence-effect compatibility or other interactions involving this variable (all *p*s > .1). Mean error rates are shown in Table 2.3.

Table 2.3

Mean RTs (in ms), MTs (in ms), and error rates (in %) in Experiment 3, presented as a function of Sentence type, Sentence-effect compatibility, Effect amplitude, and Action-effect relation. The values in parentheses represent standard errors

	Concrete sentences		Abstract sentences	
	Compatible	Incompatible	Compatible	Incompatible
RT (first session)				
Small effect amplitude				
Regular action-effect relation	1770 (37)	1796 (25)	1905 (23)	1968 (31)
Transformed action-effect relation	1903 (72)	1865 (72)	2080 (89)	1984 (53)
Large effect amplitude				
Regular action-effect relation	1957 (76)	1902 (54)	2070 (60)	2053 (60)
Transformed action-effect relation	1840 (35)	1846 (39)	2004 (37)	2049 (49)
MT (across sessions)				
Small effect amplitude				
Regular action-effect relation	208 (18)	210 (19)	217 (18)	211 (19)
Transformed action-effect relation	227 (26)	229 (27)	238 (29)	235 (29)
Large effect amplitude				
Regular action-effect relation	264 (28)	252 (28)	267 (30)	260 (27)
Transformed action-effect relation	262 (26)	257 (27)	262 (28)	282 (32)
Error rate (across sessions)				
Small effect amplitude				
Regular action-effect relation	1.9 (0.8)	1.3 (0.7)	1.3 (0.7)	2.3 (0.8)
Transformed action-effect relation	1.6 (0.8)	1.3 (0.7)	1.9 (0.8)	2.3 (0.8)
Large effect amplitude				
Regular action-effect relation	3.2 (1.1)	1.9 (0.6)	2.3 (0.8)	2.2 (1.3)
Transformed action-effect relation	2.2 (0.7)	3.2 (1.1)	1.6 (0.6)	2.8 (1.2)

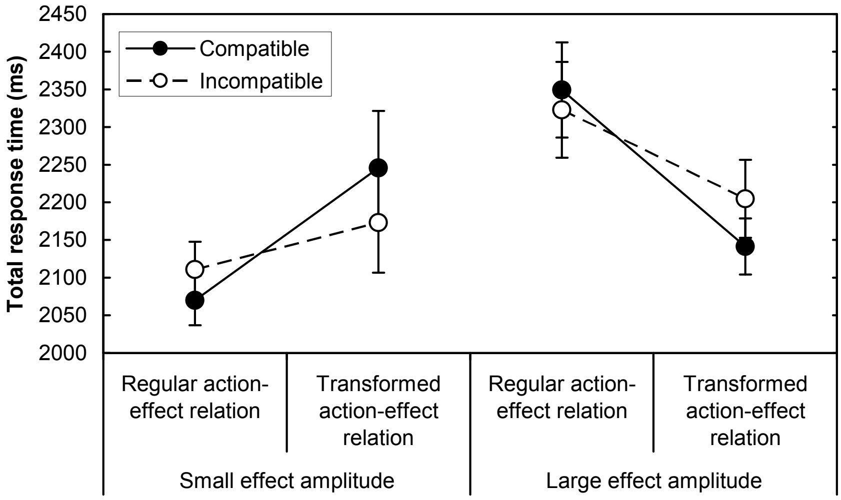

Figure 2.7. Mean TRTs (in ms) in the first session of Experiment 3 as a function of the factors Sentence-effect compatibility, Action-effect relation, and Effect amplitude. Data are averaged over concrete and abstract sentences. Error bars indicate standard errors.

2.3.3 Discussion

In this experiment, the standard ACE occurred in TRTs, at least in the group with small effect amplitude which showed a benefit in the speed of responses due to a match between sentence direction and response direction. While the ACE was positive for small effect amplitude, there was a tendency toward a negative ACE for large effect amplitude. Because of the existence of a negative ACE, again, the reversal of the effect in the condition with transformed action-effect relation in both groups cannot be unambiguously interpreted: It could either be interpreted as a movement-related ACE with the same direction as in the regular condition (staying positive in the small-amplitude group and staying negative in the large-amplitude group), or it could be interpreted as an effect-related ACE with the opposite direction as in the regular condition (becoming negative in the small-amplitude group and becoming positive in the large-amplitude group). Thus, it is not possible to confirm or reject the hypothesis that the representation of the sentence uses abstract codes. Based on this assumption, a very salient movement effect due to a large amplitude should have caused the ACE to become effect-related or, when already effect-related for small effect amplitude, should have enhanced the ACE. Even though the manipulation of effect amplitude indeed modulated the ACE, it cannot be determined whether this modulation referred to the ACE becoming effect-related and it did not refer to an enhancement of the ACE, but instead referred to the sign of the ACE.

Now that a negative ACE appeared to some extent in RTs and TRTs, too, exploring the potential causes of the negative ACE would enable a better understanding of the processes underlying the ACE and hence would help to interpret the occurring results. With regard to the data of the present experiment, it is interesting that in the large-amplitude group, the RT level was raised by more than 200 ms compared to the small-amplitude group. Perhaps the amplitude transformation from movement to effect in the group with large effect amplitude required longer response preparation which could have induced the negative ACE.

In order to take a first look at the possibility that response timing influences the sign of the ACE, a variable was created which reflected how fast each participant from the large-amplitude group responded on average. This Speed variable consisted of participants' mean RTs of all correct trials of the first session containing sensible toward and away sentences. As a test of whether there is a relationship between participants' speed and the results in the large-amplitude group, the Speed variable was included as a covariate in a three-way mixed factor ANOVA performed on the RT data of the large-amplitude group's first session. Sentence-effect compatibility (compatible, incompatible) and Sentence type (concrete, abstract) were entered as within-subjects factors, and Action-effect-relation (regular, transformed) as a between-subjects factor. Indeed, results showed a significant main effect of Speed ($F(1, 12) = 74170.77$, $MSE = 11.07$, $p < .01$) as well as a significant interaction between Sentence-effect compatibility, Action-effect relation, and Speed ($F(1, 12) = 6.16$, $MSE = 2870.6$, $p < .05$). The scatter plot depicted in Figure 2.8 illustrates the nature of the relationship between participants' speed (the above mean RTs) and the magnitude of the ACE for regular action-effect relation. The magnitude of the ACE was calculated as the difference between RTs for incompatible trials and RTs for compatible trials which results in positive numbers when participants show a compatibility advantage and in negative numbers when they show a compatibility disadvantage. So, on a descriptive level, the slower the participants responded the more they seemed to exhibit a compatibility disadvantage in the regular condition. In the transformed condition, the opposite pattern appeared: The slower the participants responded, the more they tended to produce a compatibility advantage. However, for the same reasons as discussed above, a clear interpretation of the results for this condition is not possible. Nonetheless, these results provide a first indication that the relative timing between movement preparation and sentence comprehension might play a role for the reversal of the ACE. Explanations for this link will be discussed in the following sections.

2.4 Discussion of Experiments 1, 2, and 3

The first three experiments attempted to find out whether the ACE arises on the level of motor codes or on the level of more abstract feature codes referring to distal movement effects. Unfortunately, the occurrence of a negative ACE in all three experiments (either in error rates or in response times) makes it difficult to decide this question from the present results. The existence of a negative ACE – an incompatibility effect between sentence direction and response direction – renders it impossible to interpret a reverse ACE in the condition with transformed action-effect relation. Therefore, this question will continue to be unanswered within the used experimental paradigm until the prerequisites for the appearance of the negative ACE are understood. A first step in this direction may be the pattern of results obtained in the follow-up analysis in Experiment 3 suggesting that early responses rather go along with a positive ACE whereas late responses go along more with a negative ACE.

With regard to the results of Experiment 3, there is an interesting analogy with the study by Richardson, Spivey, and Cheung (2001). In their first experiment, a series of pictured objects was presented that afforded an action either on the left or on the right side. Afterwards, participants should recall from memory whether they had seen a certain object or not and accordingly press a left or right key. The results showed an unexpected incompatibility effect: Responses were facilitated when the side of the required action was opposite to the side of the action afforded by the object whose representation was accessed from memory. This effect seemed to depend on the timing of the responses in the same way as our effect in Experiment 3: When in a second experiment RT data were split into an early and a late half, the late group again exhibited an incompatibility effect between motor responses and affordances of objects whose representations were activated through verbal descriptions. The early group, in contrast, displayed a non-significant tendency toward a compatibility effect. For explaining their results, the authors drew on the theory of event coding (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001) which suggests that the temporal relationship between activations of different action representations determines whether they result in interference or facilitation: Feature overlap should induce performance benefits for short time intervals, but costs for long intervals. Possibly, TEC could contribute to the understanding of the negative ACE as well.

Thus, parallel to the initial question concerning the representational level at which the ACE arises, the following three experiments addressed the role of timing between response preparation and sentence comprehension as a potential cause of the negative ACE, and in doing so contrasted predictions derived from TEC with those from other theoretical considerations.

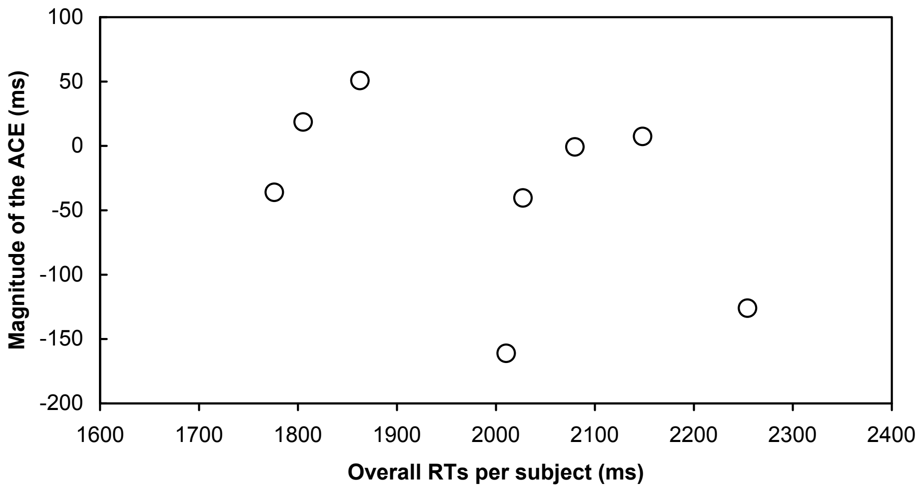

Figure 2.8. Relationship between the magnitude of the ACE (RTs for incompatible trials - RTs for compatible trials) and participants' overall RTs (means of all correct responses on critical trials of the first session) for regular action-effect relation, based on first-session data from participants who belonged to the group with large effect amplitude.

3 Temporal properties of the action-sentence compatibility effect

Embodied approaches to language comprehension like Glenberg and Robertson's (1999, 2000) indexical hypothesis provide no indication of when facilitation and when interference occurs between performing actions and processing language describing the same actions. That is, they cannot help to explain the negative ACE in the experiments described in chapter 2. As mentioned above, TEC could be of greater use for that.

TEC is based on the common coding approach in assuming that representations of perceived events and planned actions consist of identical cognitive codes referring to the distal features of the respective event. Hommel (Hommel, 2004; Hommel et al., 2001) elaborated this approach in greater detail by making a distinction between two phases of coding a perceptual or action event: the activation and the integration of feature codes. In the first phase of processing a stimulus or planning an action, feature codes representing their attributes are activated in parallel. As a consequence, accessibility of these codes is increased in the cognitive system and so they can be more easily used for coding other events with overlapping features, i.e., representations of such events are primed and performance based on them is facilitated. Because codes of different features are stored in distinct functional systems and so are distributed over different cortical areas, feature codes activated by the same event have to be bound together in order to enable an unambiguous assignment of feature codes to temporally co-occurring events and to segregate these different event representations. Therefore, in the second phase, the activated feature codes are integrated – they become connected with each other and can no longer be activated in isolation. As a result, they are less available for coding events with partial feature overlap which leads to interference between coding processes instead of facilitation. Concerning action planning, codes representing the action parameters are bound to an action plan when it comes to the specific preparation of an action. Integrated codes are occupied, and thus the planning of another action with overlapping features is impaired until the current action plan is executed or abandoned and feature codes are available again for other planning activities. In sum, increased accessibility of feature codes in the activation phase should cause compatibility benefits, whereas decreased accessibility in the subsequent integration phase (about 250-500 ms after feature activation, Stoet & Hommel, 2002) should result in compatibility costs.

Such compatibility benefits are reflected in the standard spatial stimulus-response compatibility effects (discussed in section 1.1) and can also explain affordance effects in the context of research on concept representation (discussed in section 1.3.1) as well as match effects obtained in research on sensory-motor simulations in language processing (discussed in section 1.3.2). The visual stimuli or the simulated referents of the words and concepts in these studies can be regarded as activating feature codes which then prime feature-overlapping responses.

Compatibility costs due to occupied codes have been shown between perceptual and action-planning processes as well as between different action plans. Examples of the former effects are impaired perceptual performance – the identification of a briefly presented and masked arrow pointing to the left or right – when concurrently preparing a movement that is spatially compatible with the stimulus (Müsseler & Hommel, 1997) or similar findings in the evaluative domain. In these experiments, preparing a response associated with positive or negative meaning (such as a lever movement toward the body or away from it) impaired the detection of masked stimuli with the same valence. In contrast, when the affective stimulus was presented before the action plan was formed, its activated affective code primed the response and a compatibility benefit appeared in the speed of the lever movements (Eder & Klauer, 2009). An example of compatibility costs of the latter type was provided by Stoet and Hommel (1999) who demonstrated that preparing a left or right finger movement and maintaining this action plan in memory impairs the performance of another action on the same side, even when this action is executed with the left or right foot.

The idea of code integration and occupation may also be suitable to explain costs of compatibility between performing actions and processing language describing actions. For example, interference effects which occur when action verbs are processed while an action is being prepared or executed, but turn into facilitation when the verbs are presented before action planning has started (Boulenger et al., 2006; Boulenger, Silber et al., 2008) seem to parallel the above results that were taken as evidence for TEC.

When interpreting the ACE in the light of the assumptions of TEC, then compatibility benefits and costs arise as follows: During online sentence processing, feature codes are activated that represent the action which the sentence content is referring to, among them the directional feature (toward or away from the body). If the response is being prepared during this activation phase, access to the activated directional feature of the described action is easier which facilitates responding in the same direction. At the end of the sentence when all relevant information is known, the activated feature codes are probably bound together to form a complete representation of the sentence content which means running a full simulation of the described action. If the response planning takes place not until after the completion of the sentence, access to the directional feature code is reduced because the code is now integrated into the simulation of the sentence content. As a consequence, responding in the same direction is impaired. This would account for the pattern of results obtained in Experiment 3: Fast-responding participants probably started preparing their responses already during sentence processing which induced a compatibility benefit – the positive ACE –, whereas slow-responding participants probably held off preparing the response until the end of the sentence which caused compatibility costs – the negative ACE. In the same way, the effects found in the study by Richardson et al. (2001) fit with the two phases proposed by TEC. Borreggine and Kaschak's (2006) findings seem to further strengthen this view. In order to test this TEC-based account of the ACE, the authors conducted experiments in which they manipulated the timing of the response planning. Participants only responded when they judged the sentence to be sensible, and they were informed of the movement direction required for this "yes" response by a visual cue in each trial. When the cue was presented at the onset of the sentence and responses could be planned while the sentence was being processed, a positive ACE arose. In contrast, when the cue appeared after the offset of the sentence which prevented participants from preparing the response during sentence processing, RTs were clearly slower and the ACE was eliminated with a tendency toward being reversed on a descriptive level.

This way of controlling the point in time at which the "yes" direction is prepared could be useful for obtaining clearer results concerning the question of whether the ACE emerges on the level of motor representations or on the level of distal representations of action effects. Getting participants to plan the required response while processing the sentence should lead to a positive ACE, and a potential reversal of the ACE in the condition with transformed action-effect relation should be easier to interpret. With this aim, Experiment 4 was carried out using a modified experimental paradigm: The go/no-go method from Borreggine and Kaschak (2006) was adopted which allowed to vary the response direction from trial to trial and to make participants become aware of the current "yes" direction at the onset of every sentence.

The subsequent Experiments 5 and 6 served to take a closer look at the impact of the timing between movement preparation and sentence comprehension on the sign of the ACE.

To this end, stimulus onset asynchrony (SOA) was manipulated within this modified paradigm, that is, the cue indicating the current response direction was presented at different points in time relative to sentence onset. As a consequence, directional features of the action described in the sentence and of the response might be activated during different phases of coding the respective other event. This might produce different patterns of facilitation and interference.

3.1 Experiment 4

The purpose of Experiment 4 was to investigate the role of movement effects in the ACE using a modified procedure. The modification consisted in applying a go/no-go method and varying the "yes" direction randomly from trial to trial. By instructing participants about the current "yes" direction at sentence onset, the influence of the timing factor should be controlled.

3.1.1 Method

Participants. Sixteen volunteers (mean age = 24.8 years; 6 males, 10 females) took part in the experiment. The data from three participants were excluded and replaced (details are provided in the Results section).

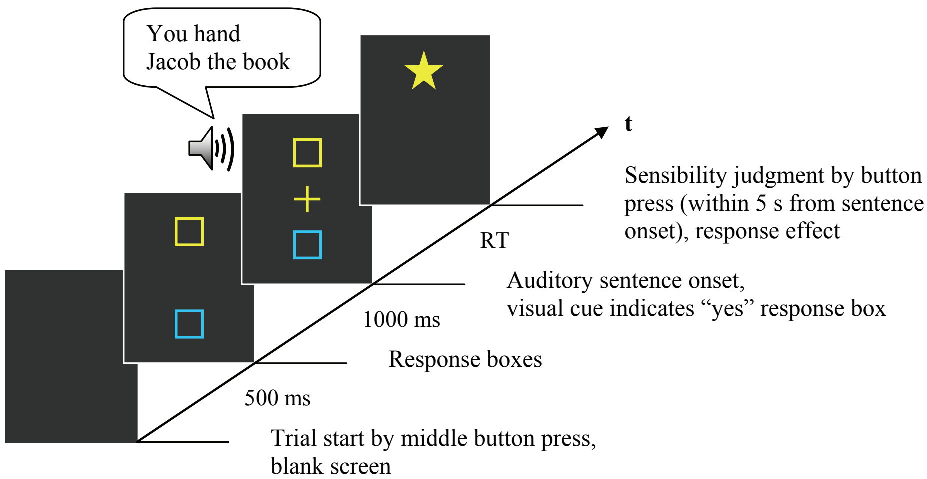

Figure 3.1. Sequence of events in an experimental trial of Experiment 4. This trial gives an example of a sensible away sentence presented in the yes-is-far condition.

Materials and procedure. Materials and procedure were the same as in Experiment 1, except for some changes entailed by the use of a go/no-go task. In this task, participants had to respond only when the sentence made sense, but should refrain from responding in case of a nonsense sentence. That way, it was more feasible to change the response direction from trial to trial which was implemented as follows (see Figure 3.1 for an illustration): The response boxes which were presented on the screen at the beginning of each trial differed in color, one of them having a blue frame and the other one being framed in yellow. At the time when the sentence presentation started, the response cue – a blue or yellow cross matching the color of either of the response boxes – appeared in the center of the screen (1.8° of visual angle). The color of the cue indicated whether the near or the far response box should be activated (via button press) if the sentence was sensible. The cue remained visible until the response was made or, in the case that the sentence was judged as nonsensical and no response was performed, until the trial timed out 5 s after sentence onset. In case of a response occurring, a star flashed up as an effect of the button press which was colored corresponding to the color of the activated response box. The response buttons used as well as the distance between them and between the response boxes and effect stars on the screen were the same as in Experiment 1, that is, amplitudes of movements and movement effects were equal in size.

As the response assignment changed from trial to trial, sessions were not subdivided into blocks any more. Therefore, there was only one practice phase consisting of two practice blocks at the beginning of each session. At first, participants performed 32 practice trials to get used to the response mode. They were presented with the German words “Ja” [yes] and “Nein” [no] and had to activate the near response box in half of the “yes” trials and the far response box in the other half as indicated by the visual response cue, while they should not make any response in “no” trials. Feedback about the correctness of the responses was provided as in the previous experiments. After these trials, they received 20 trials with practice sentences which proceeded exactly like the experimental trials and which appeared with the two response assignments each in one half of the trials.

Design and analysis. Experimental design and data analysis were the same as in Experiment 1, except that effect direction (yes-is-near, yes-is-far) now varied from trial to trial. This was done, again, by assigning the two material blocks of stimulus sentences to one of the effect directions each, but this time, in each trial a sentence was selected randomly from one or the other material block. The assignment of material blocks to conditions of effect direction and action-effect relation and the occurrence of these combinations in the first or second session were counterbalanced across participants (see Appendix B for the complete counterbalance scheme).

3.1.2 Results

The data from three participants were excluded from analyses: two because they too often did not move the whole hand to the response buttons (one in 15.5% and the other in 15.4% of the sensible trials), and one because he missed the second session. The elimination of outliers from the data of the final sample resulted in a total of 4.8% excluded trials for RTs and of 5.5% for MTs.

RTs. There was no significant interaction between Sentence-effect compatibility and Order of action-effect relations in the ANOVA across sessions ($p > .07$), but the same analysis yielded a significant main effect of Sentence-effect compatibility ($F(1, 14) = 5.93$, $MSE = 931.16$, $p < .05$) and a significant interaction between Sentence-effect compatibility, Action-effect relation, and Sentence type ($F(1, 14) = 6.58$, $MSE = 730.41$, $p < .05$). The means are shown in Table 3.1. As separate ANOVAs on RTs to concrete and abstract sentences revealed, this interaction resulted from an interaction between Sentence-effect compatibility and Action-effect relation for concrete sentences ($F(1, 15) = 5.07$, $MSE = 1252.8$, $p < .05$), while for abstract sentences there was only a significant main effect of Sentence-effect compatibility ($F(1, 15) = 8.1$, $MSE = 1013.8$, $p < .05$). The latter effect reflected faster RTs in trials where sentence direction and effect direction were incompatible compared to trials with compatible directions which held across action-effect relations. Also concrete sentences showed a marginally significant disadvantage for compatible cases, but only in the condition with regular action-effect relation ($t(15) = 1.88$, $p = .08$); in the transformed condition, the RT difference between compatible and incompatible trials was numerically reversed, but far from significant ($p > .2$).

Thus, a negative ACE occurred in RTs. This effect was modulated by action-effect relation during responses to concrete sentences, but not during responses to abstract sentences.

MTs. The MT analysis yielded a significant interaction between Sentence-effect compatibility and Order of action-effect relations ($F(1, 14) = 6.29$, $MSE = 158.21$, $p < .05$). When analyzing data of the first session only, significant interactions appeared between

Sentence-effect compatibility and Action-effect relation ($F(1, 14) = 4.7$, $MSE = 108.25$, $p < .05$) as well as between Sentence-effect compatibility and Sentence type ($F(1, 14) = 8.05$, $MSE = 43.67$, $p < .05$). Mean MTs are listed in Table 3.1. Further ANOVAs performed separately for each sentence type revealed that during responses to concrete sentences, movements were faster across action-effect relations when sentence direction and effect direction were incompatible than when they were compatible ($F(1, 14) = 8.35$, $MSE = 80.51$, $p < .05$). In contrast, there was a significant interaction between Sentence-effect compatibility and Action-effect relation ($F(1, 14) = 6.33$, $MSE = 71.41$, $p < .05$) in responses to abstract sentences, resulting from movements being faster in trials with incompatible sentence and effect directions compared to trials with compatible directions only when action-effect relation was transformed ($t(7) = 2.52$, $p < .05$), while no significant difference was found for regular action-effect relation ($p > .1$).

So, unlike RTs, MTs for concrete sentences showed a negative ACE that was not modulated by action-effect relation, and those for abstract sentences displayed a compatibility disadvantage only in the condition with transformed action-effect relation. Because of this discrepancy between RTs and MTs, again TRTs were analyzed.

TRTs. As for MTs, there was a significant interaction between Sentence-effect compatibility and Order of action-effect relations ($F(1, 14) = 6.59$, $MSE = 1630.07$, $p < .05$). Therefore, further analyses focused on the first session (see Figure 3.2 for mean TRTs) which yielded a significant main effect of Sentence-effect compatibility ($F(1, 14) = 4.67$, $MSE = 1344.46$, $p < .05$) and a significant interaction between Sentence-effect compatibility, Sentence type, and Action-effect relation ($F(1, 14) = 6.73$, $MSE = 843.77$, $p < .05$). Separate ANOVAs for each sentence type revealed similar results as for MTs: A compatibility disadvantage occurred in responses to concrete sentences across action-effect relations ($F(1, 14) = 4.59$, $MSE = 851.22$, $p = .05$) and was also observed in responses to abstract sentences in the condition with transformed action-effect relation ($t(7) = 2.98$, $p < .05$), but not in the regular condition ($p > .6$), resulting in a significant interaction between Sentence-effect compatibility and Action-effect relation for abstract sentences ($F(1, 14) = 4.63$, $MSE = 1337.0$, $p < .05$).

Error rates. In the ANOVA on error rates, neither significant interactions between Sentence-effect compatibility and Order of action-effect relations were found (all ps > .1) nor other significant effects involving the compatibility variable (all *p*s > .1). Mean error rates are given in Table 3.1.

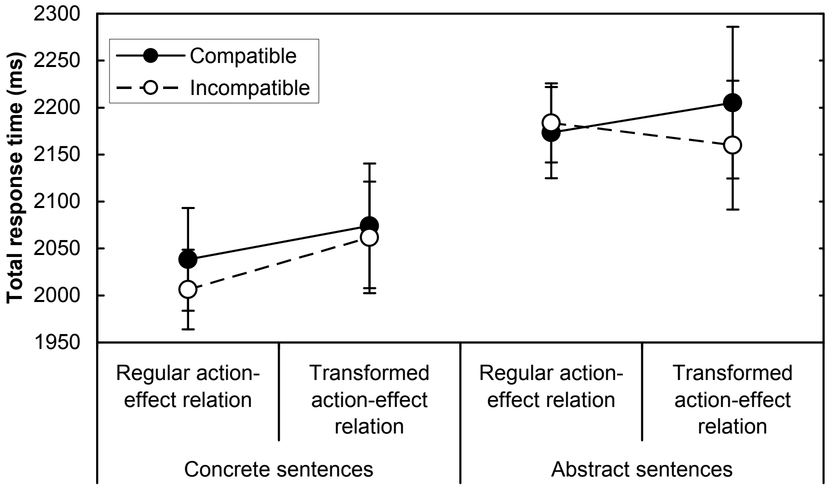

Figure 3.2. Mean TRTs (in ms) in the first session of Experiment 4 as a function of the factors Sentence-effect compatibility, Action-effect relation, and Sentence type. Error bars indicate standard errors.

Table 3.1

Mean RTs (in ms), MTs (in ms), and error rates (in %) in Experiment 4, presented as a function of Sentence type, Sentence-effect compatibility, and Action-effect relation. The values in parentheses represent standard errors

	Concrete sentences		Abstract sentences	
	Compatible	Incompatible	Compatible	Incompatible
RT (across sessions)				
Regular action-effect relation	1783 (24)	1759 (20)	1915 (26)	1897 (25)
Transformed action-effect relation	1767 (35)	1784 (28)	1923 (41)	1896 (36)
MT (first session)				
Regular action-effect relation	239 (29)	234 (26)	233 (25)	241 (24)
Transformed action-effect relation	238 (26)	226 (25)	229 (24)	222 (24)
Error rate (across sessions)				
Regular action-effect relation	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)
Transformed action-effect relation	0.0 (0.0)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)

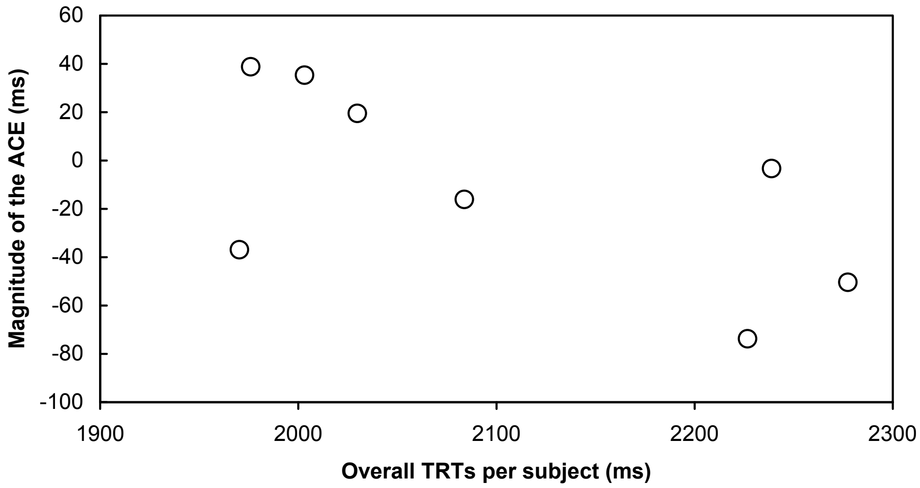

Figure 3.3. Relationship between the magnitude of the ACE (TRTs for incompatible trials - TRTs for compatible trials) and participants' overall TRTs (means of all correct responses on critical trials of the first session), shown in the first session of Experiment 4 with regular action-effect relation.

3.1.3 Discussion

According to predictions based on TEC and to findings of Borreggine and Kaschak (2006), a positive ACE was expected to arise from cueing the "yes" direction at sentence onset because in this way, response planning should take place while features of the semantic content of the sentence are activated. Instead, the present experiment produced a negative ACE in TRTs, at least for concrete sentences, that seemed to refer to movement effect. In principle, the data could also reflect a movement-related ACE that turned into the opposite under the condition of transformed action-effect relation, but as the compatibility effect did not interact with the action-effect relation factor, the more parsimonious and thus the preferable interpretation of the results is that the ACE has the same sign in both action-effect relation conditions and therefore can be regarded as being effect-related. Since for abstract sentences, the ACE did not occur in the condition with regular action-effect relation, it cannot be determined whether the ACE in the transformed condition relied on movement or effect.

The obtained compatibility disadvantage could possibly result from participants not immediately paying attention to the response cue when it appeared on the screen. Since the cue was visible throughout the whole sentence presentation, a large part of participants might have postponed the processing of the cue and the response preparation to the end of the sentence where features of the described action become integrated. Thus, again, the different timing between response preparation and sentence comprehension could be responsible for this result. This should become apparent in different effects depending on early or late response preparation which in turn should be reflected in fast or slow responses. Therefore, as in Experiment 3, a Speed variable was created, but this time based on TRTs as this measure seemed to reflect the response processes more completely than RTs in this experiment. Participants' speed values were calculated by averaging their TRTs across all correct trials of the first session containing sensible toward and away sentences. As a covariate, this Speed variable then entered into a three-way mixed factor ANOVA performed on the TRT data of the first session with Sentence-effect compatibility (compatible, incompatible) and Sentence type (concrete, abstract) as within-subjects factors and with Action-effect-relation (regular, transformed) as a between-subjects factor. The analysis revealed a significant interaction between Sentence-effect compatibility and Speed ($F(1, 13) = 12.53$, $MSE = 737.24$, $p < .01$). To get an idea of what this interaction means, a scatter plot is shown in Figure 3.3 which illustrates the relationship between participants' speed (their mean TRTs) and the magnitude of the ACE for regular action-effect relation. The magnitude of the ACE was calculated in the same way as in Experiment 3 (but based on TRTs), and so again positive numbers indicate a compatibility advantage and negative numbers a compatibility disadvantage. Descriptively, the slower the participants responded the more they showed a compatibility disadvantage. Only some of the fastest participants exhibited a compatibility advantage. For transformed action-effect relation, the picture was the same, only that even the fastest participants produced no compatibility advantage – instead, they showed no compatibility difference at all. This pattern of results resembles the pattern obtained in Experiment 3: Slow responses which probably reflect response preparation after the completion of the sentence seem to promote the emergence of a negative ACE.

Although this roughly supports the account of the ACE based on the mechanisms proposed by TEC, this account does not seem to provide the full explanation of the data, as even fast-responding participants showed no strong positive ACE. However, there could be an alternative way of how the negative ACE emerges.[2] Perhaps the ACE consists of two successive compatibility effects with opposite directions instead of only one effect. At first, there may be an interference effect: Response preparation might start right at the beginning of each trial because – in experiments with instructions for whole blocks of trials – participants recollect the direction of the "yes" response, or the trial-specific cue automatically triggers the activation of the indicated directional feature of the response. As a consequence, the feature code representing the "yes" direction may be occupied by the formed action plan and so may be less available when sentence processing requires the direction of the described action to be coded. Due to this interference between semantic processing and concurrent response preparation, sentence comprehension is slower for compatible than for incompatible cases. The second compatibility effect corresponds with the standard interpretation of the ACE: After sufficient information from the sentence has accrued to enable the judgment on its sensibility, the respective response is selected and executed. This process can be subject to priming because now the directional feature required for the response is more easily accessible due to its activation in the course of sentence processing, thereby facilitating response selection. Whether the ACE observed in the end is positive or negative, may result from the additive combination of the early interference effect and the late priming effect. The relative contribution of these two components to the overall effect may be influenced by different factors. Some may strengthen the initial response preparation or prolong the sentence comprehension process, thereby increasing the contribution of the early interference effect and making an overall negative ACE more likely. For instance, the slow-responding participants in Experiments 3 and 4 might be less skilled comprehenders who need more time to understand a sentence and therefore have a more pronounced early interference effect leading to a negative ACE in the end.

In order to better understand the negative ACE and to distinguish between these two accounts, the next experiment served to take a closer look at how the sign of the ACE is influenced by response preparation at different points in time relative to the sentence comprehension process.

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[2] Wolfgang Prinz is thanked for suggesting this account.

3.2 Experiment 5

The two presented accounts of the ACE differ in their predictions of when the negative ACE should occur: In the TEC-based account as presented above and as advocated by Borreggine and Kaschak (2006), the ACE should become negative only when response preparation takes place around the end of the sentence – at a time where feature codes are bound to the simulation of the described action. According to the alternative two-component account, the negative ACE is most likely to appear when the response is planned around the onset of the sentence because that way, the "yes" direction is already occupied by the action plan when the directional feature is to be coded during sentence processing.

The present experiment attempted to contrast these predictions by presenting the cue indicating the "yes" direction at different points in time and thus varying from when on response preparation is possible.

3.2.1 Method

Participants. Forty-eight adults (mean age = 24.3 years; 10 males, 38 females) participated in the experiment. The data from eight participants were discarded and replaced (details are provided in the Results section).

Materials and procedure. The only difference between the present experiment and Experiment 4 was that the SOA between sentence onset and the presentation of the response cue was manipulated within subjects and varied randomly from trial to trial. Figure 3.4 illustrates the sequence of trial events. One of the five SOA conditions corresponded with Experiment 4 in that the response cue appeared on the screen simultaneously with the onset of the sentence presentation (SOA = 0 ms). In the other conditions, the cue was presented 1000 ms before sentence onset (SOA = -1000 ms), 500 ms before sentence onset (SOA = -500 ms), in the middle of the sentence presentation (SOA = 50% of the sentence length), and at the end of the sentence presentation (SOA = 100% of the sentence length).

At the start of each session, participants first received 40 trials to practice the response mode and after that, they performed 20 trials with practice sentences. These two kinds of practice trials proceeded basically like the practice trials in Experiment 4, except that not only the response assignment changed from trial to trial, but also the SOA, with all combinations of them occurring equally often.

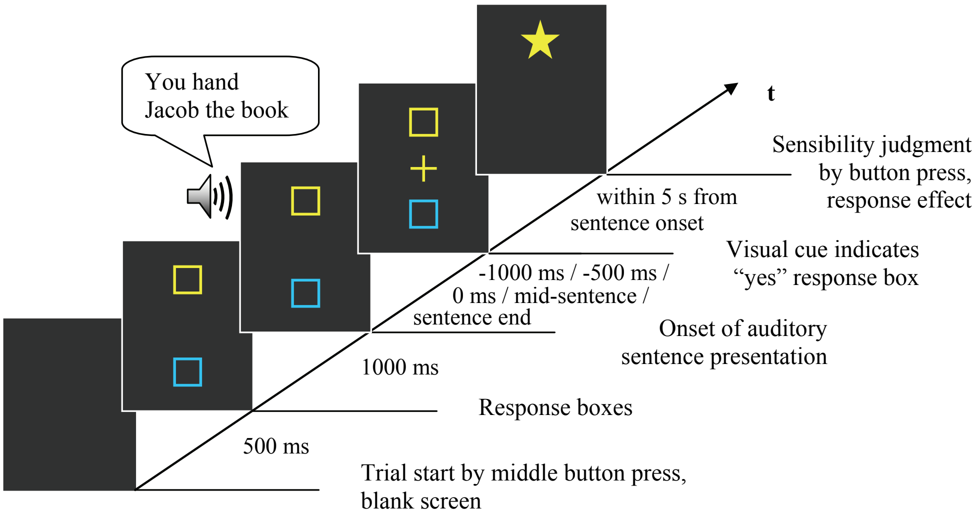


Figure 3.4. Sequence of events in an experimental trial of Experiment 5 by the example of a sensible away sentence presented in the yes-is-far condition.

Design and analysis. Experimental design and data analysis were identical to that of Experiment 4, apart from the additional within-subjects factor SOA (-1000 ms, -500 ms, 0 ms, 50% of sentence length, 100% of sentence length) which varied from trial to trial. The sentences were selected randomly in each trial from either of the two material blocks which were assigned to the two effect directions in the same counterbalanced way as in the preceding experiment. On top of it, an equal number of sentences of each category in each material block was randomly assigned to the five SOA conditions. Across participants, all combinations of material blocks, effect directions, and action-effect relations occurred equally often per session.

3.2.2 Results

The data from eight participants were dropped from analyses for the following reasons: Two participants missed the second session, two participants did not receive the intended version of the experiment by mistake, and four participants did not move the whole hand to the response buttons in 23.3%, 16.9%, 15.8%, and 35.8% of the sensible trials, respectively. No further trials were eliminated from the data of the final sample because in the present experiment, median RTs and median MTs were computed for each participant in each condition instead of means. Since the additional SOA manipulation resulted in too few data points per condition to identify and remove outliers, analyses of medians appeared to be more appropriate.

RTs. The ANOVA on median RTs yielded a significant interaction between Sentence-effect compatibility, SOA, and Order of action-effect relations ($F(4, 184) = 6.06$, $MSE = 16584.09$, $p < .01$), but the analysis of the data of the first session showed no significant effects for the variable Sentence-effect compatibility (all *p*s > .09). The means of the first session are given in Table 3.2.

MTs. The analysis on median MTs across sessions revealed neither significant interactions between Sentence-effect compatibility and Order of action-effect relations (all *p*s > .1) nor significant effects involving the compatibility variable (all *p*s > .3). Means are shown in Table 3.2.

Error rates. For error rates, the same was true as for MTs: Across sessions, neither significant interactions between Sentence-effect compatibility and Order of action-effect relations were found (all *p*s > .1) nor other significant compatibility effects (all *p*s > .5). Mean error rates are also listed in Table 3.2.

Thus, no ACE was found in this experiment.

3.2.3 Discussion

As no ACE appeared in this experiment, it did not provide the desired insight into the processes responsible for the emergence of the negative ACE.

Possibly, the ACE was masked by noise again because the response cue was visible until the end of the trial and participants may have differed in their strategies of when to attend to the cue and prepare the “yes” direction. The random order of SOA conditions may have additionally contributed to participants adopting a general strategy for dealing with these conditions as this is more economical than switching between different strategies from trial to trial. Perhaps the mixed presentation of the SOA conditions has also added noise to the data by itself due to participants’ uncertainty as to when exactly the cue would appear.

Therefore, the experiment was repeated with some changes that should help to avoid these problems.

Table 3.2

Mean RTs (in ms), MTs (in ms), and error rates (in %) in Experiment 5, presented as a function of Sentence type, Sentence-effect compatibility, Action-effect relation, and SOA. The values in parentheses represent standard errors

	Concrete sentences		Abstract sentences	
	Compatible	Incompatible	Compatible	Incompatible
RT (first session)				
Regular action-effect relation				
SOA = -1000 ms	1843 (37)	1795 (33)	2002 (44)	2014 (38)
SOA = -500 ms	1765 (27)	1770 (32)	1926 (33)	1948 (38)
SOA = 0 ms	1800 (28)	1789 (24)	1913 (36)	1957 (37)
SOA = 50% of the sentence length	1743 (26)	1762 (30)	1971 (38)	1959 (30)
SOA = 100% of the sentence length	2140 (36)	2147 (29)	2368 (28)	2385 (43)
Transformed action-effect relation				
SOA = -1000 ms	1846 (34)	1883 (44)	1988 (35)	2070 (54)
SOA = -500 ms	1898 (49)	1825 (36)	2009 (35)	2028 (43)
SOA = 0 ms	1873 (37)	1846 (47)	2027 (49)	1990 (38)
SOA = 50% of the sentence length	1857 (37)	1890 (37)	2002 (35)	2024 (33)
SOA = 100% of the sentence length	2244 (31)	2219 (34)	2493 (35)	2470 (33)
MT (across sessions)				
Regular action-effect relation				
SOA = -1000 ms	232 (11)	242 (11)	239 (10)	244 (12)
SOA = -500 ms	234 (11)	235 (11)	242 (12)	258 (22)
SOA = 0 ms	239 (9)	234 (11)	252 (13)	245 (10)
SOA = 50% of the sentence length	238 (10)	238 (9)	246 (13)	239 (10)
SOA = 100% of the sentence length	228 (10)	227 (11)	229 (12)	222 (10)
Transformed action-effect relation				
SOA = -1000 ms	248 (16)	252 (15)	253 (15)	249 (13)
SOA = -500 ms	247 (13)	237 (12)	255 (14)	251 (13)
SOA = 0 ms	253 (14)	247 (13)	259 (16)	248 (15)
SOA = 50% of the sentence length	254 (15)	242 (14)	246 (13)	260 (16)
SOA = 100% of the sentence length	248 (13)	243 (13)	233 (11)	251 (15)
Error rate (across sessions)				
Regular action-effect relation				
SOA = -1000 ms	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (0.5)
SOA = -500 ms	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
SOA = 0 ms	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
SOA = 50% of the sentence length	0.0 (0.0)	0.0 (0.0)	0.5 (0.5)	0.0 (0.0)
SOA = 100% of the sentence length	0.5 (0.5)	0.7 (0.7)	0.0 (0.0)	0.0 (0.0)
Transformed action-effect relation				
SOA = -1000 ms	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
SOA = -500 ms	0.7 (0.7)	0.5 (0.5)	1.0 (0.7)	1.0 (1.0)
SOA = 0 ms	0.5 (0.5)	0.0 (0.0)	0.5 (0.5)	0.0 (0.0)
SOA = 50% of the sentence length	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)	0.0 (0.0)
SOA = 100% of the sentence length	0.0 (0.0)	0.0 (0.0)	1.0 (0.7)	1.0 (0.7)

3.3 Experiment 6

Because of the discussed problems in Experiment 5, Experiment 6 addressed the same questions again by trying to force the response preparation at the given points in time. The response cue was presented only for a short period of time in order to prevent participants from postponing the processing of the cue. Moreover, to reduce noise in the data, SOA conditions were arranged in separate blocks so that participants could adapt themselves to the respective temporal structure to be prepared for the arrival of the cue. For the same reason, the condition in which the cue had been presented in the middle of the sentence (which was a variable point) was changed in such a way that the cue now appeared constantly 500 ms after sentence onset.

3.3.1 Method

Participants. Forty volunteers (mean age = 24.4 years; 15 males, 25 females) were tested. The data from ten participants were excluded and replaced (details are provided in the Results section).

Materials and procedure. Materials and procedure were identical to those used in Experiment 5 except for the following modifications: The cue signaling the direction of the "yes" response was visible only for 500 ms. As in the preceding experiment, the cue appeared on the screen either 1000 ms or 500 ms before the onset of the sentence (SOA = -1000 ms, SOA = -500 ms), at the onset of the sentence (SOA = 0 ms) or at the end of the sentence (SOA = 100% of the sentence length). Yet the condition in which the cue had been presented in the middle of each sentence was replaced by a condition in which the cue was given 500 ms after sentence onset (SOA = 500 ms). This new point of cue presentation roughly coincided with the onset of the verbs within the toward sentences and with the end of the verbs within the away sentences. A further difference to Experiment 5 was the blocked presentation of SOA conditions instead of the mixed mode, but within the separate SOA blocks, the "yes" direction continued to vary in a random order (see Figure 3.5 for an illustration).

The two blocks of practice trials at the beginning of each session were basically identical to those of Experiment 5, except that they underwent the same modifications as the experimental trials.

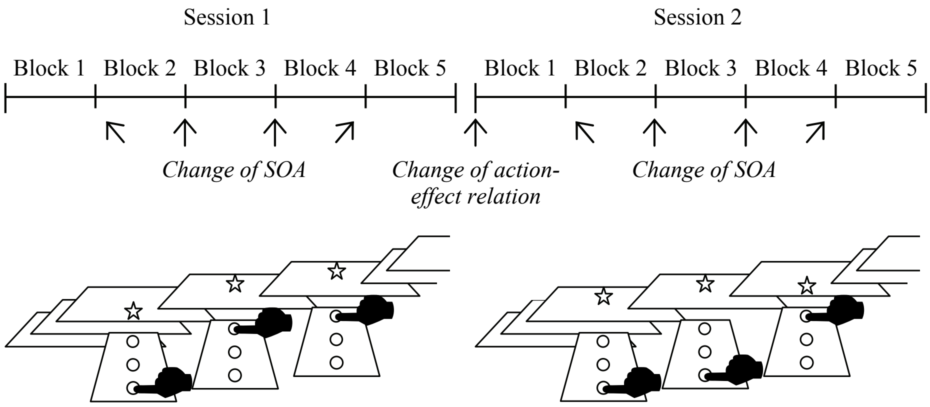


Figure 3.5. Structure of Experiment 6. The upper part of the figure depicts the arrangement of variables in sessions and blocks, the lower part illustrates the effect direction varying randomly from trial to trial throughout the blocks with a different action-effect relation in each session.

Design and analysis. Experimental design and data analysis were basically the same as in Experiment 5. Concerning the blocked presentation of SOA conditions, the order of blocks was counterbalanced so that across participants each SOA condition occurred with an equal frequency at each position of the block presentation order. This applied to all combinations of material blocks, effect directions, and action-effect relations that occurred in the two sessions (see Appendix B for more details about the counterbalance scheme). Again, for each participant, an equal number of sentences of each category in each material block was pseudorandomly assigned to the SOA conditions in such a way that across participants each combination of effect directions, SOAs, and action-effect relations contained each sentence with equal frequency.

3.3.2 Results

The data from ten participants were removed from analyses – three because they made errors in 15.8%, 17.2%, and 16.9% of the trials, respectively, and seven because too often they did not move the whole hand to the response buttons (in 20.8%, 51.3%, 18%, 16.7%, 35%, 16.5%, and 15.7% of the sensible trials, respectively). For the same reasons as in Experiment 5, median RTs and MTs were analyzed and hence no outliers were eliminated. Yet this time, trials with two particular triads of sentences (a concrete and an abstract one) were excluded from analyses. They were erroneously judged as nonsensical by a large part of participants which led to unbalanced frequencies of these sentences in the different conditions. Since there were relatively few data points per condition in this experiment, it happened that some conditions did not include any correct response to these sentences at all while other conditions did. This could have distorted the results due to the different sentence lengths, and therefore, trials containing these sentences were removed from the other conditions, too.[3] This eliminated 3.9% of the data.

RTs. The analysis of the median RTs yielded a significant interaction between Sentence-effect compatibility, Action-effect relation, SOA, and Order of action-effect relations ($F(4, 152) = 3.99$, $MSE = 15471.68$, $p < .01$). When looking at the data of the first session only, a significant interaction between Sentence-effect compatibility and SOA was observed ($F(4, 152) = 4.38$, $MSE = 19836.38$, $p < .01$). Condition means are shown in Table 3.3. Further analyses performed separately on RTs under the five SOA conditions revealed significant main effects of Sentence-effect compatibility for the SOA of 0 ms ($F(1, 38) = 4.99$, $MSE = 24368.07$, $p < .05$) and for the SOA of 500 ms ($F(1, 38) = 6.13$, $MSE = 18202.65$, $p < .05$) and a marginally significant main effect of Sentence-effect compatibility for the condition in which the SOA was 100% of the sentence length ($F(1, 38) = 3.05$, $MSE = 16525.46$, $p = .09$). While for the SOA of 0 ms, responses across action-effect relations were faster when sentence direction and effect direction were compatible than when they were incompatible, the opposite pattern was obtained for conditions in which the SOAs were 500 ms and 100% of the sentence length – they showed slower responses in trials with compatible directions than in trials with incompatible directions, again holding across action-effect relations. In conditions with SOAs of -1000 ms and -500 ms, no significant compatibility effects were observed (all ps > .1).

Thus, there was a compatibility benefit when the cue was presented at sentence onset, but when the cue appeared 500 ms after sentence onset or at the end of the sentence, compatibility costs occurred. These effects were not modulated by action-effect relation.

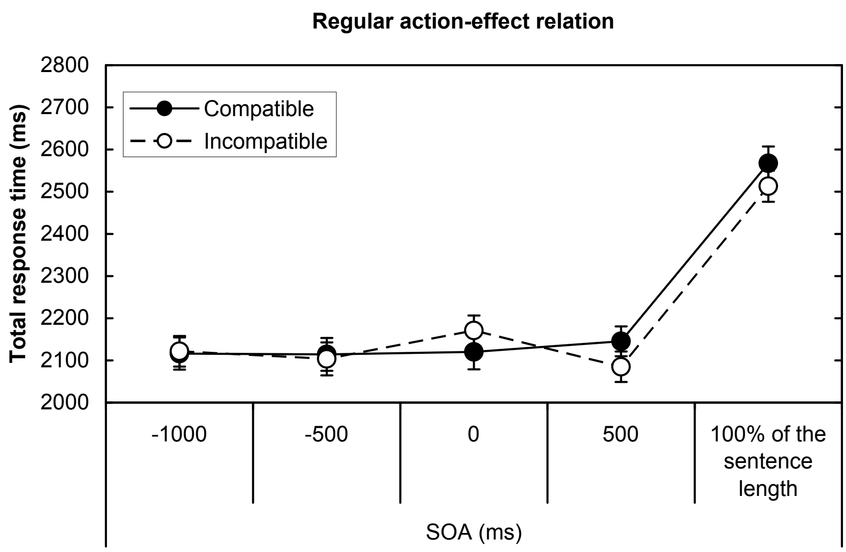
[3] In Experiments 1 through 4, all sentences appeared much more often per condition, and so, the exclusion of incorrect trials did not have the same consequences as in Experiment 6. Even in Experiment 5, the distribution of the remaining correct trials containing these sentences was not as unbalanced across conditions as in Experiment 6 – there was no condition in which all trials with a particular sentence were incorrect.

MTs. In the median MT analysis across sessions, no significant interaction between Sentence-effect compatibility and Order of action-effect relations (all *p*s > .2) was found. The same analysis yielded a significant interaction between Sentence-effect compatibility, Action-effect relation, and Sentence type ($F(1, 38) = 5.28$, $MSE = 878.68$, $p < .05$). Means are listed in Table 3.3. While responses to concrete sentences showed no significant effects for the compatibility factor (all *p*s > .1), responses to abstract sentences displayed a significant interaction between Sentence-effect compatibility and Action-effect relation ($F(1, 38) = 4.21$, $MSE = 941.62$, $p < .05$). This interaction resulted from faster movements in trials where sentence direction and effect direction were compatible compared to trials where they were incompatible, holding across SOA conditions, but only when action-effect relation was transformed ($F(1, 38) = 4.87$, $MSE = 1392.24$, $p < .05$), whereas no compatibility effects were obtained in the condition with regular action-effect relation (all *p*s > .7).

Since results under the transformed condition contradict those obtained for RTs for conditions in which the SOAs were 500 ms and 100% of the sentence length, TRTs were analyzed as well.

TRTs. The analysis of the median TRTs showed a significant interaction between Sentence-effect compatibility, Action-effect relation, SOA, and Order of action-effect relations ($F(4, 152) = 3.99$, $MSE = 16830.69$, $p < .01$), because of which further analyses focused on the first session. Mean TRTs of the first session are depicted in Figure 3.6; since no effect of sentence type was observed, data are presented averaged over concrete and abstract sentences. There was a significant interaction between Sentence-effect compatibility and SOA ($F(4, 152) = 4.58$, $MSE = 23265.86$, $p < .01$), arising from a similar pattern of results as for RTs with some slight differences. As separate analyses for each SOA condition revealed, again, significant main effects of Sentence-effect compatibility appeared for the SOA of 0 ms ($F(1, 38) = 5.91$, $MSE = 30448.17$, $p < .05$) and for the SOA of 500 ms ($F(1, 38) = 6.09$, $MSE = 20211.36$, $p < .05$), with the former reflecting a compatibility advantage across action-effect relations and the latter reflecting a compatibility disadvantage across action-effect relations. Unlike for RTs, compatibility effects were absent not only for the SOA of -1000 ms, but also for the condition in which the SOA was 100% of the sentence length (all *p*s > .1), while a significant interaction between Sentence-effect compatibility and Action-effect relation emerged for the SOA of -500 ms ($F(1, 38) = 5.33$, $MSE = 19064.59$, $p < .05$). However, this interaction only resulted from significantly faster responses for trials with compatible directions of sentence and movement effect than for trials with incompatible directions when action-effect relation was transformed ($F(1, 19) = 6.53$, $MSE = 24843.67$, $p < .05$), whereas compatible and incompatible trials did not differ significantly in the regular condition (all *p*s > .4).

Error rates. Regarding error rates, there was a significant interaction between Sentence-effect compatibility, Action-effect relation, SOA, and Order of action-effect relations ($F(4, 152) = 3.08$, $MSE = 52.42$, $p < .05$). The analysis of the data of the first session yielded a significant interaction between Sentence-effect compatibility and Action-effect relation ($F(1, 38) = 8.04$, $MSE = 38.89$, $p < .01$), resulting from significant effects involving the compatibility variable in the regular condition in contrast to non-significant effects in the transformed condition (all *p*s > .1), as follow-up ANOVAs for the two action-effect relation conditions revealed. Mean error rates in these conditions are shown in Figure 3.7; for the same reasons as above, data are presented averaged over the two sentence types. In the regular condition, a significant main effect of Sentence-effect compatibility appeared ($F(1, 19) = 5.63$, $MSE = 31.58$, $p < .05$) as well as a significant interaction between Sentence-effect compatibility and SOA ($F(4, 76) = 3.78$, $MSE = 44.26$, $p < .05$). When looking separately at errors under the five SOA conditions to interpret this interaction, only the condition with an SOA of -1000 ms showed a significant main effect of Sentence-effect compatibility ($F(1, 19) = 6.91$, $MSE = 72.37$, $p < .05$), reflecting higher error rates for trials with compatible sentence and effect directions than for trials with incompatible directions. In the remaining SOA conditions, no significant differences between compatible and incompatible trials were observed (all *p*s > .2). As significant ACEs occurred in different SOA conditions for error rates and for RTs and TRTs respectively, a speed-accuracy trade-off can be ruled out.



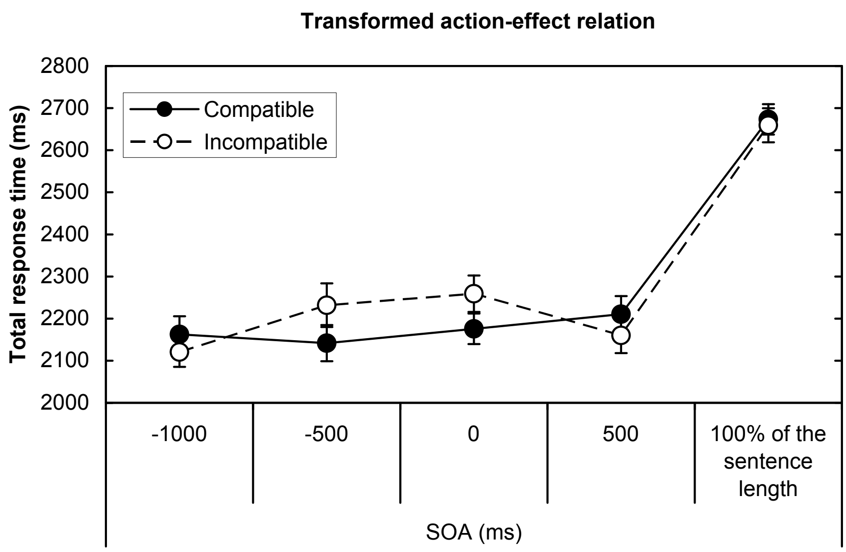


Figure 3.6. Mean TRTs (in ms) in the first session of Experiment 6 as a function of Sentence-effect compatibility, SOA, and Action-effect relation (top panel: regular action-effect relation; bottom panel: transformed action-effect relation). Data are averaged over concrete and abstract sentences. Error bars represent standard errors.

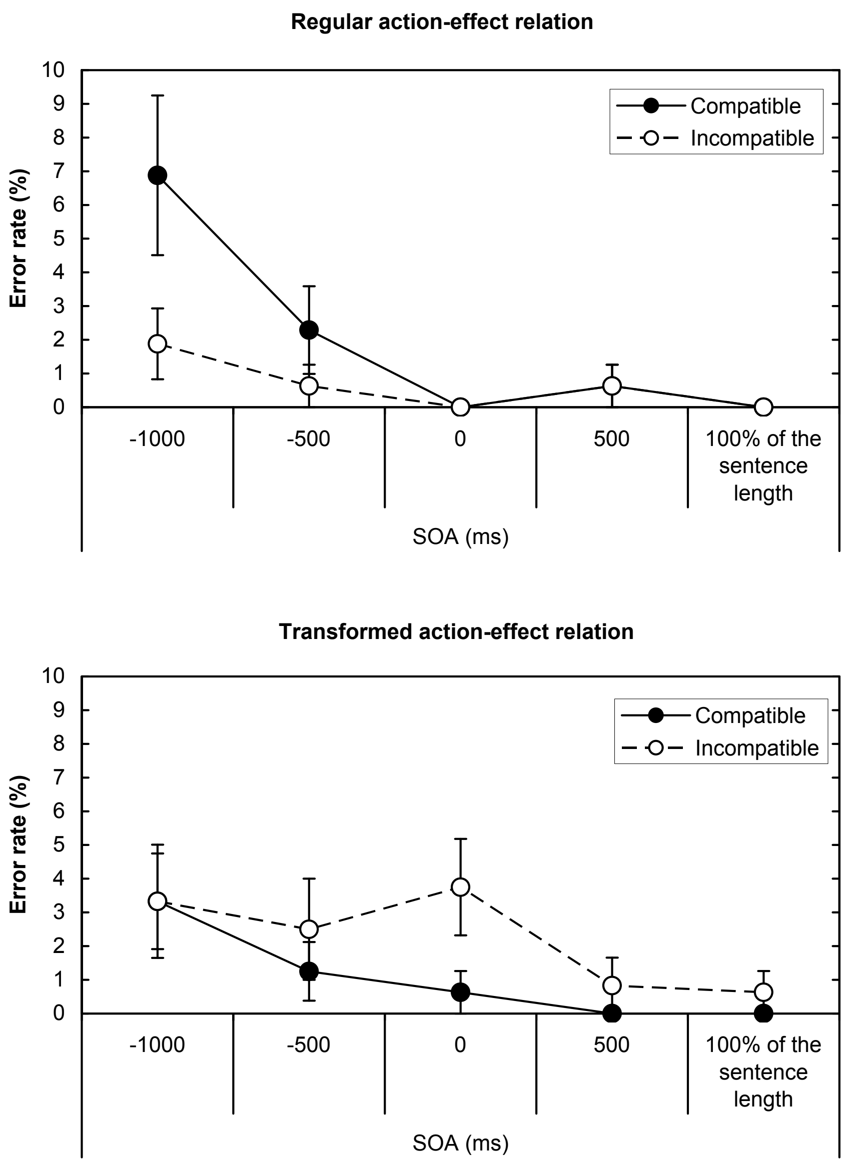


Figure 3.7. Mean error rates (in %) in the first session of Experiment 6 as a function of Sentence-effect compatibility, SOA, and Action-effect relation (top panel: regular action-effect relation; bottom panel: transformed action-effect relation). Data are averaged over concrete and abstract sentences. Error bars represent standard errors.

Table 3.3

Mean RTs (in ms) and MTs (in ms) in Experiment 6, presented as a function of Sentence type, Sentence-effect compatibility, Action-effect relation, and SOA. The values in parentheses represent standard errors

	Concrete sentences				Abstract sentences			
	Compatible		Incompatible		Compatible		Incompatible	
RT (first session)								
Regular action-effect relation								
SOA = -1000 ms	1773	(37)	1827	(35)	1933	(50)	1902	(38)
SOA = -500 ms	1765	(31)	1780	(33)	1925	(48)	1913	(55)
SOA = 0 ms	1795	(47)	1817	(34)	1916	(51)	1980	(35)
SOA = 500 ms	1819	(33)	1753	(40)	1936	(43)	1893	(40)
SOA = 100% of the sentence length	2203	(45)	2135	(36)	2381	(39)	2368	(28)
Transformed action-effect relation								
SOA = -1000 ms	1819	(41)	1763	(30)	1963	(60)	1916	(34)
SOA = -500 ms	1799	(39)	1900	(87)	1954	(59)	1992	(45)
SOA = 0 ms	1831	(36)	1895	(61)	1987	(43)	2059	(45)
SOA = 500 ms	1878	(34)	1824	(48)	2017	(67)	1970	(46)
SOA = 100% of the sentence length	2325	(43)	2269	(37)	2519	(38)	2514	(46)
MT (across sessions)								
Regular action-effect relation								
SOA = -1000 ms	237	(16)	242	(16)	246	(14)	246	(15)
SOA = -500 ms	243	(15)	243	(14)	246	(15)	251	(15)
SOA = 0 ms	239	(12)	240	(12)	246	(14)	245	(14)
SOA = 500 ms	238	(13)	231	(11)	250	(13)	244	(15)
SOA = 100% of the sentence length	241	(13)	252	(12)	240	(12)	239	(12)
Transformed action-effect relation								
SOA = -1000 ms	252	(17)	252	(15)	246	(15)	260	(16)
SOA = -500 ms	248	(14)	241	(12)	251	(16)	256	(15)
SOA = 0 ms	246	(14)	251	(14)	251	(15)	263	(16)
SOA = 500 ms	248	(12)	241	(12)	247	(14)	250	(12)
SOA = 100% of the sentence length	245	(13)	241	(13)	241	(13)	248	(17)

3.3.3 Discussion

The aim of the present experiment was to investigate the temporal dynamics of the interaction between the processes of sentence comprehension and response preparation in order to draw conclusions from that about the emergence conditions of the negative ACE.

As the changes in Experiment 6 have proved to be effective in producing clearer results, now predictions derived from the two presented accounts of the negative ACE can be evaluated from the data.

First of all, the results indicate that the timing between sentence comprehension and response preparation indeed affects whether the ACE is present at all and, if so, whether it is positive or negative. When the response was being planned 1000 ms or 500 ms before the onset of the sentence, the ACE was absent in response times. Actually, in the last-named case, TRTs showed a compatibility effect in the condition with transformed action-effect relation, but without having an ACE in the regular condition, it cannot be distinguished between a positive effect-related and a negative movement-related ACE in the transformed condition, and therefore, this effect should not receive too much attention. When response planning and sentence processing started at the same time, there was a positive ACE, whereas the ACE became negative when participants began to prepare the response 500 ms after sentence onset and finally, the ACE disappeared again when the response was being prepared after the end of the sentence. All of the significant ACEs turned out to be related to the movement effect. As already explained in the Discussion section of Experiment 4, this is the preferable interpretation of the data when the compatibility effects are not modulated by action-effect relation.

The positive ACE in the condition with the response cue appearing at sentence onset fits better with the TEC-based explanation than with the alternative two-component framework of the ACE: When the “yes” direction is indicated at the beginning of the sentence and this direction is compatible with the direction of the described action, priming occurs between the representation of the sentence content and the response representation. This is because both activate the directional feature at the same time before it is bound to the one or the other event (see Figure 3.8 for an illustration of the temporal relations between the processes involved).

Nevertheless, the early interference effect within the two-component framework is not completely unfounded and would fit into the logic of the TEC-based account as well. Not only integrated features of the semantic representation of the sentence should impair late response preparation, but also integrated features of an early response preparation should impair subsequent sentence processing. The reason why no interference effect emerged in the condition with the cue appearing at sentence onset may simply be that the directional code was not yet bound to the action plan when it was activated during sentence processing.

If one assumes that the RTs in the condition with cue presentation at the end of the sentence reflect the time it takes to decode the cue and to plan the response, then response preparation is completed and feature codes are integrated at about 500 ms after the arrival of the cue. Regarding sentence comprehension, the direction of the described action is clear once subject and verb (the first two words in the sentence) are processed. This point may even shift to the subject of the sentence after participants have understood the unchanged syntactic structure. As the end of the verbs lies between 500 ms (for concrete sentences) and 850 ms (for abstract sentences) after sentence onset and as the uniqueness point at which the word is recognized and the direction of the described action becomes clear lies somewhere before this, there seems to be a temporal overlap of the activation of the directional code during response planning and sentence processing. Thereby, the comprehension of the sentence is facilitated which leads to a positive ACE (see Figure 3.8 for an illustration).

Tentative indications for the presence of an early interference effect are possibly discernible in the SOA conditions in which the response cue appeared before the beginning of the sentence presentation. Under these conditions (at least for the SOA of -1000 ms), response preparation should definitely be completed at the time where the directional code is needed to comprehend the sentence. Thus, feature codes should be occupied by the action plan and therefore be less accessible to sentence comprehension which should make an overall negative ACE more likely. Consistent with this, a negative ACE was observed in the error rates of the condition with an SOA of -1000 ms and regular action-effect relation. However, it is unclear why the ACE manifested itself in error rates and not in response times in this particular case, and so this result should be dealt with care.

The result of the negative ACE that occurred when the response cue was given 500 ms after sentence onset appears at first glance to be contrary to the predictions of both accounts. Presumably, both would have expected priming of the response (and no early interference) because subject and verb are processed and so the directional feature of the sentence representation is activated before the "yes" direction is prepared. Yet the negative ACE becomes more plausible if one assumes that the activation of the directional feature during sentence processing has already decayed when it is needed to prepare the response. According to the linguistic focus hypothesis (Taylor & Zwaan, 2008), the activation of representations of actions, objects, etc. that are denoted by the words in a sentence occurs immediately once a certain word is encountered and is rather short-lived. In the course of processing a sentence, the attentional focus is shifted from one to the next element of the described situation and their representations are activated only as long as they are within the linguistic focus. This hypothesis was supported by findings demonstrating that motor activation was restricted to sentence regions that specified an action such as verbs (Zwaan & Taylor, 2006) or adverbs that modified the described action (Taylor & Zwaan, 2008), or any part of speech disambiguating properties of the described action (Taylor, Lev Ari, & Zwaan, 2008). Thus, while in our case the response was being prepared between 500 and 1000 ms after sentence onset, the linguistic focus might have already shifted to the next part of the sentence where another element of the described situation had to be coded. As a consequence, the directional code was no longer active and no priming could occur.

Alternatively, the negative ACE in the condition with an SOA of 500 ms could be explained following Kaschak and Borreggine's (2008) interpretation of their results: In their experiment, participants were presented with the usual sentences describing transfer toward the body or away from the body, but this time, compatible or incompatible motor responses had to be executed at different points during sentence processing. Among others they found that a positive ACE arose in RTs when responses were executed at an early point in the sentences, but disappeared when responses were executed in the middle of the sentences. Similar to the current experiment, responses that were performed 500 ms after the onset of sentences whose length and syntax was comparable to our sentences descriptively displayed compatibility costs. According to the authors, the disappearance of the ACE in the middle of the sentence results from a rather early running of the simulation which might be possible because the last part of the sentences is quite predictable. Thus, in our experiment as well the activated feature codes may have become integrated into the representation of the sentence content at an early point within the sentence. This might have impaired the preparation of a compatible response and entailed a delayed response selection (see Figure 3.8; the possible early point of integration is presented in brackets).

It can only be speculated which of these explanations might hold for the negative ACE in the 500-ms SOA condition. The second explanation appears to fit slightly better with the data than the explanation based on the linguistic focus hypothesis. If the activation of the directional feature during sentence processing had just decayed, one would rather expect the ACE to disappear than to turn into the opposite, whereas early integration of the activated features would indeed cause interference and reverse the effect. This explanation would also fit better with the result that the ACE disappeared in the condition in which the response cue was presented at the end of the sentence: If the directional feature needed for planning the response was integrated into the simulation of the sentence content at the end of the sentence, one would have expected interference with response preparation and thus a negative ACE. Yet if the integration and with it the temporary occupation of the directional feature occurred earlier in the sentence, the feature code might become available again for response preparation around the end of the sentence, thereby diminishing the interference effect.

In sum, the results of Experiment 6 fit within the framework of theories like TEC. Also the finding that the ACE emerges on the higher representational level of movement effects is consistent with these theories as they propose the processes of activation and integration of feature codes to reside on such a more abstract distal-coding level.

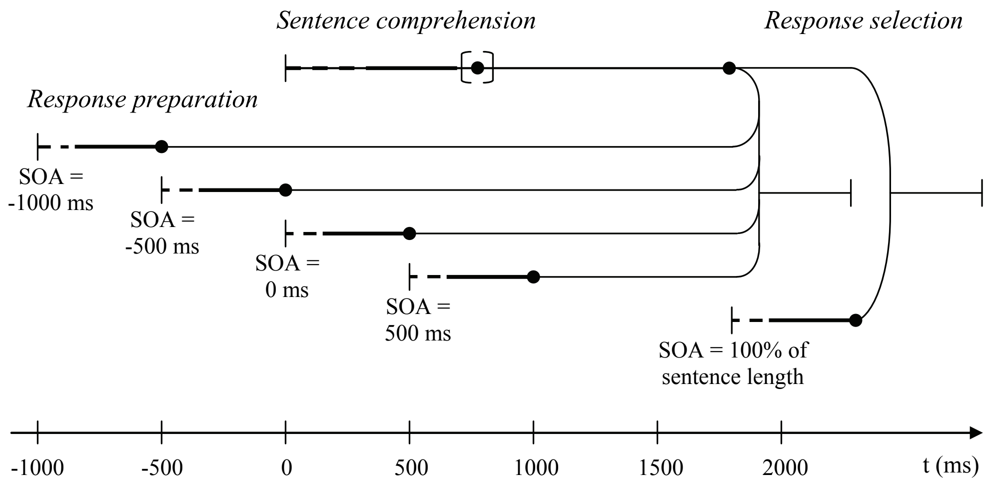


Figure 3.8. Schematic of the temporal relations between the processes of sentence comprehension, response preparation, and response selection depending on SOA conditions. The vertical lines on the left represent the start of the respective process. The thick horizontal line indicates the time region within the respective process where the directional code is probably activated. The line is dashed for the period within sentence comprehension where the first word is processed and where the activation of the directional code might be shifted after some experience. It is dashed as well for the period within response preparation where cue decoding and its transition to feature activation occurs. An overlap of the activation phases (thick lines) within sentence comprehension and response preparation on the time axis indicates priming between the processes. The dots mark the point where the codes are probably integrated and subsequent code activation is impaired.

3.4 Discussion of Experiments 4, 5, and 6

While continuing to pursue the initial research question of whether the ACE relies on movements or on movement effects, in parallel, the second series of experiments addressed the new question of whether the timing between sentence comprehension and response preparation determines magnitude and sign of the ACE. Experiment 4 mainly focused on the initial question and only intended to control the timing factor, whereas Experiments 5 and 6 manipulated the timing factor in order to investigate its consequences for the shape of the ACE.

Since it appeared problematic in Experiments 4 and 5 that participants were not really forced to process the cue and plan the response at the given point in time, basically only the results of Experiment 6 are meaningful with regard to the questions of interest. In this experiment, the positive ACE was obtained when presentations of the sentence and of the response cue started at the same time. This suggests that the positive ACE emerges when codes representing shared properties of the verbally described action and of the to-be-performed response are activated simultaneously and thus can produce priming. In contrast, the negative ACE seems to arise when feature codes of one of these actions are already integrated into the respective action representation and are temporarily not available for coding the other event which leads to interference. This was probably the case when response cueing occurred 500 ms after sentence onset and is also consistent with the indications for a connection between the negative ACE and slow RTs and TRTs respectively in Experiments 3 and 4 (given that slow RTs and TRTs reflect late response planning).

All in all, the mechanisms proposed by TEC seem to be applicable to the ACE, that is, the two phases of event coding and the resulting interactions between different coding processes seem to be applicable to the coding of actions that are simulated during sentence comprehension and to interactions between them and real actions. Also in line with TEC and the common coding approach, the effect-related ACEs found in Experiment 6 demonstrate that the interaction between language and action takes place on a higher representational level: The component of action planning which enters into the ACE is the premotor component that refers to the features of the intended action effect. Therefore, it can be concluded that the motor representations that are activated during sentence understanding are based on distal feature codes instead of low-level motor codes.

4 General discussion

In the following, I will first review the experimental findings of this thesis. Afterwards, I will address some issues raised by the data that have been left aside so far, discuss alternative interpretations of our results, and offer some suggestions for future research. Finally, I will relate the observed effects to the relevant theoretical approaches described in the introduction.

4.1 Summary of findings

The embodied approach to language comprehension suggests that the understanding of linguistic descriptions of actions involves the activation of action representations which means engaging the same systems also involved in producing real actions. The aim of this thesis was to shed more light on the nature of action representations that contribute to the comprehension of sentences in which descriptions of actions are not very detailed (which is the case in most of the everyday utterances referring to actions). When details of described actions remain unspecified, their representations are assumed to be more abstract. In particular, the question was pursued whether these representations reside on a higher level referring to distal information such as features of the action effect or whether they reside on a lower level referring to specific motor programs. This was addressed by testing whether action representations that are activated during sentence comprehension interact with representations of intended effects of real actions or with representations of the motor component of these actions. Since the action-sentence compatibility effect ACE reflects an interaction between sentence comprehension and action, this effect was used as basis for investigating this issue.

In the paradigm used, participants were presented with sentences describing concrete or abstract transfer actions that (in the critical versions) were directed either toward the body or away from the body. For judging the sensibility of these sentences, participants had to produce an action effect at a location near the body or far from the body by moving their hand to a button with its location either corresponding with the location of the to-be-produced effect or being opposed to it. This way of dissociating movement and effect in principle allowed to determine whether the ACE – the compatibility effect between the direction of the described action and the direction of the response – relies on movement or on movement effect.

While movement and movement effect had the same amplitudes in Experiment 1, these amplitudes were manipulated in Experiments 2 and 3 to obtain further evidence for the representational level on which the ACE arises. A modulation of the ACE induced by manipulating parameters of the movement would have spoken in favor of the interaction taking place on a lower level, whereas a modulation of the ACE caused by manipulating the salience of the movement effect would have supported the assumption that the interaction occurs on the higher level of movement effects. Resolving this question turned out to be more difficult than expected because the ACE either appeared only for error rates or only in the condition with transformed action-effect relation and thus was difficult to interpret. Solely Experiment 3 in which the effect amplitude was varied showed a significant ACE for response times also in the condition with regular action-effect relation. Yet even in this experiment, results did not reveal a more or less effect-related ACE depending on the amplitude of the movement effect as was predicted in case of distal, high-level representations. Instead, the ACE appeared to be reversed for the larger effect amplitude.

Since there were indications that the reversal of the ACE could be connected with the relative timing between sentence comprehension and response preparation, the next three experiments attempted either to control the influence of the timing factor (Experiment 4) or to investigate the role of timing in the ACE directly (Experiments 5 and 6) while at the same time continuing to follow the initial research question. Again, the first two of these three experiments did not produce proper results to answer one of the questions, but Experiment 6 did. Concerning the timing issue, results showed that the standard positive ACE emerges when the response is being prepared at the beginning of the sentence processing, whereas the negative ACE arises when the response is being prepared around the middle of the sentence. This suggests that the positive ACE results from priming between action representations activated during sentence processing and response planning when both processes concurrently activate the same directional feature. In contrast, the negative ACE results from interference between the two processes that seems to arise because the directional feature is already bound to the representation of the sentence content and thus is less accessible when needed for planning the response. Regarding the representational level, the results support the assumption that the interaction occurs on the more abstract level of distal representations as the ACE was related to the movement effect in all of the conditions in which it appeared for response times. Thus, action representations activated during the understanding of action sentences seem to reside on the same abstract level, using the same codes as representations of action effects.

4.2 Some remaining questions concerning the experimental findings

In Experiment 6, results relatively clearly indicated that the ACE refers to the movement effect, but one might wonder why the pattern looked different in the other experiments in which an ACE occurred (e.g., Experiment 3). When the ACE had a movement-related shape, at least two alternative interpretations were possible in addition to the interpretation that the ACE is related to the movement and relies on motor codes. First, such a movement-related appearance of the ACE could also emerge from representing the response in terms of resident instead of remote movement effects (see [1]), that is, the ACE would in fact be effect-related. Perhaps participants are more inclined to code the response in terms of its remote effect when the effect direction changes from trial to trial as in Experiments 4 to 6. This might be because it is less economical to translate the given effect direction into the associated movement direction anew in each trial compared to the situation where the effect direction changes only once in the middle of the session as in Experiments 1 to 3. Second, the reversal of the ACE in the condition with transformed action-effect relation could as well reflect an ACE of the opposite sign that refers to the remote movement effect. For example, a positive ACE could become negative in the transformed condition because responding is more difficult (usually resulting in slower RTs) and therefore response codes might be activated at a later point where feature codes of the semantic representation of the sentence are already bound together. Since it is difficult to determine exactly the interplay of factors that caused the single patterns of effects, one can only conclude that the ACE can arise on the level of distal movement effects, but it cannot be ruled out that the ACE can also arise on the level of motor programs.

Further corroborating evidence for distal representations underlying the ACE would be provided if it could be demonstrated that the ACE also arises when the response effect consists in a continuous movement toward or away from the body, while the manual response producing this effect contains no movement. Since Glenberg and Kaschak (2002) found no ACE in a no-movement condition where participants kept their hands on the near and far response buttons, indicating that spatial features alone are not sufficient to evoke the ACE, generating an ACE solely by a moving action effect would strongly confirm that the interaction takes place on an abstract, distal representational level. Another possibility to further strengthen this view would be to show that the ACE can also be observed in responses requiring arm movements when sentences describe transfer actions with the foot, such as “Paul kicks the football to you”.

Another issue which is associated with the above question of why the ACE was modulated by action-effect relation in some of the experiments is that the ACE often occurred only for transformed action-effect relation. Perhaps compatibility effects were more pronounced in this condition because the more difficult responding required participants to concentrate more on the direction of the response. In this way, the directional feature might have become stronger activated and thus led to stronger interactions with the respective feature activated during sentence comprehension. The reason for having obtained a more reliable ACE in the second series of experiments than in the first series could be similar: The presentation of the response cue, the variation of the effect direction from trial to trial, and the fact that only “yes” responses had to be executed might have caused a stronger activation of the “yes” direction and this way again stronger interactions with the directional feature activated during sentence comprehension.

In the beginning of the empirical part of this thesis (see 1.5), the question was raised whether there might be a difference between concrete and abstract sentences with regard to their representational level. Concerning the semantic representation of the abstract sentences used, the action goal or action effect might be highlighted because representations of agent and recipient can be activated and the syntactic construction may evoke the transfer action schema. Moreover, the verbs of the abstract sentences may not activate such specific movements as the verbs used in the concrete sentences which for their part could be better represented in motor codes. However, results suggest that the contents of both types of sentences are represented on the same level as there were no systematic effects involving the sentence type variable and as (especially in Experiment 6) the ACE was effect-related for both concrete and abstract sentences.

Future studies could investigate whether the generalized action schema assumed to be activated by the syntactic construction might be responsible for the finding that abstract representations of toward and away actions were activated for both sentence types. If this was true, the ACE should also occur – in an effect-related shape – for sentences using the double-object construction when these sentences contain only pseudowords apart from the personal pronoun and the character name, such as the German pseudosentence “Max stronnt dir die Schnofte”.

When looking at our data, it is noticeable that the obtained ACEs were often weaker and less reliable compared to the effects found in other ACE experiments (e.g., Glenberg & Kaschak, 2002; Borreggine & Kaschak, 2006; Kaschak & Borreggine, 2008). One reason for this could be that we investigated the ACE in German instead of in English and that differences between the languages could have caused differences in the mental simulation during sentence processing. One of the differences between the English and German linguistic material consisted in the sentence construction. In the studies listed above, half of the sentences used the double-object construction (e.g., “Courtney handed you the notebook”/”You handed Courtney the notebook”) and half used the dative construction (e.g., “Andy delivered the pizza to you”/”You delivered the pizza to Andy”), whereas our German sentences only were in the double-object form (e.g., “Andrea bringt dir die Pizza”/”Du bringst Andrea die Pizza”) because the dative form is not very common in the German language and for most of the verbs used it would be even wrong. Following the linguistic focus hypothesis (Taylor & Zwaan, 2008), especially this dative form may give rise to a strong ACE: In this construction, the recipient is postponed to the end of the sentence whereby the direction of transfer is brought back into the attentional focus at this late point of processing. The renewed activation of the directional feature around the end of the sentence may enable priming of a compatible response even when response preparation occurs rather late. In contrast, the construction of our German sentences entails that at the end of the sentences the focus is shifted to the transferred object instead of to the direction of transfer which may contribute to the particular temporal dynamics of the ACE observed in Experiment 6.

Another special feature of the German language that could have weakened the ACE concerns the functions of the present tense which was used in our sentences. Present tense not only carries the meaning that something occurs at this moment in time, but it very often expresses future events, and this might have affected the mental simulation. It is assumed (at least for the English language) that verb tense and aspect influence how the described event is constructed and which of its elements is highlighted. For example, imperfective aspect (e.g., “He was giving me a book”) is thought to highlight the described activity, and thus the simulations should be dominated by the activation of motor programs, whereas perfective aspect (e.g., “He gave me a book”) is suggested to place emphasis on the resultant state of the described event and therefore, the action outcome should be more strongly activated (Ferretti, Kutas, & McRae, 2007; Steedman, 2005). Possibly, German sentences in present tense as well do not necessarily highlight the activity, but another element of the described event because they can be understood as referring to something in the future, and thus, the direction of action was maybe not very strongly activated during the processing of our sentences which reduced the ACE.

4.3 Potential alternative interpretations of the findings

In the linguistic material used, the direction of action implied by the sentence was confounded with the sentence construction. Away sentences always began with the personal pronoun “Du” [you] and recipient and transferred object were mentioned farther at the back of the sentence, while toward sentences always began with the name of the other character with the personal pronoun and object being mentioned later in the sentence. Possibly, the emergence of the ACE could also be explained on the basis of the word order without assuming that action representations are activated during sentence processing. When participants hear the personal pronoun referring to them, their attention could be directed toward themselves which may create a bias towards making a response toward themselves. Therefore, toward sentences in the course of which attention is shifted toward the body would lead to faster responses toward the body, whereas away sentences in the course of which attention is shifted away from the body would cause faster responses away from the body – that is, the usual ACE pattern would appear.

This alternative account of the ACE can be tested based on the neutral sentences. As also in these sentences, both the personal pronoun and the character names were mentioned either at the beginning or at a later point, the alternative account would predict an ACE. According to the simulation account, no ACE should arise because the neutral sentences expressed no transfer, and thus, no representations of actions toward the body or away from the body should be activated during sentence comprehension that could interact with the direction of the response. To compare these predictions, RTs to the neutral sentences in Experiment 3 were analyzed as in this experiment (at least in the small-amplitude group) RTs to the other sentences showed a significant ACE. Neutral sentences that began with the personal pronoun were treated as away sentences and those that began with a character name as toward sentences. Then, similar to the real toward and away sentence, their compatibility with the effect direction was determined and formed the variable Sentence-effect compatibility (compatible, incompatible). The analysis was the same as for the other sentences, and for reasons of comparability only data of the first session were examined. Results of the ANOVA revealed neither a significant main effect of Sentence-effect compatibility nor interactions involving the compatibility variable (all *p*s > .3), and also separate analyses for amplitude groups did not yield significant compatibility effects (all *p*s > .3). Thus, the neutral sentences showed no ACE which speaks in favor of action simulation as basis of the ACE and against the alternative account.

Another alternative interpretation concerns the result of the effect-related ACE. According to Barsalou (1999b), linguistic descriptions evoke multimodal representations of their referents, i.e., they reactivate experiences that were encoded and stored by different modality-specific systems. Although not very probable, it cannot be ruled out that the simulation of the action sentences used was dominated by the visual modality. If this was the case, the visual representation of the described action could have primed the imagined response effect in terms of which the response is represented and which then triggers the response according to the ideomotor principle. Thus, on the assumption that visual simulation of the sentence content occurs instead of action simulation, an effect-related ACE would be predicted, too. In order to distinguish between these alternatives, a future study might investigate the ACE with one slight modification of the paradigm: Participants might respond to toward and away sentences as usual by making a movement toward or away from the body, but they either face forward (in the direction of the movements) or have the head turned and face to the side. If the sentence evokes a visual simulation which in turn evokes the corresponding action, this simulation would probably be projected toward the direction of the head and would not be able to facilitate the response in the condition with the turned head. As a consequence, the ACE should be eliminated in this condition, whereas the direction of the head should be irrelevant for the occurrence of the ACE if it is based on action simulation.

4.4 Relating the results to theoretical approaches

Our results are in line with the common coding approach and with theory of event coding (TEC) when extended to linguistic stimuli by making the additional assumption (following the embodied approach to language comprehension) that semantic meaning of linguistic stimuli is represented in the same format as the perceptual and action events these stimuli refer to. Derived from the notion that the meaning of actions is represented in terms of the intended action effects, it could be claimed that the semantic representations of action words and sentences on a higher cognitive level are shaped by the goals or effects of the described actions. Because of these shared high-level representations of action-related language and real actions, compatibility effects should arise between that kind of linguistic stimuli and intended response effects, and this was confirmed by the finding of the effect-related ACE in Experiment 6.

Consistent with this result, there are also other studies indicating that interactions between language processing and action can occur on the level of action effects. For instance, another stimulus-effect compatibility effect with word stimuli was obtained by van Dantzig, Pecher, and Zwaan (2008): Responses to positive words were facilitated when producing an effect with a positive connotation (approach), whereas responses to negative words were facilitated when producing an effect with a negative connotation (avoidance). So in this case, representations of emotional words and response representations overlapped because of shared affective codes on the level of action effects which resulted in priming (see also Eder & Klauer, 2007, 2009; Eder & Rothermund, 2008). In a study by Lindemann, Stenneken, van Schie, and Bekkering (2006), semantic processing of words was facilitated when they denoted the goal of an action that was prepared before, i.e., the word meaning was primed by the activated action goal which again suggests distal coding. At first glance, this positive compatibility effect appears to be contrary to the TEC-based account for interactions between language and action with regard to the timing issue. This account predicts interference when language processing draws on codes that are already bound to the action plan, but as there is not a partial but a complete overlap between the representations of action goal and word meaning, reusing the whole representation is beneficial.

As explained several times (see 3.3.3 and 3.4), also the negative ACE and the related time-course of the ACE that was revealed in Experiment 6 appears to be broadly consistent with the mechanisms of code activation and integration proposed by TEC. However, for providing more conclusive evidence of whether the principles of TEC can be applied to the ACE and to other interactions between language processing and action, it first has to be determined exactly what kind of action information is activated at which point of a linguistic description, how long this information remains active, when the action information is integrated into a complete semantic representation of the sentence, and how long it takes until it disintegrates and the single features can be activated again.

The formulation of the other approaches presented in the introduction is not detailed enough to deal with incompatibility effects such as the negative ACE or with temporal dynamics of interactions between language comprehension and action, but it allows to discuss whether these approaches can account for the results concerning the nature of the underlying representations.

The mirror system hypothesis - proposing that language comprehension engages the mirror neuron system - is also in line with the finding of the effect-related ACE, which is not very surprising since mirror mechanisms are considered to be the neurophysiological equivalent of the common coding principle. As there are putative mirror areas coding the action goal or the abstract action concept and other putative mirror areas coding the involved effector and more specific movement features, the mirror neuron system could in principle activate specific, low-level action representations as well as more abstract, distal action representations during the processing of action-related language. In the case of the sentences used for producing the ACE which described actions not very detailed, the activation of a distal action representation and its interaction with the distal representation of the planned response would have been predicted correctly.

According to the view of distributed semantic representations, meanings of words are represented by traces of prior experiences with the referents of the words which are stored in brain structures overlapping with those structures that were involved in encoding these experiences. Yet on top of such modal representations more abstract representations are assumed to exist as well (Pulvermüller, 2008). As concerns action-related words, their meanings are supposed to be not only represented in terms of specific motor programs, but in the case of more general action concepts they are also supposed to be coded by higher-order disjunction neurons in which alternative motor programs associated with a particular concept in different contexts converge. Such higher-order action representations could correspond to the notion of distal representations of actions in the common coding framework and when activated during sentence comprehension could interact with the representation of the distal response effect. Thus, also the view of distributed semantic representations does not stand in contrast with the result of the effect-related ACE and would interpret it as reflecting underlying high-level, distal representations, too.

The situation is different with the multimodal simulations that Barsalou (1999b) suggested to underlie the representation of concepts. Although related to the view of distributed semantic representations in assuming that linguistic descriptions reactivate associated experiences, these representations are regarded as being simulated solely by modality-specific systems. In the case of action sentences, presumably mainly experiences of motor states are simulated, thereby preparing the motor system for corresponding actions. This would be reflected in priming of the low-level motor component of actions instead of the distal component, and therefore the view of modal simulations could not account for the occurrence of the effect-related ACE. It could only be explained on the basis of low-level, modal representations when assuming a dominant visual simulation during the comprehension of action sentences (see 4.3). This seems not very plausible, but it remains to be tested.

The indexical hypothesis claims that sentences are comprehended by activating representations of referential objects and actions of the words and by deriving affordances from these representations depending on the current bodily state, current goals and the learning history of the comprehender. If the comprehender has learned that in the current situation an action effect in a certain direction can only be achieved by making a movement in the opposite direction, then processing a transfer sentence may activate a certain transfer goal (e.g., through the meaning of the syntactic construction) as well as a movement representation opposite to the direction of transfer. In this way, an effect-related ACE could be produced. According to this account, the ACE would rely both on distal representations and on low-level motor representations. If the sentence content was represented solely by abstract feature codes, it would be hard to explain why for one thing muscle activity was found to be modulated during the processing of the same transfer sentences that also gave rise to the ACE (Glenberg, Sato, Cattaneo et al., 2008) and why for another thing the fatiguing of effectors was shown to affect the comprehension of these transfer sentences (Glenberg, Sato, & Cattaneo, 2008).

However, the most suitable account for the results reported in this thesis is still provided by TEC as this is the only theory that has the potential to deal not only with the effect-related ACE, but also with the negative ACE and with its specific temporal properties.

4.5 Conclusions

The current work investigated the representational level on which interactions between action-related language and action can occur by using a stimulus-response compatibility paradigm and inserting an action-effect transformation. The presented results revealed that the comprehension of less detailed linguistic descriptions of actions involves the activation of higher-order action representations referring to more distal effects of these actions. Because these semantic representations of action sentences use the same format as distal representations of to-be-performed actions, interactions can occur between them. Whether also low-level motor programs associated with the described actions are always activated during sentence comprehension and, if so, under which conditions high-level or low-level representations dominate, remains to be found out. The interactions appear to be very sensitive to diverse factors on the part of the linguistic stimuli as well as on the part of the actions. In our experiments, especially the temporal relationship between the two processes turned out to be an important influencing factor: Even a few hundred milliseconds timing difference decide on whether the processing of action sentences has a positive or a negative effect on planning and executing corresponding actions. Altogether, our findings once again confirm the close coupling of cognition and action and beyond that provide evidence for the importance of action effects also in linguistic representations.

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Appendix

Appendix A

Table A1

Sensible sentences for Experiments 1 through 6, describing concrete transfer

Sentence direction	Stimuli	Approximate English translations
Toward	*Alexander gibt dir die Münzen.*	Alex gives you the cash.
Away	*Du gibst Alexander die Münzen.*	You give Alex the cash.
Neutral	*Du zählst mit Alexander die Münzen.*	You count the cash with Alex.
Toward	*Andrea bringt dir die Pizza.*	Andrea deliveres you pizza.
Away	*Du bringst Andrea die Pizza.*	You deliver Andrea pizza.
Neutral	*Du verspeist mit Andrea die Pizza.*	You eat the pizza with Andrea.
Toward	*Elena steckt dir eine Medaille an.*	Helen awards you a medal.
Away	*Du steckst Elena eine Medaille an.*	You award Helen a medal.
Neutral	*Du bewunderst mit Elena die Medaille.*	You admire the medal with Helen.
Toward	*Jakob reicht dir das Buch.*	Jacob hands you the book.
Away	*Du reichst Jakob das Buch.*	You hand Jacob the book.
Neutral	*Du liest mit Jakob das Buch.*	You read the book with Jacob.
Toward	*Vinzenz bietet dir Süßigkeiten an.*	Vincent offers you some sweets.
Away	*Du bietest Vinzenz Süßigkeiten an.*	You offer Vincent some sweets.
Neutral	*Du isst mit Vinzenz Süßigkeiten.*	You eat some sweets with Vincent.
Toward	*Maria reicht dir das Brot.*	Mary passes you the bread.
Away	*Du reichst Maria das Brot.*	You pass Mary the bread.
Neutral	*Du isst mit Maria das Brot.*	You eat the bread with Mary.
Toward	*Markus gibt dir die Karten.*	Mark deals you the cards.
Away	*Du gibst Markus die Karten.*	You deal Mark the cards.
Neutral	*Du spielst mit Markus Karten.*	You play cards with Mark.
Toward	*Laura bringt dir das Mittagessen.*	Laura brings you the lunch.
Away	*Du bringst Laura das Mittagessen.*	You bring Laura the lunch.
Neutral	*Du kostest mit Laura das Mittagessen.*	You taste the lunch with Laura.
Toward	*Lukas gibt dir den Schlüssel.*	Lucas entrusts you the key.
Away	*Du gibst Lukas den Schlüssel.*	You entrust Lucas the key.
Neutral	*Du bewachst mit Lukas den Schlüssel.*	You watch over the key with Lucas.

Table A1 (continued)

Sentence direction	Stimuli	Approximate English translations
Toward	*Katja reicht dir den Löffel.*	Katie passes you the spoon.
Away	*Du reichst Katja den Löffel.*	You pass Katie the spoon.
Neutral	*Du musterst mit Katja den Löffel.*	You inspect the spoon with Katie.
Toward	*Christina bringt dir ein Eis.*	Christine brings you ice cream.
Away	*Du bringst Christina ein Eis.*	You bring Christine ice cream.
Neutral	*Christina kostet mit dir das Eis.*	Christine tries the ice cream with you.
Toward	*Diana wirft dir den Stift zu.*	Diana throws you the pen.
Away	*Du wirfst Diana den Stift zu.*	You throw Diana the pen.
Neutral	*Diana kauft mit dir einen Stift.*	Diana buys a pen with you.
Toward	*Felix wirft dir den Ball zu.*	Felix throws you the ball.
Away	*Du wirfst Felix den Ball zu.*	You throw Felix the ball.
Neutral	*Felix betrachtet mit dir den Ball.*	Felix looks at the ball with you.
Toward	*Sarah bringt dir das Tablett.*	Sarah gives you the cafeteria tray.
Away	*Du bringst Sarah das Tablett.*	You give Sarah the cafeteria tray.
Neutral	*Sarah kauft mit dir das Tablett.*	Sarah buys a cafeteria tray with you.
Toward	*Steffi zeigt dir das Notizbuch.*	Stephanie shows you the notebook.
Away	*Du zeigst Steffi das Notizbuch.*	You show Stephanie the notebook.
Neutral	*Steffi liest mit dir das Notizbuch.*	Stephanie reads the notebook with you.
Toward	*Anton versetzt dir einen Faustschlag.*	Anthony deals you a blow.
Away	*Du versetzt Anton einen Faustschlag.*	You deal Anthony a blow.
Neutral	*Anton hat mit dir eine Schlägerei.*	Anthony has a fight with you.
Toward	*Michael schickt dir die Murmel.*	Michael sends you the marble.
Away	*Du schickst Michael die Murmel.*	You send Michael the marble.
Neutral	*Michael betrachtet mit dir die Murmel.*	Michael inspects the marble with you.
Toward	*Angela schickt dir ein Bild.*	Angela sends you a picture.
Away	*Du schickst Angela ein Bild.*	You send Angela a picture.
Neutral	*Angela beurteilt mit dir das Bild.*	Angela assesses the picture with you.
Toward	*Lena reicht dir einen Zettel.*	Lena hands you a note.
Away	*Du reichst Lena einen Zettel.*	You hand Lena a note.
Neutral	*Lena studiert mit dir den Zettel.*	Lena studies the note with you.
Toward	*Paul gibt dir den Ball zurück.*	Paul returns you the ball.
Away	*Du gibst Paul den Ball zurück.*	You return Paul the ball.
Neutral	*Paul verfolgt mit dir den Ball.*	Paul runs after the ball with you.

Table A2

Sensible sentences for Experiments 1 through 6, describing abstract transfer

Sentence direction	Stimuli	Approximate English translations
Toward	*Adam überbringt dir die Nachricht.*	Adam transmits you the news.
Away	*Du überbringst Adam die Nachricht.*	You transmit Adam the news.
Neutral	*Du beurteilst mit Adam die Nachricht.*	You judge the news with Adam.
Toward	*Matthias erteilt dir das Patent.*	Matthew issues you a patent.
Away	*Du erteilst Matthias das Patent.*	You issue Matthew a patent.
Neutral	*Du entwickelst mit Matthias das Patent.*	You develop a patent with Matthew.
Toward	*Arthur stellt dir das Thema vor.*	Arthur presents you the topic.
Away	*Du stellst Arthur das Thema vor.*	You present Arthur the topic.
Neutral	*Du erörterst mit Arthur das Thema.*	You discuss the topic with Arthur.
Toward	*Sabine erteilt dir einen Auftrag.*	Sabine transmits you the orders.
Away	*Du erteilst Sabine einen Auftrag.*	You transmit Sabine the orders.
Neutral	*Du lehnst mit Sabine den Auftrag ab.*	You refuse the orders with Sabine.
Toward	*Lorenz übermittelt dir die Botschaft.*	Lawrence conveys you the message.
Away	*Du übermittelst Lorenz die Botschaft.*	You convey Lawrence the message.
Neutral	*Du verfasst mit Lorenz eine Botschaft.*	You write a message with Lawrence.
Toward	*Tanja widmet dir Zeit.*	Tania devotes you her time.
Away	*Du widmest Tanja Zeit.*	You devote Tania your time.
Neutral	*Du verbringst mit Tanja Zeit.*	You spend your time with Tania.
Toward	*Anna überträgt dir die Verantwortung.*	Anna delegates you the responsibility.
Away	*Du überträgst Anna die Verantwortung.*	You delegate Anna the responsibility.
Neutral	*Du diskutierst mit Anna über die Verantwortung.*	You discuss the responsibilities with Anna.
Toward	*Daniel vertraut dir ein Geheimnis an.*	Daniel confesses you his secret.
Away	*Du vertraust Daniel ein Geheimnis an.*	You confess Daniel your secret.
Neutral	*Du bewahrst mit Daniel ein Geheimnis.*	You keep a secret with Daniel.
Toward	*Johannes widmet dir ein Lied.*	John dedicates you the song.
Away	*Du widmest Johannes ein Lied.*	You dedicate John the song.
Neutral	*Du erinnerst dich mit Johannes an ein Lied.*	You remember the song with John.
Toward	*Franz richtet an dich eine Beschwerde.*	Francis addresses the complaint to you.
Away	*Du richtest an Franz eine Beschwerde.*	You address the complaint to Francis.
Neutral	*Du hörst mit Franz eine Beschwerde.*	You hear the complaint with Francis.

Table A2 (continued)

Sentence direction	Stimuli	Approximate English translations
Toward	*Johanna trägt dir ein Gedicht vor.*	Jane recites you a poem.
Away	*Du trägst Johanna ein Gedicht vor.*	You recite Jane a poem.
Neutral	*Johanna liest mit dir ein Gedicht.*	Jane reads a poem with you.
Toward	*Nora gibt dir die Meldung durch.*	Nora radioes the message to you.
Away	*Du gibst Nora die Meldung durch.*	You radio the message to Nora.
Neutral	*Nora bespricht mit dir die Meldung.*	Nora discusses the message with you.
Toward	*Stefan macht dir ein Kompliment.*	Steven pays you compliments.
Away	*Du machst Stefan ein Kompliment.*	You pay Steven compliments.
Neutral	*Stefan überlegt sich mit dir ein Kompliment.*	Steven thinks up compliments with you.
Toward	*Miriam spricht dir ihre Dankbarkeit aus.*	Miriam expresses you her gratitude.
Away	*Du sprichst Miriam deine Dankbarkeit aus.*	You express Miriam your gratitude.
Neutral	*Miriam spricht mit dir über Dankbarkeit.*	Miriam speaks about gratitude with you.
Toward	*Christian gibt dir einen Ratschlag.*	Christian offers you an advice.
Away	*Du gibst Christian einen Ratschlag.*	You offer Christian an advice.
Neutral	*Christian befolgt mit dir den Ratschlag.*	Christian follows the advice with you.
Toward	*Ulrike drückt dir ihre Wertschätzung aus.*	Ulrike pays you tribute.
Away	*Du drückst Ulrike deine Wertschätzung aus.*	You pay Ulrike tribute.
Neutral	*Ulrike kommentiert mit dir eine Wertschätzung.*	Ulrike comments on a tribute with you.
Toward	*Hendrik erteilt dir eine Lektion.*	Henry teaches you a lesson.
Away	*Du erteilst Hendrik eine Lektion.*	You teach Henry a lesson.
Neutral	*Hendrik erinnert sich mit dir an die Lektion.*	Henry remembers the lesson with you.
Toward	*Julia erzählt dir eine Geschichte.*	Julia tells you the story.
Away	*Du erzählst Julia eine Geschichte.*	You tell Julia the story.
Neutral	*Julia liest mit dir eine Geschichte.*	Julia reads the story with you.
Toward	*Albert stellt dir einen Plan vor.*	Albert presents you the plan.
Away	*Du stellst Albert einen Plan vor.*	You present Albert the plan.
Neutral	*Albert überlegt sich mit dir einen Plan.*	Albert works out a plan with you.
Toward	*Andreas schlägt dir eine Idee vor.*	Andy suggests you an idea.
Away	*Du schlägst Andreas eine Idee vor.*	You suggest Andy an idea.
Neutral	*Andreas diskutiert mit dir eine Idee.*	Andy discusses an idea with you.

Appendix B

Table B1

Counterbalance scheme for Experiments 1, 2, and 3

Counter-balance	Session	Action-effect relation	Block 1		Block 2	
			Effect direction	Material block	Effect direction	Material block
1	1	regular	yes-is-near	1	yes-is-far	2
	2	transformed	yes-is-near	2	yes-is-far	1
2	1	transformed	yes-is-near	2	yes-is-far	1
	2	regular	yes-is-near	1	yes-is-far	2
3	1	transformed	yes-is-near	1	yes-is-far	2
	2	regular	yes-is-far	1	yes-is-near	2
4	1	regular	yes-is-near	2	yes-is-far	1
	2	transformed	yes-is-far	2	yes-is-near	1
5	1	transformed	yes-is-far	1	yes-is-near	2
	2	regular	yes-is-far	2	yes-is-near	1
6	1	regular	yes-is-far	2	yes-is-near	1
	2	transformed	yes-is-far	1	yes-is-near	2
7	1	regular	yes-is-far	1	yes-is-near	2
	2	transformed	yes-is-near	1	yes-is-far	2
8	1	transformed	yes-is-far	2	yes-is-near	1
	2	regular	yes-is-near	2	yes-is-far	1

Table B2

Counterbalance scheme for Experiments 4 and 5

Counterbalance	Session	Action-effect relation	Assignment of material blocks (MB) to effect directions	
			Yes-is-near	Yes-is-far
1	1	regular	MB 1	MB 2
	2	transformed	MB 1	MB 2
2	1	transformed	MB 1	MB 2
	2	regular	MB 1	MB 2
3	1	regular	MB 1	MB 2
	2	transformed	MB 2	MB 1
4	1	transformed	MB 1	MB 2
	2	regular	MB 2	MB 1
5	1	regular	MB 2	MB 1
	2	transformed	MB 2	MB 1
6	1	transformed	MB 2	MB 1
	2	regular	MB 2	MB 1
7	1	regular	MB 2	MB 1
	2	transformed	MB 1	MB 2
8	1	transformed	MB 2	MB 1
	2	regular	MB 1	MB 2

Table B3

Counterbalance scheme for Experiment 6

Counter-balance	Session	Action-effect relation	Assignment of material blocks (MB) to effect directions		SOA (ms)				
			Yes-is-near	Yes-is-far	Block 1	Block 2	Block 3	Block 4	Block 5
1	1	reg.	MB 1	MB 2	-1000	-500	0	500	100% SL
	2	transf.	MB 2	MB 1	500	0	100% SL	-1000	-500
2	1	reg.	MB 1	MB 2	-1000	500	100% SL	-500	0
	2	transf.	MB 2	MB 1	0	-1000	-500	500	100% SL
3	1	reg.	MB 1	MB 2	-500	0	-1000	100% SL	500
	2	transf.	MB 2	MB 1	100% SL	500	0	-500	-1000
4	1	reg.	MB 1	MB 2	-500	100% SL	500	0	-1000
	2	transf.	MB 2	MB 1	-1000	0	-500	100% SL	500
5	1	reg.	MB 1	MB 2	0	-500	-1000	100% SL	500
	2	transf.	MB 2	MB 1	-500	-1000	0	500	100% SL
6	1	reg.	MB 1	MB 2	0	500	100% SL	-1000	-500
	2	transf.	MB 2	MB 1	100% SL	-500	-1000	0	500
7	1	reg.	MB 1	MB 2	500	-1000	-500	0	100% SL
	2	transf.	MB 2	MB 1	0	100% SL	500	-500	-1000
8	1	reg.	MB 1	MB 2	500	100% SL	0	-500	-1000
	2	transf.	MB 2	MB 1	-500	500	100% SL	-1000	0
9	1	reg.	MB 1	MB 2	100% SL	-1000	-500	500	0
	2	transf.	MB 2	MB 1	-1000	100% SL	500	0	-500
10	1	reg.	MB 1	MB 2	100% SL	0	500	-1000	-500
	2	transf.	MB 2	MB 1	500	-500	-1000	100% SL	0
11	1	transf.	MB 1	MB 2	-1000	0	-500	100% SL	500
	2	reg.	MB 2	MB 1	500	100% SL	0	-500	-1000
12	1	transf.	MB 1	MB 2	-1000	100% SL	500	0	-500
	2	reg.	MB 2	MB 1	-500	0	-1000	100% SL	500
13	1	transf.	MB 1	MB 2	-500	-1000	0	500	100% SL
	2	reg.	MB 2	MB 1	100% SL	0	500	-1000	-500
14	1	transf.	MB 1	MB 2	-500	500	100% SL	-1000	0
	2	reg.	MB 2	MB 1	-1000	-500	0	500	100% SL
15	1	transf.	MB 1	MB 2	0	-1000	-500	500	100% SL
	2	reg.	MB 2	MB 1	-500	100% SL	500	0	-1000
16	1	transf.	MB 1	MB 2	0	100% SL	500	-500	-1000
	2	reg.	MB 2	MB 1	100% SL	-1000	-500	500	0
17	1	transf.	MB 1	MB 2	500	-500	-1000	100% SL	0
	2	reg.	MB 2	MB 1	0	500	100% SL	-1000	-500
18	1	transf.	MB 1	MB 2	500	0	100% SL	-1000	-500
	2	reg.	MB 2	MB 1	0	-500	-1000	100% SL	500
19	1	transf.	MB 1	MB 2	100% SL	-500	-1000	0	500
	2	reg.	MB 2	MB 1	-1000	500	100% SL	-500	0
20	1	transf.	MB 1	MB 2	100% SL	500	0	-500	-1000
	2	reg.	MB 2	MB 1	500	-1000	-500	0	100% SL

Table B3 (continued)

Counter-balance	Session	Action-effect relation	Assignment of material blocks (MB) to effect directions		SOA (ms)				
			Yes-is-near	Yes-is-far	Block 1	Block 2	Block 3	Block 4	Block 5
21	1	reg.	MB 2	MB 1	-1000	0	-500	100% SL	500
	2	transf.	MB 1	MB 2	0	500	100% SL	-1000	-500
22	1	reg.	MB 2	MB 1	-1000	100% SL	500	0	-500
	2	transf.	MB 1	MB 2	0	-500	-1000	100% SL	500
23	1	reg.	MB 2	MB 1	-500	-1000	0	500	100% SL
	2	transf.	MB 1	MB 2	-1000	500	100% SL	-500	0
24	1	reg.	MB 2	MB 1	-500	500	100% SL	-1000	0
	2	transf.	MB 1	MB 2	500	-1000	-500	0	100% SL
25	1	reg.	MB 2	MB 1	0	-1000	-500	500	100% SL
	2	transf.	MB 1	MB 2	100% SL	0	500	-1000	-500
26	1	reg.	MB 2	MB 1	0	100% SL	500	-500	-1000
	2	transf.	MB 1	MB 2	-1000	-500	0	500	100% SL
27	1	reg.	MB 2	MB 1	500	-500	-1000	100% SL	0
	2	transf.	MB 1	MB 2	-500	100% SL	500	0	-1000
28	1	reg.	MB 2	MB 1	500	0	100% SL	-1000	-500
	2	transf.	MB 1	MB 2	100% SL	-1000	-500	500	0
29	1	reg.	MB 2	MB 1	100% SL	-500	-1000	0	500
	2	transf.	MB 1	MB 2	500	100% SL	0	-500	-1000
30	1	reg.	MB 2	MB 1	100% SL	500	0	-500	-1000
	2	transf.	MB 1	MB 2	-500	0	-1000	100% SL	500
31	1	transf.	MB 2	MB 1	-1000	-500	0	500	100% SL
	2	reg.	MB 1	MB 2	100% SL	500	0	-500	-1000
32	1	transf.	MB 2	MB 1	-1000	500	100% SL	-500	0
	2	reg.	MB 1	MB 2	0	100% SL	500	-500	-1000
33	1	transf.	MB 2	MB 1	-500	0	-1000	100% SL	500
	2	reg.	MB 1	MB 2	0	-1000	-500	500	100% SL
34	1	transf.	MB 2	MB 1	-500	100% SL	500	0	-1000
	2	reg.	MB 1	MB 2	500	0	100% SL	-1000	-500
35	1	transf.	MB 2	MB 1	0	-500	-1000	100% SL	500
	2	reg.	MB 1	MB 2	-500	500	100% SL	-1000	0
36	1	transf.	MB 2	MB 1	0	500	100% SL	-1000	-500
	2	reg.	MB 1	MB 2	-500	-1000	0	500	100% SL
37	1	transf.	MB 2	MB 1	500	-1000	-500	0	100% SL
	2	reg.	MB 1	MB 2	100% SL	-500	-1000	0	500
38	1	transf.	MB 2	MB 1	500	100% SL	0	-500	-1000
	2	reg.	MB 1	MB 2	-1000	100% SL	500	0	-500
39	1	transf.	MB 2	MB 1	100% SL	-1000	-500	500	0
	2	reg.	MB 1	MB 2	500	-500	-1000	100% SL	0
40	1	transf.	MB 2	MB 1	100% SL	0	500	-1000	-500
	2	reg.	MB 1	MB 2	-1000	0	-500	100% SL	500

Note. reg. = regular; transf. = transformed; 100% SL = 100% of the sentence length.

Appendix C

Table C1

Further significant main effects and interactions obtained from the ANOVA on RTs across sessions for Experiment 1. For MTs and error rates, no further significant effects were found

Source	*df*	*F*	*MSE*	*p*
Sentence type	1	374.27	2550.52	.01
Action-effect relation x Sentence type x Order of action-effect relations	1	10.32	1623.17	.01

Table C2

Further significant main effects and interactions obtained from the ANOVA on RTs of the first session of Experiment 2. For MTs and error rates, no further significant effects were found

Source	*df*	*F*	*MSE*	*p*
Sentence type	1	350.85	1821.68	.01

Table C3

Further significant main effects and interactions obtained from the ANOVAs on RTs and MTs for Experiment 3. No further significant effects were found for error rates

Source	*df*	*F*	*MSE*	*p*
RT (first session)				
Sentence type	1	210.86	3594.61	.01
MT (across sessions)				
Sentence type	1	9.61	428.60	.01
Action-effect relation x Order of action-effect relations	1	6.94	5252.83	.02

Table C4

Further significant main effects and interactions obtained from the ANOVA on RTs across sessions for Experiment 4. For MTs and error rates, no further significant effects were found

Source	*df*	*F*	*MSE*	*p*
Sentence type	1	183.17	3152.13	.01
Action-effect relation x Order of action-effect relations	1	17.51	10351.97	.01

Table C5

Further significant main effects and interactions obtained from the ANOVAs on RTs and MTs for Experiment 5. No further significant effects were found for error rates

Source	*df*	*F*	*MSE*	*p*
RT (first session)				
Sentence type	1	518.87	15090.61	.01
SOA	4	247.28	25195.68	.01
Sentence type x SOA	4	3.71	17275.02	.01
Action-effect relation	1	4.89	270740.59	.04
MT (across sessions)				
Sentence type	1	5.44	2235.53	.03
SOA	4	4.34	2085.64	.01
Action-effect relation x Order of action-effect relations	1	8.60	23662.84	.01

Table C6

Further significant main effects and interactions obtained from the ANOVAs on RTs, MTs, and error rates for Experiment 6

Source	*df*	*F*	*MSE*	*p*
RT (first session)				
Sentence type	1	167.41	28101.71	.01
SOA	4	166.26	40163.47	.01
MT (across sessions)				
Action-effect relation x Order of action-effect relations	1	17.11	18952.65	.01
Sentence type	1	6.16	1481.09	.02
Error rate (first session)				
SOA	4	5.56	129.40	.01

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Diefenbach, Christiane

INTERACTIONS BETWEEN SENTENCE COMPREHENSION AND CONCURRENT ACTION:
THE ROLE OF MOVEMENT EFFECTS AND TIMING

Dissertation
Fakultät für Biowissenschaften, Pharmazie und Psychologie der Universität Leipzig

127 Seiten, 122 Literaturangaben, 19 Abbildungen, 19 Tabellen

Referat

Embodied approaches to language comprehension suggest that we understand sentences by using our perception and action systems for simulating their contents. In line with this assumption, the action-sentence compatibility effect (ACE) shows that sensibility judgments for sentences are faster when the direction of the described action matches the direction of the response movement.

The aim of this thesis was to investigate whether this compatibility is effective between sentence direction and movement direction or between sentence direction and the direction of the movement effect. To this end, movements were dissociated from their effects in several experiments. Participants indicated whether sentences describing transfer actions toward or away from the body are sensible or not by producing a movement effect on a screen at a location near the body or far from the body. These movement effects were achieved by moving the hand from a middle button to a near or far button, i.e., toward the body or away from the body. In one condition, a movement effect resulted from pressing the button whose location corresponded with the location of the effect. Crucially for the above research question, there was another condition in which an action effect resulted from pressing the button at the opposite location.

Since in the first series of experiments, the ACE turned out to be unreliable and in part seemed to be reversed, it was difficult to address the initial question. Therefore, a second series of experiments additionally investigated the role of timing between response preparation and sentence comprehension as a potential cause of the negative ACE. Results showed a positive ACE when the same directional feature was concurrently activated within

the two processes, leading to priming between them. A negative ACE appeared when the directional feature was already bound into the sentence representation and thus was less accessible when needed for response preparation. In both cases, the ACE was related to the movement effect. These results suggest that the ACE occurs on the higher level of cognitive representations referring to distal information.

Zusammenfassung

Einleitung

Neuere Forschung zum Sprachverstehen, die auf dem „Embodied Cognition Approach“ basiert, legt nahe, dass sprachliche Handlungsbeschreibungen durch mentale Simulation dieser Handlungen verstanden werden. Bei der mentalen Simulation werden gespeicherte motorische Erfahrungen mit den beschriebenen Handlungen aktiviert, was bedeutet, dass die neuronalen Substrate des Sprachverstehens mit jenen der Handlungsausführung überlappen. Theorien, die den „Embodied Cognition Approach“ vertreten, wie die „Mirror Neuron Theory” (Rizzolatti & Craighero, 2004), die “Theory of Perceptual Symbol Systems” (Barsalou, 1999), die „View of Distributed Semantic Representations” (z.B. Pulvermüller, 2005, 2008) und die “Indexical Hypothesis” (Glenberg & Robertson, 1999, 2000), nehmen an, dass die beim Sprachverstehen aktivierten Handlungsrepräsentationen hauptsächlich auf der unteren motorischen Ebene der Handlungsplanung angesiedelt sind. Einige der Theorien schließen jedoch nicht aus, dass auch Handlungsrepräsentationen auf einer höheren (kognitiven) Ebene beteiligt sein könnten. Die Natur dieser Handlungsrepräsentationen wurde in der vorliegenden Dissertation genauer untersucht.

Als Evidenz dafür, dass dem Sprachverstehen Repräsentationen auf der unteren Ebene der motorischen Programme zugrunde liegen, werden spezifische Interaktionen zwischen dem Verstehen einer sprachlichen Handlungsbeschreibung und einer auszuführenden motorischen Reaktion herangezogen. Bei diesen Interaktionen handelt es sich für gewöhnlich um eine Erleichterung der Reaktion, wenn sie Merkmale mit der sprachlich beschriebenen Handlung teilt. Eine ähnliche Art der Interaktion stellen auch Reiz-Reaktions-Kompatibilitätseffekte dar. Diese Effekte gelten als Beleg der „Common Coding Theory“ (Prinz, 1990, 1997), die dem „Embodied Cognition Approach“ verwandt ist und besagt, dass Wahrnehmungsinhalte und Inhalte von Handlungsplänen im gleichen Repräsentationsformat codiert werden. Die gemeinsame Codierung von Wahrnehmung und Handlung wird dadurch erklärt, dass Handlungen in Bezug auf ihre wahrnehmbaren Konsequenzen in der Umwelt repräsentiert werden. Entsprechend werden die gemeinsamen Codes hier auf einer abstrakteren, höheren Repräsentationsebene verortet, nämlich der Ebene, auf der die intendierten Handlungseffekte codiert werden. Übereinstimmend mit dieser Vorstellung zeigt die Forschung zur Reiz-Reaktions-Kompatibilität, dass die Ausführung von Handlungen auch dann erleichtert wird, wenn sich wahrgenommene Reize und intendierte Handlungseffekte in ihren Merkmalen ähneln (Hommel, 1993).

Bei Untersuchungen zu Kompatibilitätseffekten zwischen dem Satzverstehen und gleichzeitig auszuführenden eigenen Handlungen wurde bislang nicht zwischen den Repräsentationen von Handlungen und den Repräsentationen von Handlungseffekten unterschieden. Es wäre demnach auch hier denkbar, dass diese Effekte nicht auf gemeinsamen Repräsentationen auf unterer motorischer Ebene beruhen, sondern auf höheren kognitiven Repräsentationen, die sich auf die distalen Merkmale des Handlungseffekts beziehen. Dieser Frage wurde in der vorliegenden Arbeit nachgegangen. In Anlehnung an die Studie von Hommel (1993) wurde untersucht, ob die beim Satzverstehen aktivierten Handlungsrepräsentationen mit den Repräsentationen der intendierten Effekte von Handlungen interagieren oder mit den Repräsentationen der motorischen Komponente dieser Handlungen. Die Grundlage dafür bildete der „Action-Sentence Compatibility Effect" (ACE; Glenberg & Kaschak, 2002), der einen Kompatibilitätseffekt zwischen der Richtung einer beschriebenen Handlung und der Richtung der Reaktion darstellt.

Im verwendeten Paradigma hatten die Probanden die Aufgabe zu beurteilen, ob die ihnen auditiv dargebotenen Sätze sinnvoll sind oder nicht („Ja"- vs. „Nein"-Antwort). Diese Sätze enthielten konkrete oder abstrakte Transferhandlungen, die (in den entscheidenden Versionen) entweder zum Körper hin oder vom Körper weg gerichtet waren. Zur Beurteilung der Sätze sollten Handbewegungen von einer mittleren zu einer nahen oder entfernten Taste ausgeführt werden (d.h. zum Körper hin oder von ihm weg), die dazu dienten, einen Bewegungseffekt an einer nahen oder entfernten Position auf einem vertikal angebrachten Bildschirm hervorzurufen. Die Position des als „Ja"- bzw. „Nein"-Antwort zu erzeugenden Effekts auf dem Bildschirm stimmte entweder mit dem Ort des Tastendrucks überein (untransformierte Bedingung) oder sie war ihm entgegengesetzt (transformierte Bedingung). Mit Hilfe der Dissoziation von Bewegung und Bewegungseffekt in der transformierten Bedingung sollte bestimmt werden, ob die Kompatibilität beim ACE zwischen der Satzrichtung und der Bewegungsrichtung wirksam ist oder zwischen der Satzrichtung und der Richtung des Bewegungseffekts.

Zusammenfassung der wissenschaftlichen Ergebnisse

Im ersten Experiment besaßen die Bewegung und der Bewegungseffekt die gleiche Amplitude, d.h., der Abstand zwischen der nahen und der entfernten Taste entsprach demjenigen zwischen dem nahen und dem entfernten Bewegungseffekt auf dem Bildschirm. Jeweils eine dieser Amplituden wurde im zweiten und dritten Experiment manipuliert, um weitere Hinweise auf die Repräsentationsebene zu erhalten, auf der der ACE entsteht. Würde der ACE durch eine Manipulation der Bewegungsparameter moduliert, spräche das dafür, dass die Prozesse des Sprachverstehens und Handelns auf einer unteren motorischen Ebene interagieren. Dagegen würde eine Modulation des ACE durch Manipulation des Bewegungseffekts die Annahme stützen, dass die Interaktion auf der höheren Ebene der Bewegungseffekte stattfindet.

Die Beantwortung dieser Frage erwies sich als schwieriger als erwartet, da der ACE in diesen Experimenten entweder nur in den Fehlerraten auftrat (obwohl er sich üblicherweise in den Reaktionszeiten niederschlägt) oder nur in der transformierten Bedingung, wodurch er schwer zu interpretieren war. Einzig im dritten Experiment, in dem die Amplitude des Bewegungseffekts variiert wurde, ergab sich ein signifikanter ACE auch in den Reaktionszeiten der regulären Bedingung. Doch auch in diesem Experiment zeigte sich ein unerwartetes Ergebnis. Während sich bei kleiner Effektamplitude ein normaler ACE einstellte, schien dieser sich bei großer Effektamplitude in sein Gegenteil zu verkehren. Eine Nachanalyse legte nahe, dass diese Umkehrung des ACE mit dem Zeitpunkt der Reaktionen zusammenhängen könnte: Späte Reaktionen (durch die die Gruppe mit der großen Effektamplitude gekennzeichnet war) schienen zu einem negativen ACE zu führen, wohingegen frühe Reaktionen mit einem positiveren ACE einherzugehen schienen.

Aufgrund der Anzeichen dafür, dass das Vorzeichen des ACE von der zeitlichen Beziehung zwischen den Prozessen des Satzverstehens und der Reaktionsvorbereitung abhängen könnte, wurde der Einfluss dieses zeitlichen Faktors in den darauffolgenden drei Experimenten entweder zu kontrollieren versucht (Experiment 4) oder direkt untersucht (Experimente 5 und 6). In Anlehnung an die „Theory of Event Coding“ (Hommel et al., 2001) könnten der positive und der negative ACE folgendermaßen zustande kommen: Wenn die Codes, die die Richtung der verbal beschriebenen Handlung und der auszuführenden Reaktion repräsentieren, gleichzeitig aktiviert werden, sind diese Codes besser zugänglich, was die Prozesse im Fall gemeinsamer Richtungsmerkmale erleichtert („priming“) und zu einem positiven ACE führt. Wenn dagegen der Richtungscode bereits in eine der beiden

Handlungsrepräsentationen integriert wurde, ist er vorübergehend nicht verfügbar, um die jeweils andere Handlung zu codieren. Bei gemeinsamen Richtungsmerkmalen entsteht dadurch Interferenz und somit ein negativer ACE. Codes gelten als integriert, wenn die Vorbereitung der Reaktion abgeschlossen ist oder wenn eine vollständige Repräsentation des Satzinhalts gebildet und damit die beschriebene Handlung simuliert wurde.

Im vierten Experiment wurde der Zeitpunkt kontrolliert, ab dem die Probanden die Richtung der „Ja"-Antwort vorbereiten konnten (Go/No-go-Aufgabe). Die erforderliche Information wurde zu Beginn der Satzpräsentation bereitgestellt, da dies zu einer großen zeitlichen Überlappung der Aktivierung der Richtungsmerkmale beim Satzverstehen und bei der Reaktionsvorbereitung führen und somit einen positiven ACE ermöglichen sollte. In den Experimenten 5 und 6 wurde der Zeitpunkt manipuliert, zu dem die Probanden über die Richtung der „Ja"-Antwort informiert wurden: Sie erhielten die Information entweder vor Beginn der Satzpräsentation, gleichzeitig mit dem Satzbeginn, während der Satzpräsentation oder am Satzende. Auf diese Weise entstanden verschiedene Anordnungen und Grade der zeitlichen Überlappung der Aktivierung der Richtungscodes beim Satzverstehen und bei der Reaktionsvorbereitung, und dies sollte das Vorzeichen des auftretenden ACEs beeinflussen.

Erneut erbrachten die ersten beiden dieser drei Experimente keine aussagekräftigen Ergebnisse, da es sich als problematisch herausstellte, dass die Probanden nicht direkt gezwungen waren, die Information über die Antwortrichtung zum jeweils vorgegebenen Zeitpunkt zu verarbeiten und die Reaktion vorzubereiten. Dieses Problem wurde im sechsten Experiment gelöst, indem die Information nur für kurze Zeit bereitgestellt wurde. So konnten die erhaltenen Ergebnisse schließlich zur Klärung der untersuchten Fragen beitragen.

Im Hinblick auf die Rolle des zeitlichen Faktors zeigten die Ergebnisse, dass der positive ACE entsteht, wenn die Reaktion zu Beginn der Satzverarbeitung vorbereitet wird, wohingegen der negative ACE auftritt, wenn die Reaktionsvorbereitung mitten in der Satzverarbeitung erfolgt. Der positive ACE scheint also tatsächlich dadurch hervorgerufen zu werden, dass beim Satzverstehen und bei der Reaktionsvorbereitung gleichzeitig das gleiche Richtungsmerkmal aktiviert wird, wodurch es zum „priming" zwischen den beiden Handlungsrepräsentationen kommt. Ebenfalls in Übereinstimmung mit den obigen Annahmen ergab sich der negative ACE aus der Interferenz zwischen den beiden Prozessen, die anscheinend dadurch verursacht wurde, dass das Richtungsmerkmal bereits an die

Repräsentation des Satzinhalts gebunden und daher nicht mehr gut zugänglich war, als es für die Reaktionsvorbereitung benötigt wurde.

Was die Ebene der Repräsentationen betrifft, sprechen die Ergebnisse für die Annahme, dass die Interaktion zwischen den Prozessen des Sprachverstehens und Handelns auf der abstrakteren Ebene der distalen Repräsentationen stattfindet. In allen Bedingungen, in denen der ACE in den Reaktionszeiten zu beobachten war, bezog er sich auf die Kompatibilitätsbeziehung zwischen der Satzrichtung und der Richtung des Bewegungseffekts. Demnach scheinen Handlungsrepräsentationen, die beim Verstehen von Handlungssätzen aktiviert werden, auf der gleichen kognitiven Ebene angesiedelt zu sein und die gleichen Codes zu verwenden wie die Repräsentationen der Handlungseffekte.

Summary

Introduction

According to the embodied approach to language comprehension, understanding linguistic descriptions of actions engages neural substrates that overlap with those involved in performing the described actions. In other words, understanding action-related language relies on action simulation which consists in the reactivation of stored motor experiences. Theories representing this embodied perspective, such as the mirror neuron theory (Rizzolatti & Craighero, 2004), the view of distributed semantic representations (e.g., Pulvermüller, 2005, 2008), the theory of perceptual symbol systems (Barsalou, 1999), and the indexical hypothesis (Glenberg & Robertson, 1999, 2000), mainly assume that action representations activated during language comprehension reside on a lower level referring to specific motor programs. However, some of the theories suggest that also more abstract, higher-level action representations might be involved. The aim of this thesis was to shed more light on the nature of these action representations.

Findings taken as evidence for low-level motor representations are content-specific interactions between the understanding of a verbally described action and a concurrently performed motor response. Usually these interactions reflect a facilitated execution of the motor response when the response shares some features with the semantic meaning of the action-related words and sentences presented as stimuli. In this sense, they are similar to standard stimulus-response compatibility effects which support the common coding approach (Prinz, 1990, 1997) proposing that perceived events and planned actions are coded in a common representational format. But since common coding of perception and action is explained by the representation of actions in terms of their perceptual consequences (Prinz, 1990), the shared representations are assumed to reside on a more abstract, higher cognitive level where intended action effects are coded. In line with this, research on stimulus-response compatibility effects indicates that performance of actions can be facilitated under conditions in which stimuli share some features with the intended action effects (Hommel, 1993).

So far, experiments investigating compatibility effects between sentence comprehension and concurrent action did not differentiate between the representations of action and action effect. Therefore, it could be possible as well that they rely on shared high-level representations referring to distal features of the action effect instead of on low-level motor representations. Following Hommel (1993), this question was addressed by testing whether action representations activated during sentence comprehension interact with representations of intended effects of actions or with representations of the motor component of these actions. For investigating this issue, the action-sentence compatibility effect (ACE; Glenberg & Kaschak, 2002) was used which reflects a compatibility effect between the direction of a described action and the direction of the response.

In the paradigm employed, participants were presented with sentences describing concrete or abstract transfer actions that were directed either toward the body or away from the body (in the critical versions). For judging the sensibility of these sentences, participants had to produce a movement effect on a screen at a location near the body or far from the body. These movement effects were achieved by moving the hand from a middle button to a near or far button (i.e., toward the body or away from the body) with the location of the button either corresponding with the location of the to-be-produced effect (regular action-effect relation condition) or being opposed to it (transformed action-effect relation condition). In the transformed condition, movement and movement effect were dissociated which in principle allowed to determine whether the ACE relies on movement or on movement effect.

Summary of experimental findings

In Experiment 1, movement and movement effect had the same amplitudes, i.e., the distances between the locations of the near and far button and of the near and far movement effect on the screen were identical. These amplitudes were manipulated in Experiments 2 and 3 to obtain further evidence for the representational level on which the ACE arises. A modulation of the ACE induced by manipulating parameters of the movement would have spoken in favor of the interaction taking place on the lower motor level, whereas a modulation of the ACE caused by manipulating the salience of the movement effect would have supported the assumption that the interaction occurs on the higher level of movement effects.

Resolving this question turned out to be more difficult than expected because the ACE either appeared only for error rates (usually, the ACE manifests itself in response times) or only in the condition with transformed action-effect relation and thus was difficult to interpret. Solely Experiment 3 in which the amplitude of the movement effect was varied showed a significant ACE for response times also in the condition with regular action-effect relation. Yet even in this experiment, results did not reveal a more or less effect-related ACE depending on the effect amplitude as was predicted in case of the activation of representations on the level of intended movement effects. Instead, the ACE was reversed for the larger effect amplitude. A follow-up analysis suggested that the reversal of the ACE could be connected with response timing: Early responses went along more with a positive ACE whereas late responses (which were characteristic of the large-amplitude group) promoted the emergence of a negative ACE.

Since the sign of the ACE seemed to depend on the relative timing between sentence comprehension and response preparation, the next three experiments attempted either to control the influence of the timing factor (Experiment 4) or to investigate the role of timing in the ACE directly (Experiments 5 and 6). Based on Hommel et al. (2001), the positive ACE should emerge when the codes representing the direction of the verbally described action and of the to-be-performed response are concurrently activated and thus can produce priming. In contrast, the negative ACE should arise when the directional code of one of these actions is already integrated into the respective action representation and thus is temporarily not available for coding the other event which leads to interference. Codes are assumed to become integrated when response preparation is completed or when a complete representation of the sentence content is formed and thus the described action is simulated.

In Experiment 4, the point in time at which participants were able to prepare the required response direction was controlled. This point in time was determined to be the onset of the sentence as this should lead to a large temporal overlap between activations of the directional features during sentence processing and response preparation and thus should enable priming (i.e., a positive ACE) in the case of shared feature codes. Experiments 5 and 6 then manipulated the point in time at which participants were informed of which response direction to prepare: The information was provided either before sentence onset, at sentence onset, within the sentence presentation, or at the end of the sentence. In this way, different orders and degrees of temporal overlap were created concerning the activation of the directional codes during sentence processing and response preparation, and this should influence the sign of the resulting ACE.

Again, the first two of these three experiments did not produce clear results to answer one of the questions, since it appeared problematic that participants were not really forced to process the information about the required response direction and to plan the response at the given points in time. This problem was solved in Experiment 6 by making the information available only for a short period of time. So we finally obtained meaningful results with regard to the questions of interest. Concerning the timing issue, results showed that the standard positive ACE emerges when the response is being prepared at the beginning of sentence processing, whereas the negative ACE arises when the response is being prepared around the middle of the sentence. This suggests that the positive ACE indeed results from priming between action representations activated during sentence processing and response planning when both processes concurrently activate the same directional feature. Also in line with the above assumption, the negative ACE resulted from interference between the two processes that seemed to arise because the directional feature was already bound to the representation of the sentence content and thus was less accessible when needed for planning the response.

Regarding the representational level, the results support the assumption that the interaction occurs on the more abstract level of distal representations as the ACE was related to the movement effect in all of the conditions in which it appeared for response times. Thus, action representations activated during the understanding of action sentences seem to reside on the same cognitive level, using the same codes as representations of action effects.

Curriculum Vitae

Name:	Christiane Diefenbach, geb. Hauser
Geburtsdatum:	21.03.1980
Geburtsort:	Halle (Saale)

Wissenschaftlicher Werdegang:

2006 - 2009	Stipendiatin des Graduiertenkollegs „Funktion von Aufmerksamkeit bei kognitiven Prozessen“ an der Universität Leipzig unter Betreuung von Prof. Dr. Wolfgang Prinz und Prof. Dr. Erich Schröger
2005	Diplom in Psychologie
2001 - 2005	Studium der Psychologie an der Katholischen Universität Eichstätt-Ingolstadt
1998 - 2001	Studium der Psychologie an der Martin-Luther-Universität Halle-Wittenberg

Wissenschaftliche Veröffentlichungen und Vorträge

Tagungsbeiträge

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