ESP07

EMBODIED SENTENCE PROCESSING

Behavioural, neuropsychological, and computational perspectives

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FRIDAY AUGUST 17 PROGRAM

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11:30 Activation and retention of modality-specific information during language comprehension
Pecher, Erasmus University, Rotterdam

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FRIDAY AUGUST 17 PROGRAM

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Crocker[1], Mayberry[1], & Knoeferle[2], Saarland University(1) UCSD(2)

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Tettamanti, San Raffaele Scientific Institute Milan

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15:30 The Word Action Compatibility Effect (WACE)
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SATURDAY AUGUST 18 PROGRAM

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Barsalou, Emory University Atlanta

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Andonova & Janyan, University of Bremen

Poster 2 Eye-tracking reveals looks to simulated distractor imagery during sentence processing
Polley, University of Hawaii at Manoa

Poster 3 Embodiment of abstract concepts: Neurocognitive evidence from motor-meaning congruity and visual hemifield effects
Casasanto & Lozano, Stanford

Poster 4 Powerful metaphors; The role of spatial schemata in representing the concept of power
Dantzig, Boot, & Pecher, Erasmus University, Rotterdam

Poster 5 Incremental interpretation of motor knowledge affects the time course of visual attention during situated comprehension
Steinberg & Knoeferle, Saarland University (1), UCSD (2)

Poster 6 Modelling speech-gesture perception in Type Logics
Giorgolo, Utrecht University

Poster 7 Processing motor language affects unrelated motor tasks
Han, Bergen, & Schafer, University of Hawaii at Manoa

Poster 8 The effect of simulated shape on eye fixation
Jawee, Perla, & Han, University of Hawaii at Manoa

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Pyykkönen, Van Gompel, & Hyönä, University of Turku (1) University of Dundee (2)

Poster 10 Individual experience affects mental simulation in sentence processing
Wheeler & Bergen, University of Hawaii at Manoa

Poster 11 What a moving dot can tell us about language
Xierong & Altmann, University of York

Poster 12 The role of sensory-motor information in early categories
Zinchenko & Snedeker, Harvard University

Poster 13 Motor resonance during language comprehension
Taylor & Zwaan, Erasmus University, Rotterdam

Embedded and displaced comprehension

Zwaan, Erasmus University Rotterdam

Language comprehension has long been understood as the comprehension of language--first as the recovery of the syntactic and semantic structure of the linguistic input, and later as the construction of a situation model based on the linguistic input and background knowledge. I will describe two forms of language comprehension: embedded comprehension (in which the communicative and referential situation overlap and the comprehender perceives and acts in the referential situation) and displaced comprehension (in which the two situations do not overlap and the comprehender gets "re-situated" in the referential situation by way of linguistic cues). The so-called "visual-world" paradigm has been used to study embedded comprehension. I will describe the newly developed "visual-memory" paradigm, which can be used to study displaced comprehension. I will report data that my lab has collected using this paradigm. I will conclude that both embedded and displaced language comprehension involve a rapid integration of linguistic and perceptual information, which suggests that language and (visual) perception use similar representational formats and processing mechanisms.

Activation and retention of modality-specific information during language comprehension

Pecher, Erasmus University Rotterdam

According to embodied cognition theories, language comprehenders simulate sensorimotor experiences when they represent the meaning of what they read. According to these theories, systems for perception and action re-enact what is described in language. There is now evidence in the literature that subtle perceptual variations that are implied by sentences, but not explicitly described, can affect subsequent visual perception (Stanfield & Zwaan, 2001, Zwaan, Stanfield, & Yaxley, 2002). Moreover, representations of meaning can be modality specific (Pecher, Zeelenberg, & Barsalou, 2003). Although these findings support the embodied view, strategic imagery may also play a role. In studies that investigated the effect of match between sentences and pictures, participants were always aware of the relatedness between sentence and picture. In most cases, the task was to verify that an object displayed by a picture was mentioned in the preceding sentence. In order to enhance their performance, participants may have consciously created visual images during sentence reading. Such a strategy may explain the match effect. To prevent these strategies, we investigated long term effects of sentence reading on object recognition. Language comprehenders first read a list of sentences about objects. Only after the complete list had been read was recognition memory tested with pictures. Thus, at the time of sentence reading, participants were not aware that they would have to recognize pictures of objects at test. Recognition performance was better if the modality (Exp. 1) or the orientation or shape (Exp. 2) of the object matched that implied by the sentence. These results indicate that previously found match effects were not due to strategic imagery, and show that details of sensorimotor simulations are retained over longer periods.

Motion in music: The effects of auditory motion on sentence comprehension

Lynnott, Coventry, & Peacock, Northumbria University Newcastle

"Courtney handed you the notebook". "John looked at the steak in the butcher's window". "The chair toppled". All of these sentences have something in common; they have been used in recent studies that suggest that people automatically represent implicit, modality-specific information when comprehending language. However, the empirical findings have not been straightforward. Depending on whether stimuli are congruent (i.e., stimuli that match on a key dimension) or incongruent (i.e., mismatching) and presented cross-modally or intra-modally, very different effects emerge (Bergen, 2007).

Kaschak and colleagues (2006) investigated whether auditory stimuli affected language comprehension. They observed that congruent stimuli (e.g., a sound indicating upward motion and a sentence indicating upward motion) will only produce a facilitative effect (faster responses) when the stimuli are presented in the same modality (e.g., both presented auditorially). This is due to competition for attentional resources, resulting in serial processing of the stimuli, resulting in priming. However, if the stimuli are presented cross-modally, this results in a match-inhibition effect because the stimuli are competing for separate, modality-specific attentional resources; this means that attention can be given to both sound and sentence concurrently, resulting in the auditory stimulus acting as a distractor for the processing of the visually presented sentence.

In this paper we present a study using a cross-modal sentence-sensibility judgement paradigm, similar to that used by Kaschak et al. While there are some differences in design, our predictions follow directly from the theoretical account they propose. (i)If cross-modal presentation does not produce competition for attentional resources, we expect incongruent conditions to be responded to more quickly than congruent conditions. Alternatively (ii) such competition does occur and congruent conditions facilitate responses or (iii) congruency is irrelevant to the task and so will have no impact on responses.

Thirty undergraduates completed this experiment, which had a two-factor, 4x3 within-participants design. The first factor, Sentence Type, contained four levels; Ascending Motion, Descending Motion, No Motion and Nonsense. The second factor, Music Tone, had three levels of Ascending, Descending and Flat. Thirty-six sentences were constructed, nine for each condition, depicting either ascending motion (e.g., The window cleaner climbed up the tall ladder), descending motion (e.g., The man tripped and fell down the stairs), no motion (The judges decided who would be the winner), and nonsense sentences (e.g., The zip line was mended technician employed it). All sentences contained 8 words to ensure they would all be displayed for the same total length of time using a Rapid Visual Stimulus Presentation paradigm (RVSP). The audio files were prepared by generating samples with pitch ascending (100Hz-800Hz), descending (800Hz, 100hz) and constant (400Hz). Response times and error rates were measured and analysed, treating both participants and items as random factors.

Participants performed a sentence-sensibility judgement task; judging visually-presented sentences, while listening to tones in their headphones. Each audio segment played for the duration of the sentence and ended once a judgement had been made. Judgements were made by pressing the M key for a "Yes" judgement or V for a "No" judgement. Trial presentation was andomized.

We observed no main effect of Music Type or Sentence Type, but there was a significant interaction ($F1(6,174)=3.642$, $MSE=20165$, $p=0.002$; $F2(6,64)=3.06$, $MSE=6817$, $p=0.011$). For the Ascending Music condition, people responded more quickly to sentences involving Ascending motion (527ms) compared to Descending motion sentences (670ms); $p<0.05$. The direction of this effect was reversed for the Descending music condition, with Descending Sentence responses faster than Ascending sentences responses. Overall, this can be seen as a Match facilitation effect with Match responses (566ms) being significantly faster than Mismatch responses (658ms). Analysing error rates, there was no effect of Sentence Type or Music Type.

The observed match facilitation effect is the opposite to that found by Kaschak et al (2006). Following their results, we would have expected that using a cross-modal paradigm (sentences presented visually, with auditory motion stimuli), would not result in competition for attentional resources when sound and sentence were congruent in terms of directionality. However, this was not the case. Instead, responses were significantly faster (>100 ms) when stimuli were congruent. Therefore, we would suggest that having congruent stimuli in different modalities can act as facilitative primes. Although the sound files depicting upward or downward motion are playing concurrently with the sentence presentation (RSVP. Word by word), it is also the case that the audio is present in advance of when participants actually make a speeded sensibility judgement. Thus, even in a simultaneous cross-modal presentation paradigm, serial processing may still allow a stimulus that is congruent to facilitate rather than inhibit responses (e.g., Meteyard et al, 2007) . It is possible that the different effects observed here and in Kaschak et al (2006) are down to design differences (e.g., block versus non-block design), material sets, or audio file stimuli. These factors are the focus of our ongoing work to fully understand the dynamics of the activation of modality specific information in sentence processing tasks.

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Pushing versus pulling: Desiderative sentence mood facilitates approach related motor actions

Claus & Bader, Saarland University

There is growing evidence for the view that language comprehension involves embodied mental simulations, which are grounded in perception and action. In addition to neuroscientific support (e.g., Hauk, Johnsrude & Pulvermüller, 2004; Pulvermüller, Härle & Hummel, 2001), there are also behavioural studies that suggest that a sentence is understood through a sensorimotor simulation of the described situation as their results indicate that language comprehension involves the activation of motor programs (e.g., Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006). For example, in the study by Glenberg & Kaschak (2002), responses to a sentence-sensibility judgment task were faster when the direction of the hand movement required for correctly responding to the task (away vs. toward participant's body) matched the movement implied by the sentence (away from the body, e.g., "You handed Courtney the notebook"; toward the body, e.g., "Courtney handed you the notebook") compared to when there was a mismatch. This action-sentence compatibility effect was not only found for sentences describing a concrete transfer but also for sentences describing a nonphysical transfer (e.g., "Liz told you the story" / "You told Liz the story").

The aim of the present study was to explore whether an embodied account of language comprehension could also handle abstract information like sentence mood. More specifically, it was investigated whether processing sentences in desiderative mood (expressed by verbs like "to want" or "to wish") might involve the facilitation of specific motor actions. One starting point was the distinction between two systems, approach and avoidance, in accounts of the regulation of behaviour (for a review see Elliot & Covington, 2001): The approach system is associated with desires and goals, whereas the avoidance system is associated with fears and threats. In social psychological studies of automatic evaluation, it was found that participants responded faster to positively valenced stimuli when the response required an approach-related motor action (e.g., flexing the arm as if pulling something toward one) compared to when it required an avoidance-related reaction (e.g., extending the arm as if pushing something away); for negatively valenced stimuli the pattern was reversed (e.g., Chen & Bargh, 1999). With regard to the issue of the present study, we hypothesized that processing sentences in desiderative mood activates the approach system. This hypothesis predicts that desiderative sentence mood facilitates approach reactions, such as pulling, compared to avoidance reactions, such as pushing. One first experiment was carried out to test this prediction.

The experiment was conducted in German. Participants listened to sentences and made sensibility judgments about these sentences. Each experimental sentence had two versions, which differed with regard to sentence mood: in the desiderative version, the sentence described a desired situation ("Lea will eine Pyramide besichtigen" [Lea wants to visit a pyramid]); in the factual control version, the same situation was described as being factual ("Lea hat eine Pyramide besichtigt" [Lea has visited a pyramid]). Participants indicated their sensibility judgment by either pulling a joystick (approach reaction) or by pushing a joystick (avoidance reaction). Each participant was initially randomly assigned to the yes-is-pulling (no-is-pushing) or yes-is-pushing (no-is-pulling) condition. Halfway through the experiment, they were instructed to reverse the assignment of response (yes / no) to movement direction (pulling / pushing) for the second half of the experiment.

The manipulation of the response direction differentially affected the sensibility-judgment times in the two sentence mood conditions. When the sentences were in factual mood (control), the judgment times did not differ significantly between the yes-is-pulling and yes-is-pushing condition. In contrast, when the sentences were in desiderative mood, judgment times were significantly affected by the response direction. It took participants less time to judge desiderative-mood sentences as sensible if this required pulling the joystick compared to if this required pushing the joystick.

The finding that manipulating the response direction affected the judgment times for the sentences describing a desired situation but not for the sentences describing a factual situation suggest that the direction of the motor action was specifically relevant when processing sentences in desiderative mood. Furthermore, the fact that the judgment times for the desiderative mood sentences were shorter in the pulling condition than they were in the pushing condition is consistent with the hypothesis that sentences in desiderative mood trigger the approach system. This hypothesis implies that processing a desiderative-mood sentence should facilitate approach reactions such as pulling a joystick. The present experiment provides initial empirical support for the idea that sentence mood facilitates or inhibits approach-related or avoidance-related motor actions.

The result is in line with results from the aforementioned studies indicating that language comprehension involves the activation of motor programs (Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006). The specific contribution of the present experiment is the finding that even a rather abstract concept like desiderative sentence mood can facilitate particular motor reactions.

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On the Influence of time in language comprehension

Elke van der Meer, Humboldt University Berlin

Time is one of the most central aspects of human life. However, no sense or sense organ is known by which time can be perceived directly. Based on experimental studies researchers argue that time is an abstraction at which we arrive by means of the changes of things (cf., Mach, 1886). Thus, the fundamental aspects of psychological time (duration, temporal order, and perspective, Block, 1990) are assumed to be mediated by perception, action, affect, and language (Kesner, 1998). This fits well with the global view that cognition does not operate independently of modality-specific systems for perception and action. Instead, mechanisms in these systems play central roles in cognition (cf., Barsalou, 2003; Martin, 2007; Barsalou, Breazeal, & Smith, 2007). From this perspective, knowledge is considered a simulation in modality-specific systems. This experiental-simulations approach is supported by behavioral experiments. For example, Zwaan et al. (2002) found that people construct visual simulations when comprehending sentences. Kaup et al. (2007) demonstrated that comprehenders mentally simulate a described situation even when this situation is explicitly negated in the sentence. Furthermore, Glenberg and Kaschak (2002) found that when people comprehend a sentence, they construct a motor simulation to represent its meaning. These findings illustrate that higher cognition, such as language comprehension, is grounded in modality-specific representations.

Freyd (1987, 1992) has been proposed that all mental representations reflect the dynamic character of our environment, that is, the temporal dimension is inextricably embedded in the representation. This internal temporal dimension is assumed to be like external time, directional (familiar sequences of real-life events are organized unidirectionally) and continuous. Several findings support this claim. For example, sentence and text comprehension is impaired if there is a mismatch between the chronological order and the reported order of events (cf., Ohtsuka & Brewer, 1992; van der Meer et al., 2002). Münte, Schiltz, and Kutas (1998) measured event-related brain potentials (ERPs) as participants read “before” and “after” sentences. “Before” sentences elicited, within 300 ms, greater negativity in the left-anterior part of the brain than “after” sentences. That is, deviations from chronological order increase cognitive effort.

The aim of our experiments was to focus on temporal aspects of events to analyze the dependency between cognition, perception and action in language comprehension in more detail. Following Freyd (1992), events and sequences of events are assumed to hold an intrinsic temporal structure, highlighting both the chronological organization of events (time’s arrow) and their temporal distance. Are experiential simulations an optional by-product of language comprehension or do they fulfil a certain purpose? What is the role of anticipation in language comprehension? Is time’s arrow restricted to complex sequences of events or a general phenomenon? These questions were tackled in a series of experiments. The idea was to manipulate the complexity of event information subjects were faced with (single events, event-pairs, event-triplets, sentence-probe-pairs) and to employ a combination of research methods – behavioral studies, pupillary responses, and functional neuroimaging methods. The results show strong evidence of directional and distance properties in event representations. Taken together, the experiential-simulations approach seems well supported by the empirical evidence.

Embodied language production: Evidence from gesture, speech disfluency, and motor action

Casasanto & Lozano, Stanford

Much of the evidence for the embodiment of language and concepts comes from studies involving language comprehension. Here we report a series of experiments exploring the embodied basis of language production, in which spontaneous gestures during storytelling were either elicited or inhibited to reveal relationships between word meanings and manual motor actions.

Experiments 1 & 2: Spatializing the Non-Spatial. Do speakers produce spontaneous gestures that are congruent with both the literal and metaphorical spatial content of the stories they tell? Even when they're not using any spatial language? To find out, we asked pairs of naïve participants (N=28) to take turns studying and then retelling brief stories. Participants knew that they were being videotaped, but they were not instructed to gesture, and did not know the experiment had anything to do with gestures. Each participant retold three types of stories:

(1) Literal Spatial Language stories (e.g., My rocket went higher...)
(2) Metaphorical Spatial Language stories (e.g., My grades went higher...)
(3) Non-Spatial Language stories (e.g., My grades got better...)

Literal Spatial Language (LSL) stories described physical objects and events directed either upward, downward, right, or left. Metaphorical Spatial Language (MSL) stories described non-spatial phenomena that are nevertheless commonly expressed using spatial metaphors. Non-Spatial Language (NSL) stories were identical to the MSL stories, except that all metaphorical spatial language was replaced with non-spatial language conveying nearly the same meaning. Each participant retold six target stories, two in each language condition.

Blind coding revealed that 87% of participants' gestures were congruent with the a priori predicted orientations and directions. This was true not only in the Literal Spatial Language condition (e.g., upward gesture accompanying "the rocket went higher"), but also in the Metaphorical Spatial Language condition (e.g., upward gesture accompanying "my grades went higher"), and critically in the Non-Spatial Language condition, as well (e.g., upward gesture accompanying "my grades got better"). Schema congruity did not differ across language conditions; even when participants used no spatial language, their gestures revealed that they formed spatio-motor representations corresponding to the abstract ideas they expressed.

A second experiment showed that participants (N=28) produced 37% more verbal disfluencies when they were prevented from gesturing by holding down buttons on a keyboard than when they were allowed to gesture freely. Disfluencies (i.e., repeats, repairs, fillers, insertions) increased equivalently during target clauses in all three conditions (LSL, MSL, and NSL), but not during non-target control clauses ($F(1,54)=4079.20$, $p=.000000001$). Together, these findings suggest that gesturing interacts with the process of formulating literal and metaphorical spatial concepts -- not just accessing spatial words.

Experiment 3: Motor action and concept formation. How does gesture benefit speaking and thinking? Both gestures and words function as communicative signs. Perhaps speakers describe spatial concepts more fluently when gesturing because producing one sign (the gesture) facilitates producing another sign (the word or phrase) that signifies the same concept. Alternatively, gestures may facilitate speech because the motor programs that generate directed hand and arm movements also activate or reinforce the spatio-motoric schemas that partly constitute concrete and abstract word meanings.

We created a dual-task experiment to distinguish effects of the semiotic and the purely motoric components of gesture on speech production. While telling the stories used in Experiments 1 and 2, participants continually transferred marbles with both hands between pairs of boxes that were stacked on top of one another in front of the storyteller. Marble movements were timed by a metronome, and participants moved marbles in the same assigned direction

throughout the experiment. Importantly, movements were either congruent or incongruent with the spatial schemas implied by the target clauses.

We reasoned that if the semiotic function of gesture is responsible for the increased verbal fluency observed when free gesturing is allowed, then disfluency results in Experiment 3 should resemble those of our previous gesture prevention manipulation: all marble movements -- whether schema-congruent or schema-incongruent -- should impair verbal fluency equivalently, since all marble movements disrupt meaningful gesturing.

Alternatively, if the motoric component of gestures influences verbal fluency, schema-congruent and schema-incongruent marble movements should have opposite effects. Schema-incongruent movements should impair verbal fluency because they depend on motor plans that conflict with the spatio-motor schemas underlying target word meanings. By contrast, schema-congruent marble movements should promote verbal fluency because they depend on motor plans that activate or reinforce the spatio-motoric schemas underlying word meanings.

Participants (N=16) produced verbal disfluencies at a dramatically higher rate during schema-incongruent marble movements than during schema-congruent movements (difference=61%; $t(15)=33.50$, $p=.000000001$). Results strongly support the proposal that motor actions, per se, are the active ingredient in the cognitive function of literal and metaphorical gestures, and suggest that their motoric form can influence speech fluency independent of any semiotic function.

Together, these experiments demonstrate that congruity effects between motor action and word meaning extend beyond language comprehension to language production.

Grammar modulates mental simulation

Bergen & Wheeler, University of Hawaii at Manoa

Evidence from linguistic (Lakoff, 1987), behavioral (Zwaan et al., 2002; Glenberg & Kaschak, 2002; Richardson et al., 2003, among others) and brain imaging studies (Pulvermueller et al., 2001; Tettamanti et al., 2005) has shown that sentence comprehenders construct mental simulations - or mental imagery - of motor and perceptual components of described scenes. Processing a sentence like "Jenny hurled the water balloon at her little brother" might drive understanders to mentally simulate the motor action of throwing a water balloon, including the required handshape and trajectory of the arm. Or they might simulate visual components of the scene, like a water balloon flying through the air. The words in a processed utterance, like "hurl" and "water balloon", clearly contribute to the construction of mental simulations. But grammatical structures have also been suggested to play a role, namely to modulate mental simulations (Bergen & Chang 2005). If content words tell you what to simulate, then grammatical structures tell you how to simulate it. Two studies provide experimental evidence that grammar - specifically, grammatical aspect and grammatical person - do indeed modulate mental simulation.

Our first experiment investigated how grammatical aspect ("Jenny has hurled the water balloon" versus "Jenny is hurling the water balloon") affects the degree of detail of a motor simulation. It has been hypothesized (Chang et al., 1998; Madden & Zwaan, 2003) that one function of aspect is to focus attention on different components of a described scene. While the perfect has been shown to lead the understander to perform more detailed mental imagery of an event's endstate (Madden & Zwaan, 2003), the progressive has been hypothesized to focus mental simulation on the middle or nucleus of a described event - e.g. the enactment of the throwing motion. In an Action-sentence Compatibility Effect study (Glenberg & Kaschak, 2002), participants read sentences with either perfect or progressive aspect, and then made manual responses to indicate whether each sentence was meaningful or not. Critically, the sentences denoted motion away from or towards the body of the actor, and the participants' manual responses required them to move their hand away from or towards their own bodies. As in previous studies, we found a significant compatibility effect, where manual responses were 25 msec faster when the participant had to move their hand in the same direction as the action described in the sentence, but this effect was only present for sentences with progressive aspect $F1(1,54)=9.34$, $p<0.01$, $F2(1,39)=6.93$, $p<0.05$, and not perfect aspect ($Fs < 1$). This suggests that, as claimed, understanders perform detailed imagery of the internal components of events when they are expressed in the progressive, but not in the perfect. Grammatical aspect modulates what part of a described event understanders simulate.

We then looked at how grammar affects the perspective adopted in mental simulations. Visual imagery can take place from a number of perspectives, including 1st person, or participant and 3rd person, or observer, perspectives. We hypothesized that grammatical person ("you" versus "Jenny") would affect the perspective adopted visual simulation. Specifically, we expected second person "you" to drive understanders to adopt a first-person perspective (they should imagine scenes from the perspective of a participant), whereas third-person referents ("Jenny") would evoke third-person, observer perspective. We tested this using a method modified from Zwaan et al. (2004). Participants heard sentences describing motion away from the agent, which was expressed in either the second- or third-person: e.g. "You kicked the ball towards the goal" and "The forward kicked the ball towards the goal". After each sentence, participants saw two pictures, which were either the same picture presented twice or two different pictures. Participants had to decide whether the two pictures were the same or different, but in all critical trials the pictures were the same. The manipulation of interest involved the size and shape of the second of these two matching pictures. Either the second image was slightly smaller than the first image or it was moved slightly to the right on the screen. These two picture conditions created illusory motion, where the object appeared to be moving away from the participant or to their right. We hypothesized faster responses to the away-moving pictures after sentences describing motion of

an object away from "you" and faster responses to the rightwards-moving pictures following sentences about objects moving away from a third person. Indeed, participants responded on average 60 msec faster in the "compatible" perspective condition, $F(1,42)=4.96$; $p<0.05$.

Grammar affects the mental simulations that understanders perform while processing language. While content words like nouns and verbs supply substance to a mental simulation - what is to be simulated, with what properties, engaged in what events - grammar appears to modulate the simulation. It provides higher-order parameterizations not of what to simulate but how to simulate it: what perspective to adopt and what part of the event to focus on.

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Grounded symbols, embodied rules: Brain-mechanics of syntax and the lexicon

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In linguistics, languages are described as systems of 10,000s of discrete meaningful symbols ordered in time according to combinatorial principles and rules. However, computational neuroscientists have cast doubt on the notions of discrete symbolic representations and combinatorial principles, arguing that a network of distributed neurons with gradual activation can capture major facts of lexico-semantic and syntactic processing. It is argued that the absence of discrete representations in current neural networks reflects a deficit of these networks: their failure to incorporate major features of neuroanatomical connectivity, especially the strong within-area connections documented for cortical tissue[1,2]. Discrete lexical representations emerge, as a result of neurophysiologically realistic correlation learning, in a new neuroanatomically grounded model of the language cortex[3,4]. This model correctly predicts neurophysiological brain responses to lexical elements (words and affixes) and matched meaningless items[5]. The apparent consistency between experiment and theory provides support for the discreteness of lexical representations[6].

A similar set of arguments holds at the level of discrete combinatorial mechanisms. Neuroanatomically realistic connection structure predicts the formation of neuronal rule-equivalents, so-called sequence detector (SDs)[7], which represent a possible brain basis for syntactic binding between syntactic constituents. Discrete sequence detectors operating on groups of lexical representations form as a consequence of Hebbian correlation learning in a network with rich auto- and heteroassociative connectivity[8]. Neurophysiological evidence for discrete combinatorial mechanisms comes from experiments comparing frequent grammatical and rare ungrammatical word strings with grammatical strings that rarely occur in language use[9]. These neurocomputational and -physiological studies provide a mechanistic foundation of discrete and combinatorial representations and their role in linguistic and other cognitive processes.

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TITLE - tba

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Processing visuospatial information during reading and listening: the reading-interference hypothesis

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Modal theories of language comprehension assume that the description of a situation is understood through a mental simulation of the experience of the situation, recruiting the modality-specific mental subsystems that are used in perception and action. A corollary of this assumption is that during language processing, the linguistically conveyed information and information from the comprehender's current real situation interact. Importantly, this interaction is assumed to occur not only in situated communication (i.e., when the linguistically conveyed information is meant to be integrated with information from the current situation), but also when the comprehender does not take the described situation as being related to his or her current real situation. Several studies have provided evidence for this interaction (e.g., Glenberg & Kaschak, 2002).

A hypothesis arising from this theoretical approach is that the modality of the linguistic input (visual vs. auditory) has an impact on the comprehension of visuospatial information. Reading involves the control of eye movements, and this requires the processing of visuospatial information from the real situation. Thus, when visuospatial information about a described situation is to be processed, it needs to compete for resources of the visuospatial subsystems. In contrast, when listening to a description, these subsystems are fully available for comprehension. Thus, the hypothesis is that compared to listening, reading is disadvantageous to the comprehension of visuospatial descriptions. (This hypothesis obviously bears some resemblance to the interference hypotheses proposed by Brooks, 1970, and Eddy & Glass, 1981).

In order to investigate the hypothesis we conducted three experiments. Participants read or listened to short narratives presented sentence-by-sentence (self-paced). There were two versions of each experimental passage, differing with regard to a particular piece of spatial information. Each participant was presented with only one version of a passage. Comprehension of the spatial information was tested by means of a probe-recognition task that named a previously mentioned entity whose accessibility could be expected to differ for the two text versions, provided the participants processed the critical spatial information properly.

In Experiment 1, the two versions of a passage differed with regard to a motion on the part of the protagonist. As a consequence of the motion, the critical entity was either relatively close to or further away from the protagonist at the time of testing. The results for the probe-recognition latencies were in line with the reading interference hypothesis. The interaction modality x spatial distance was significant. The probe-recognition latencies of the listeners were significantly shorter when the target entity was relatively close to the protagonist compared with when it was further away. For readers, no significant spatial distance effect was found.

In Experiment 2, the relevant part of a passage described a static scene, and the two versions differed with respect to the information about the protagonist's gaze direction. The critical entity was either within the protagonist's field of view or outside of it. The result pattern corresponded to that of Experiment 1. Probe-recognition latencies of the listeners but not those of the readers were affected by the manipulation of the spatial information.

Experiment 3 investigated whether the results might be due to the fact that the auditory presentation provided additional information (through intonation) or the fact that the listeners spent more time on processing the sentences compared with the readers. The same passages as in Experiment 2 were used, but one group of participants read and simultaneously listened to the passages, whereas the other group listened only. A spatial effect was found for the listening-only group but not for the reading-and-listening group, thus speaking against the alternative explanations.

Taken together, the results of our experiments support the hypothesis that the reading process interferes with the processing of visuospatial text information. As to the complete lack of spatial effects in the reading conditions, it is important to bear in mind that the hypothesis does

not state that readers generally fail to comprehend and maintain spatial information about a described situation. Rather, it says that readers experience a dual-task condition, and accordingly, that the outcome depends on several factors, for example, whether the reader considers it necessary and is able to use compensatory strategies. In our experiments, no emphasis was placed on the processing of spatial information, neither by prior layout-learning (as is the Morrow paradigm), nor by the content of the narratives, nor the probe-recognition task. Thus, the readers may not have made an effort to overcome the problem. However, there are several additional potentially relevant variables with regard to which the existing studies of spatial information processing during reading differ (for a review see Zwaan & Radvansky, 1978). The reading-interference hypothesis provides a framework for integrating the numerous seemingly inconsistent results.

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Language, scene, & attention: Towards a computational theory of situated comprehension

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The visual world paradigm has shown that people rapidly exploit linguistic and non-linguistic information sources during spoken utterance comprehension. Based on these findings, Knoeferle and Crocker (2006) proposed the coordinated interplay account (CIA) which posits that attentional processes underpin this fluid interaction: initially the unfolding utterance guides attention in the visual scene to establish reference to objects and events that then in turn rapidly influence comprehension, leading to the observed high priority of scene information. In the first part of this talk, we will review the CIA, and summarise the key experimental findings which underlie the account. In the second part of the talk we will discuss both previous and ongoing modeling of the influence of scene information during incremental sentence comprehension, instantiating the CIA.

In the newest architecture, the central innovation of the model is two isomorphic self-organizing maps (Mayberry et al, 2003) representing scene content and the sentence interpretation using flat semantic representations. The scene and sentence representations encode semantic features of scene items and words of the utterance in their respective maps. The model processes the sentence word-by-word using an attentional mechanism to increase the activation of salient scene items. When the scene is present, the nodes for the events' constituents are propagated directly to the network's hidden layer, and the attentional mechanism dynamically shifts the network's attention to the utterance-relevant event as each word is processed. The attended event thus has more influence on the developing interpretation, allowing the model to anticipate upcoming role fillers, based either on stereotypical associations or derived from depicted actions and their associated thematic roles. This mechanism both improves the overall performance over a network without attentional modulation and provides a qualitative model of human attentional behavior during situated comprehension. The system has been trained on a corpus covering the stimuli of several visual world studies, and exhibits all the hallmark behaviors: incremental processing, intergration of multimodal information, adaptive use of information from the scene, and anticipation of upcoming role fillers. The network also implements the tight temporal coordination of language and scene processing using its attentional mechanism, satisfying the central claims of the CIA.

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I did, I do, I don't

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1) I did:
The cerebral organization of action semantics in memory is still controversial. Although action semantics has been often treated as a unitary type of knowledge, recent neuropsychological evidence has opened the possibility that it can be further fractionated into action knowledge (motor-based knowledge of object utilization) and functional knowledge (including abstract, propositional properties, such as location, function and context of use). In an event-related fMRI experiment, we contrasted the "unitary" model and the "dual" model and found evidence in support of the latter view, namely that functional knowledge is not entirely based on the fronto-parietal system underlying action control.

2) I do:
The mirror neuron circuits encode an observation–execution matching system that is thought to play an important role in the understanding of actions made by others. In an fMRI experiment, we tested whether this system also becomes active during the processing of action-related sentences. The results provide evidence that listening to sentences describing actions performed by different body-parts activates a left-lateralized fronto-parieto-temporal system that largely overlap with the one activated during action execution and action observation.

3) I don't:
The effects of sentential negation on the neural activity underlying sentence processing are largely unknown. Two opposed views have been proposed based on pyscholinguistic evidence: i) negation is associated with increased computational demands; ii) negation interferes with mental simulation mechanisms leading to diminished neural activations. In an event-related fMRI study, we tested whether sentential negations can modulate the activation of the neural network related to the comprehension of action-related sentences, by contrasting sentences like "I grasp a knife" and "I do not grasp a knife". Classical fMRI data analysis and effective connectivity analysis demonstrate that negation is associated with an activation suppression in the left-lateralized fronto-parieto-temporal action representation system, compatible with the interference hypothesis.

Effects of implied perceptual information on Stroop colour-naming

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Colour is undeniably important to object representations (Halff, Ortony & Anderson; 1976; Naor-Raz et al. 2003; Tanaka & Presnell, 1999), but so too is the ability of context to alter the colour of an object (Halff et al., 1976; Joseph & Proffitt, 1996; Medin & Shoben, 1988). Theories of embodied cognition usually describe colour representation as the specialisation of a perceptual simulation to include colour information (Barsalou, 1999; Zwaan, 2004). That is, the same neural subsystems that represent colour in perception will be activated to represent colour detail in the conceptualisation of an object. Connell (2007) offered empirical support for this assertion by showing that people represent implied colour information during sentence comprehension even though doing so does not facilitate task performance (see also Stanfield & Zwaan, 2001; Zwaan et al., 2002). However, there has been little discussion of how such specialisation might take place if the object simulation is already, by default, specialised with a typical colour. For example, we know that tomatoes are usually red but we may encounter a scenario in which they are green. Which representation ñ contextually implied or canonically typical ñ plays a dominant role?

In this experiment, people were asked to perform a semantic Stroop task (Klein, 1964; Ménard-Buteau & Cavanagh, 1984) to test how canonical and/or contextual colour information is activated during sentence comprehension. The perceptual simulation view of mental representation would hold that, for a sentence such as ìJane tasted the tomato before it was ready to eatî, the representation of ìtomatoî should be specialised with the implied, contextual colour green. But how would the redness and greenness of the tomato interact in such a specialisation? Would typical red or implied green facilitate colour-naming when the word ìtomatoî is subsequently presented in a semantic Stroop task? There are three essential possibilities: 1) implied colour may not be specialised at all as it is not directly stated in the sentence; 2) implied colour may be specialised by temporarily overriding typical colour in the object representation; and 3) implied colour is specialised and represented in parallel with typical colour.

Participants (48 native speakers of English) were presented with a colour-associated word such as ìtomatoî (in either typical red or atypical green), having just read a context sentence with implicit colour information such as ìJane tasted the tomato when it was ready to eatî or ìJane tasted the tomato before it was ready to eatî (implying either typical or atypical colour for the tomato). Test items consisted of a 2 x 2 within-participants cross of implied colour (typical, atypical) and ink colour (typical, atypical) for ten objects. There were twice as many filler items (words with no associated colour and their accompanying sentences: e.g., ìbookî in turquoise) as test items.

Results showed that colour naming was facilitated both when ink colour was typical for that object and when it matched the colour implied by the previous sentence. There was no overall effect of implied colour [$F<1$], but typical ink colours were named overall faster than atypical colours [$F(1,47)=54.2$, $MSE=0.032$, $p<.0001$], and there was an interaction between factors [$F(1,47)=4.06$, $MSE=0.054$, $p=.0496$]. Planned comparisons showed that, when the ink colour was typical for that object (e.g., ìtomatoî in red), the preceding sentence -- whether implying typical ($M=0.860$s, $SE=0.0358$) or atypical ($M=0.897$s, $SE=0.0302$) colour -- made no difference to how quickly people were able to colour-name [$F<1$]. On the other hand, when the ink colour was atypical (e.g., ìtomatoî in green), people were faster to colour-name when the preceding sentence had also implied an atypical colour ($M=1.018$s, $SE=0.0399$) rather than a typical colour ($M=1.117$s, $SE=0.0390$), [$F(1,47)=4.69$, $p=.036$]. In Stroop tasks, priming the colour name facilitates naming ink colour (Cheesman & Merikle, 1986; Kouider & Dupoux, 2004), and so these results suggest that the same priming effect emerges when colour is implied rather than directly stated.

Our findings are in line with theories of embodied representation which state that perceptual information is activated during sentence comprehension, and also suggests that

context-specific specialisation is held in parallel with the more usual, typical specialisation of an object. In other words, when object-typical colour is implied then nothing out of the ordinary has happened and the object retains its usual specialisation of the typical colour (e.g., red tomato), and when object-atypical colour is implied, then something unusual is afoot and the object is represented with a parallel specialisation of both typical and atypical colours (e.g., red l green tomato). Since an object may be reasonably expected to occur with its typical colour, the fact that a particular context actually specifies something different may not be enough reason to abandon the original expectation (Johnson-Laird, 1983; Kaup, Lüdtke & Zwaan, 2006). Parallel specialisation, where typical object information is held in mind in the face of contradictory context, offers several advantages to the language comprehender, such as allowing for easy error correction and rapid identification of other (more typical) exemplars. Further research is needed to investigate the implications of such possibilities

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The Word Action Compatibility Effect (WACE)

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The present research reports on a series of studies investigating the Word Action Compatibility Effect (WACE). The Action sentence Compatibility Effect (ACE) was first described in a study by Glenberg and Kaschak (2002) which showed that processing of a sentence describing a concrete or abstract action could lead to an action compatibility effect, where the execution of an action was quicker when there was a match between the semantics of the sentence and the action, compared with when there was a mismatch. This finding has since been replicated using a similar design (Bourgeinne & Kaschak, 2006; Manuel de Vega, in preparation), as well as with sentence based studies with different kinds of actions (Wheeler & Bergen, to appear; Zwaan & Taylor, 2006). In Zwaan and Taylor, an action compatibility effect was found for the processing of verbs as well as for the entire sentence. This suggests the possibility that individual lexical items can be associated with motor schemas.

The work that will be described here reports the results of three psycholinguistic studies that investigate whether processing of single lexical items presented outside of a context leads to the activation of motor schemas which can interact with movement execution. In one study, participants made lexical decisions by moving their hand either upwards or downwards in response to words. The stimuli were spatial words, like up or down, and verbs associated with upwards or downwards movement, like rise or fall. Spatial words led to an action compatibility effect, which was not found for the verbs. In a second study, a similar methodology was used to Glenberg and Kaschak (2002), where participants had to make a hand movement towards or away from their body. Stimuli included single words encoding spatial direction, such towards or backwards, verbs of concrete actions, such as push or pull, or verbs of transferring or receiving, such as transfer or receive. Results showed an action compatibility effect when the semantics for each words matched the hand movement. A third study was inspired by findings of somatopic organisation for action verbs associated with hand or feet actions (Hauk, Johnsrude & Pulvermuller 2000). Participants made lexical decision by pressing a button with their hands, or by pressing a pedal with their feet, in response to verbs that were associated with hand or feet actions. Responses were faster when there was a match between the effector and the action.

The results and contribution of the findings of the WACE will be discussed. Action compatibility effects from the study of embodiment in lexical and sentence processing will be compared with findings of response compatibility effects such as the Simon effect (Simon & Berbaum, 1990). Examination of the Simon effect and the TEC theory of action coding (Hommel, M¸sseler, Aschersleben & Prinz, 2001) provides some explanation of the mechanisms responsible for possible response facilitation on matching trials and response interference on mismatching trials. It will be examined why, as in this case, we find a match advantage effect of faster responses when there is match between semantics and action, whereas in other ACE-like studies a mismatch advantage has been found (Buccino et al. 2005; Boulenger et al. 2005). It is argued that amongst other factors, the degree of temporal overlap is paramount to determining whether a match advantage or mismatch advantage will be shown.

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Simulating different types of negation

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Embodied accounts of language comprehension propose that comprehenders understand sentences by constructing perceptual or motor simulations of described events. Evidence for this view comes from experimental work showing that visual processing and sentence comprehension can interact with each other (Richardson et al., 2003; Kaschak et al., 2004; Bergen et al., 2007). Recent studies investigating how negated sentences are understood have shown that they too involve the activation of perceptual representations. Evidence to date suggests that processing negated sentences engages understanders to perform visual simulation of the counterfactual situation (i.e. the situation ruled out by the statement), causing facilitation effects in visual processing (Kaup et al., 2005; Kaup et al., To appear; Tseng et al., To appear). However, the world's languages display a variety of forms of negation, and different types of negation might yield different processing effects.

The current study investigated whether syntactically different forms of negation influence the simulation of counterfactual situations. We used sentences in Korean, which has two mechanisms for marking negation. The negation marker "an" can be prefixed directly to the verbal stem, forming affix-like (or predicate) negation. There isn't a good translation equivalent in English, but this negation is for something like English "un-", except that it is used to mark negation in general rather than a sense of "undoing". The second mechanism for marking negation in Korean is syntactic. The same negator "an" is combined with an auxiliary verb "do", and follows the verb, forming syntactic (or sentential) negation (roughly equivalent do English "DO+not").

Some linguists have argued that affixal and sentential negation are not semantically equivalent. According to Horn (1989), affixal negation, e.g., ìJohn is unhappyî is affirming a contrary concept (unhappiness), whereas sentential negation ìJohn is not happy" is denying an affirmative concept ìJohn is happyî. Therefore, it is argued, sentential negation induces an earlier mental performance of the counterfactual situation, but affixal negation does not. Based on this idea of Hornís, we predict that affixal negation sentences will not induce simulation of the counterfactual scene, whereas sentential negation sentences will.

We based our investigation on Tseng et al. (To appear), who found that visual imagery triggered by up- and down-related negative intransitive sentences in English (e.g. "The mule didn't climb" [up] vs. "The chair didn't topple" [down]) facilitate visual perception in specific regions of the visual field. The current study examined whether up- or down-related sentences, when negated with either affixal or sentential negation in Korean, would trigger visual simulation. The critical sentences had the following form:

(1) a. The dolphin Neg-soar (up-verb/affixal negation)
(1) b. The dolphin soar-suffix Neg-Aux (up-verb/sentential negation)
(2) a. The glass Neg-fall (down-verb/affixal negation)
(2) b. The glass fall-suffix Neg-Aux (down-verb/sentential negation)

Each trial consisted of 1) a fixation cross (1000ms), 2) an intransitive sentence (heard through headphones), 3) a variable ISI, and 4) a circle or a square appearing in the top, bottom, left or right quadrant of the screen (200ms), and 5) the subjectís response (ëzí for circle, ëxí for square).

The results for sentential negation sentences showed the predicted facilitation effect; up-verb sentences (1b) caused facilitation of responses to shapes in the upper quadrant, and down-verb sentences (2b) caused facilitation of responses to shapes in the lower quadrant ($F1(1,35)=9.293$, $p<0.05$). For the affixal negation sentences (1a and 2a), no such facilitation effect was observed ($F1(1,35)=.281$, $p=.600$). This result suggests that the counterfactual situation was simulated in the sentential negation but not in the affixal negation.

We conducted a follow-up experiment in order to test an alternative explanation ñ that the observed effect was attributed to other differences between the two different sentences types. Perhaps the affixal negation sentences were harder to process for whatever reason. We tested this using a new set of sentences (3) and (4), where the up-down content is provided by the subject noun, which is outside the scope of negation. Understanders should mentally simulate the counterfactual situation for these sentences regardless of which negation type they use.

<Up/Down Subject Condition>
(3) a. The sky Neg-darken (up-subject/affixal negation)
(3) b. The sky darken-suffix Neg-Aux (up-subject/sentential negation)
(4) a. The cellar Neg-dampen (down-subject/affixal negation)
(4) b. The cellar dampen-suffix Neg-Aux (down-subject/sentential negation)

The results showed a significant facilitation effect in both types of negation ($F1(1,23)=4.322$, $p<0.05$ for the affixal negation, and $F1(1,23)=4.026$, $p=.057$ for the sentential negation). This finding suggests that the lack of the counterfactual simulation in the affixal negation in the up/down verb condition (1a and 2a), is not due to its processing difficulty.

In summary, when the content of a mental simulation is in the scope of negation, sentential-type negation engages the simulation of the counterfactual situation, whereas the affixal type of negation does not. This finding suggests that the type of negation critically affects mental simulation performed for language understanding.

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Is a drawer that is "still open" mentally closed? Action-compatibility effects with sentences that do not describe a movement but a state.

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In the present research we asked the question whether an action-compatibility effect (ACE; Glenberg & Kaschak, 2002) would be observed even for sentences that do not describe a movement, neither literally nor metaphorically. Sentences such as (1) and (2) describe a state, but the temporal particles "still" and "yet" imply a future movement. If participants simulate this future movement, an ACE should be observed: Reading times should be shorter if the implied movement matches the response movement. Furthermore, if an ACE was found for both polarity conditions, then this would provide evidence against the idea that the ACE is based on individual words in the sentence. After all, although both sentences include the word "open", a movement towards the body would be facilitated in the affirmative and a movement away from the body in the negative version.

(1) The drawer of the desk is still open.
(2) The drawer of the desk is not yet open.

Two additional conditions were included in the first experiment, namely affirmative and negative sentences with adjectival passives [e.g., (3) and (4)]. There is one obvious difference between the adjective and the adjectival passive in our affirmative conditions: The affirmative sentence with an adjectival passive implies that a movement has taken place in the past which brought about the current state (a drawer that is still opened was opened in the past, but the same does not hold for a drawer that is still open). It seems plausible to assume that comprehenders in this case mentally simulate this past movement first, because it is explicitly mentioned in the sentence. The same does not hold for the negative adjectival passive sentences.

(3) The drawer of the desk is still opened.
(4) The drawer of the desk is not yet opened.

Taken together, we predicted an ACE for both the affirmative and the negative adjective sentences, with shorter reading times in the match than in the mismatch condition. For the adjectival-passive sentences we predicted a reverse match effect in the affirmative version.

40 students of TU Berlin read 64 sensible sentences intermixed with 64 insensible sentences. 32 of the sensible sentences acted as experimental items, and were available in eight versions each, realizing a 2(polarity: affirmative/negative) x 2(form: adjective/adjectival passive) x 2(state: open/closed) design. For half of the participants, correctly responding required a movement towards the body, and for the other half a movement away from the body. For the analyses we collapsed across the two states of each sentence (open vs. closed), and analysed the data depending on whether the response movement matched or mismatched the future movement implied by the sentence. Thus, the reading times were submitted to 2(polarity) x 2(form) x 2(match) ANOVAS with all variables being manipulated within participants and items.

The results were rather clear cut: An ACE with shorter reading times in the match than in the mismatch conditions was observed in the adjective conditions ($F1(1,31)= 5.1$, $p< .05$, $F2(1,24)= 4.3$, $p< .05$), and a reversed match effect was observed in the adjectival-passive conditions ($F1(1,31)= 4.2$, $p< .05$, $F2(1,24)=1.1$, $p=.31$; see Figure 1). The interaction of match and form was significant ($F1(1,31) = 8.9$, $p< .05$, $F2(1,24)= 4.2$, $p = .05$). The results are mostly in line with the hypotheses. The ACE observed for sentences with adjectives suggests that comprehenders indeed simulate the movement that is implied to take place in the future. For sentences with adjectival passives, a reverse ACE was observed. For affirmative versions this corresponds to the prediction that comprehenders simulate the movement that is explicitly mentioned in the sentence. For negative versions, this effect was not predicted but may be explained by the assumption that comprehenders transform the negative adjectival passive "not yet closed" into the affirmative adjectival passive "still opened".

In a second experiment, participants were presented with the same sentences but without the temporal particles "still" and "yet". We predicted that no ACE should be observed in the adjective conditions, as without the temporal particles these sentences do not imply a movement. For the adjectival passives, we expected reversed match effects as in the previous experiment. The results only partly matched these predictions. As predicted, there was no ACE in the adjective conditions (all Fs < 1). However, contrary to the predictions, there was also no match effect in the adjectival-passive conditions (all Fs < 1). Thus, it seems that when processing a sentence with an adjectival passive, participants do not simply simulate the movement mentioned in the sentence. Rather the results suggest that in case the sentence contains a temporal particle and thereby implies a future movement, participants mentally create the pre-condition for the implied movement, i.e., they mentally close the drawer when processing "the drawer is not yet opened".

A cognitive neuroscience perspective on language for human-robot Interaction

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The current research holds with the notion, prevalent in cognitive linguistics and construction grammar, that there is a crucial linkage between experientially grounded gestalts related to the performance and perception of action, and the grammatical constructions that can be used to invoke these representations. Over the last several years we have developed a neurophysiologically grounded model of how this linkage between sentence and meaning is achieved, in French, English and Japanese.

After an initial set of simulation experiments, we then embodied the grammatical construction processing model, first in a robotic system that provided visual perception of human action. In this context we demonstrated a system that could learn a small lexicon and set of grammatical constructions in the context of human action perception. This allowed the system to describe novel events that it had not previously observed. We then extended the robotic system so that it could generate actions as well. In the resulting interactions we developed a capability so that new complex action sequences could be learned, and associated with new verbs in argument constructions. This resulted in an ability to acquire new behavioural procedures with arguments, in the construction grammar framework. The talk will provide an overview of these links between language and action in the context of simulation and human-robot interaction

Modulation of the motor system during language processing

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According to the “embodied language” approach, language processing is mediated by the same neural substrates involved in perception and motion. For example the comprehension of a sentence like “I grasp a little cup” would involve the same neural structures involved in the actual execution of this object directed action. Recent findings collected by means of behavioural, neuroimaging and neurophysiological techniques supporting this approach will be presented.

By means of fMRI, it has been found that during listening to sentences expressing actions done with the hand, the mouth or the foot, different sectors of the premotor cortex, largely overlapping those involved during the execution and observation of those same actions, became active. In a behavioural study in which participants were required to decide whether a listened to action expressed either a concrete (actions done with the foot or the hand) or an abstract action, reaction times were slower when participants gave their responses with the hand while listening to hand actions as compared to foot actions. On the contrary, reactions times were slower when participants gave their responses with the foot while listening to sentences expressing foot actions as compared to sentences expressing hand actions. Coherently MEPs recorded from hand muscles decreased while listening to hand actions as compared to foot actions and viceversa.

More recently it has been shown that the modulation of the motor system also occurs during processing language material related to abstract content. In this study participants were required to read sentences expressing a “transfer” of either a concrete or an abstract object (Antonio gives you some pizza; Antonio gives you a piece of news). As control, they read sentences where this “transfer” was lacking (Antonio watches TV with you). MEPs recorded from hand muscles increased during reading sentences expressing a concrete or an abstract transfer as compared to sentences where this transfer was lacking.

As a whole, these data show a modulation of the motor system during language processing, but they do not disentangle whether this involvement is fundamental to language comprehension or rather a side effect. A very recent behavioural study addressed this issue: participants were required to read and listen to different verbs expressing either concrete actions (done with the hand or the foot) or abstract actions in a lexical decision task and in a semantic task. The study has shown that only during the semantic task, but not during the lexical decision task, reaction times were affected, thus supporting the notion that the modulation of the motor system occurs when a deeper simulation of the processed language is necessary to solve the task.

Spatial language comprehension activates premotor areas, and mediates MT+ activation during processing of static images with implied motion

Coventry, Northumbria University Newcastle

In this paper we examine whether language comprehension is underpinned by perceptual simulations of the actions language depicts (e.g., Glenberg & Kaschak, 2002; Zwaan, 2004; Zwaan & Taylor, 2006), and whether language drives or mediates processing of static spatial scenes presented immediately after sentences. In particular we examine these issues with reference to spatial language comprehension using fMRI.

Spatial language comprehension, according to the "functional geometric framework" (cf. Coventry & Garrod, 2004), involves computing where objects are, what they are, and also how they are interacting. Thus making a judgement that a bottle is over a glass involves mentally simulating how the bottle and glass typically interact or will interact over time (whether the bottle is in the correct position for the liquid to successfully reach the glass; Carlson & Kenny, 2006; Coventry et al., 2001). Hence spatial language processing is predicted to involve motion processing. A central functional structure for the processing of motion is area MT+. Kourtzi & Kanwisher (2000) reported significant activation of MT+ for static images with implied motion. We tested whether such activations are driven by knowledge of individual objects or knowledge of how objects typically interact with each other, and critically if motion processing is subject to top-down modulation vis-‡-vis spatial language consistent with predictions from the functional geometric framework. We predicted that the same objects (Nouns) presented in a sentence with a spatial relation (e.g., The bottle is over the glass) would lead to increased MT+ activation over baseline when viewing a static picture of a bottle and glass than when the same nouns were presented with a comparative adjective (e.g., The bottle is bigger than the glass). Such evidence would be among the first evidence to show that language drives or mediates motion processing activation when viewing static images.

The second major goal of the study was to examine whether MT+ and/or premotor areas are activated when reading the sentences prior to the presentation of pictures. Such activations would provide strong evidence for the view that language processing involves perceptual simulation (consistent with the results from Tettamanti et al., 2005 and Hauk et al, 2004). However, we also predicted that MT+ activation and/or premotor activation may well be mediated by the specific syntactic category (prepositions versus comparatives) occurring in sentences with the same nouns.

Subjects and Methods: We examined spatial language processing using a sentence-picture verification task. Participants (12 native English speakers) were asked to establish whether a sentence (e.g., The bottle is over the glass) presented prior to a picture was a true or false description of the picture following. Sentences and pictures were manipulated systematically in a 3 X 3 design. The language conditions comprised three different object relations: two types of spatial prepositions ("over/under/above/below" and "near/far") and a comparative relation of spatial object features ("bigger/smaller"). The picture conditions included three manipulations of typicality of functional interaction of objects: a) Functional interaction relevant: One object (bottle, cereal box etc.) was shown releasing a fluid substance (water, cereals etc.) and was positioned higher than a container object (glass, bowl etc.) consistent with typical interaction between the objects. b) Functional interaction not relevant: Same objects as in (a) but the releasing objects were positioned lower than the container object, inconsistent with how those objects typically interact. c) Non-functional controls: Objects without any functional interaction (e.g TV and apple) positioned as in (a) and (b).

The order of the 9 (3x3) different conditions in the sentence-picture verification task was determined by a pseudorandomized non-stationary probabilistic design. Functional BOLD data was acquired with an gradient Echo Planar Imaging (EPI) sequence 3T-Scanner (Siemens Magnetom Allegra) during the sentence-picture-verification, a baseline condition and a localizer task developed to define ROIs for area MT+ (which were defined by extracting the activated

clusters at the temporo-parieto-occipital junction in a motion vs. no-motion contrast with individual thresholds). Additional regions of interest were defined by group level results.

Results and Discussion: Activations during picture processing. The results showed differences in MT+ activation between picture conditions, and between language conditions. Specifically, there were significant activation differences in left area MT+ between functional interaction relevant and functional interaction not relevant conditions contrasted against the non-functional controls. Moreover MT+ (in the right hemisphere) was activated significantly more for the preposition conditions than for the comparative condition. These results show that motion processing is mediated both by specific language task and knowledge for how objects typically interact.

Activations during sentence processing. The results showed reliable differences in premotor activation comparing sentences with prepositions compared to sentences involving comparatives. This is the first direct evidence of motor involvement when reading sentences with spatial relations in them, supporting the notion that spatial language processing involves perceptual simulation. Furthermore how words "mesh" together in the comprehension process affects the extent to which dynamic perceptual simulations are activated.

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The influence of linguistic aspect on motion trajectories: On the path to understanding the dynamics of perceptual simulation

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People are often in motion, perceiving motion, or imagining motion. When talking about motion, speakers may take advantage of many resources in language, such as different motion verbs (e.g., walk, hike, and run) as well as different aspectual forms of those verbs.

English speakers may use various forms of linguistic aspect to describe past motion events, with two common forms being the simple past and the past progressive. Linguistic analyses suggest that the simple past form, as shown in (1), accentuates the end state or goal of an event, and the past progressive form, as shown in (2), emphasizes the ongoing nature of an event (Langacker, 1987).

(1) David hiked yesterday.
(2) David was hiking yesterday.

Despite subtle differences between (1) and (2), both would be an appropriate response if asked what David did yesterday. Given that these forms are often interchangeable in English, are people really sensitive to the suggested meaning differences during language use?

Prior research offers many insights into how aspect is used and its function in grammar, but many questions remain. In particular, though the linguistic dimensions of aspect have been studied extensively (e.g., Comrie, 1976; Dahl, 1985), the psychological consequences of aspectual differences in language use are just beginning to be understood. Cognitive psychologists have suggested that people readily activate different knowledge about event structure in general (Zacks & Tversky, 2001) and that grammatical aspect influences the way they construct situation models (e.g., Madden & Zwaan, 2003; Magliano & Schleich, 2000; Morrow, 1985). It is possible, given a growing body of evidence for the integration of motor information with other mental representations (e.g., Barsalou, 1999; Glenberg & Kaschak, 2002), that aspectual differences in language also influence the kind of fine-grained motor information that is active when people understand sentences about motion events. In our current research, we examine whether aspectual differences in descriptions of motion events lead to different representations of movement along a path, in both offline and online studies.

In our recent work, we have found that people generate different representations of movement along a path after reading descriptions of motion events that only differ in grammatical aspect. In one offline study, participants were given a picture of a path that terminated at a prominent destination, such as a forest, and either a simple past sentence, such as This morning David hiked to the forest, or a past progressive sentence, such as This morning David was hiking to the forest. Participants were asked to specify where David was on the path. On average people placed the character closer to the end state after reading the simple past sentence than after reading the past progressive sentence. These results, as well as those from several additional offline studies, suggest that aspectual differences in language bias people toward different understandings of trajectory as they build representations of motion events.

Additionally, the current research borrows a mouse-tracking paradigm (Spivey, Grosjean, & Knoblich, 2005) to examine the online motoric parameters of how aspect influences dynamic representations of motion events. In this study, participants heard recorded sentences such as Steve hiked (was hiking) to the forest and then camped out overnight, while viewing a display containing a silhouette character at the bottom, a curved path going upwards, and a destination at the top of the screen. Participants were simply instructed to click-grab the silhouette and place it in the picture so that it matched the sentence. During the click, drag, and drop, the recorded [x,y] coordinates of the mouse-cursor trajectory revealed that simple past clauses elicited only incidental adherence to the curved path during movement of the silhouette. In contrast, past progressive clauses elicited rather curvy movement trajectories that adhered to large proportions

of the path. Thus, despite the fact that the silhouette was always dropped in the destination region (as encouraged by the second clause), the physical manner in which the silhouette was carried to that goal differed substantially as a function of aspect. The ongoingness of the event in the past progressive seemed to promote a kind of "acting out" of the perceptual simulation associated with the sentence.

The current work using mouse-tracking adds valuable insights to our knowledge about how language use influences people's representations of motion events. Our results suggest that the representations that guide motor planning are influenced by local linguistic context, and dynamically change even in response to linguistic subtleties such as grammatical aspect. Online, continuous motor output differed depending on linguistic input: if people understand descriptions of motion events by perceptually simulating these events, grammatical differences influence this simulation and the downstream motor output.

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Grounding knowledge in the brain's modal systems

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The human conceptual system contains categorical knowledge that supports online processing (perception, categorization, inference, action) and offline processing (memory, language, thought). Semantic memory, the dominant theory, typically portrays the conceptual system as modular and amodal. According to this view, amodal symbols represent category knowledge in a modular system, separate from the brain's modal systems for perception, action, and introspection (e.g., affect, mental states). Alternatively, the conceptual system can be viewed as non-modular and modal, sharing representational mechanisms with the brain's modal systems. On a given occasion, multi-modal information about a category's members is reenacted (simulated) across relevant modalities to represent it conceptually. Behavioral and neural evidence is presented showing that modal simulations contribute to the representation of object categories, abstract categories, and to the symbolic operations of predication and conceptual combination. Although simulation plays important roles in the conceptual system, linguistic processes are important as well. Additional behavioral and neural evidence is presented showing that simulation and language contribute to conceptual processing simultaneously. Furthermore, either system can dominate under different task conditions, such that different profiles of conceptual processing emerge.

Hand, eye and mind go together: taking a jug with the wrong hand

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Recent behavioral research has implicated a number of perceptual and motor variables in language comprehension, including attempts to 'ground' language in action (Glenberg & Kaschak, 2002). Re-enactment or simulation is considered as a major mechanism involved in language comprehension (Barsalou et al., 2003). Meaning on these views is embodied rather than abstractly amodal. Evidence for perceptual simulation in language comprehension is found in the effects of implied orientation and implied shape of objects, while simulation of movement is held responsible for the impact of motor characteristics of the behavioral response during comprehension of verbal stimuli with implied movement.

What happens when implied movement and an object's orientation interact? Does the match between implied and real movement still facilitate responses even if the object's perceived functional affordance is at odds with the movement's origin and direction?

This study aims at exploring further the embodied nature of language processing. In a sensibility judgment task, participants were presented visually with 80 different verbs followed by simple black-and-white drawings of 80 common objects. The combination of the action indicated by the verb and the object in the drawing did or did not make sense (for example, 'pour with a ladle' vs. 'clean with a trumpet'). All pictures depicted objects with intrinsic sides and left/right orientation. Half of the objects were presented with a left hand functional affordance (a jug with its handle to the left from the viewer's perspective), the other half were with a right hand affordance.

All 40 participants were right-handed and saw each pictured object and each verb only once. For half of the participants, the initial and resting position of their response hand was specified to be such that making a button press required a hand movement towards the screen covering a distance of approximately 20 cm and for the other half button press involved moving one's hand 20 cm away from the screen.

In addition, the verbs that were included in this experiment fell into one of two classes. Half of the verbs referred to physical actions that could be performed on the pictured object with one hand (e.g., take), and the other half did not (neutral verbs, e.g., smell or kick). For each participant, verb type (hand action vs. neutral) was crossed with objects' functional affordance (left vs. right). Participants were randomly assigned to one of the two conditions for hand movement direction (towards vs. away from the object pictured on the screen).

Four one-way ANOVAs were carried out on the critical trials (sensible action-object combinations) and on participants' 'yes' responses only. The analyses examined the effect of movement direction of the participant's hand (towards vs. away from the object) on the sensibility judgment reaction times (RTs) for each of the 4 conditions: hand action and right-hand affordance, hand action and left-hand affordance, neutral verb and right-hand affordance, and neutral verb and left-hand affordance.

Participants took generally longer to verify the sensibility of the action-object combinations when the verb did not imply a hand movement towards the object, i.e., when the verb was movement-neutral. This was the case for objects with both left-hand and right-hand functional affordance. Furthermore, even when the verb did imply a hand movement towards the object, if at the same time the object had a left-hand affordance, these right-handed participants' reactions did not differ significantly as a function of the direction of the hand movement.

However, critically, response direction (hand moving towards vs. away from the pictured object) produced an effect on reaction times for combinations of hand action verbs and objects with right-hand affordance. Participants' verification was significantly facilitated only when their hand movement matched both with the movement implied by the verb (towards) and with the right-hand affordance of the object. In comparison, verification responses executed with a movement leading away from the object yielded longer RTs.

The results of this study clearly extend previous findings on linguistic behavior being grounded in bodily experience. Language processing is modulated by the presence or absence of

a correspondence between the direction of a real hand movement (towards vs. away from an object) and the movement direction implied in the verbal input. However, the emergence of this effect depends not only on motoric correspondence but also on the objects' functional affordances as computed on the basis of their perceptual features. Indeed, processing is optimal when sensori-motor states are compatible with cognitive states-when hand, eye, and mind go together.

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Eye-Tracking reveals looks to simulated distractor imagery during sentence processing

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The embodied nature of sentence processing is one of the key assumptions of cognitive linguistics as set forth in Langacker's theory of cognitive grammar (1987, 1990, 1991). Building on this, Barsalou (1999) has proposed a general account for symbolic reasoning which posits that cognition bootstraps off of the neural patterns created through perception and motor action. According to this view, simulation, or reactivation of the neural states that define perceptual symbols, is a fundamental process that underlies general cognition. Metzinger & Gallese (2003) further suggest how neuropsychological studies of mirror neuron systems provide further evidence that the semantic primitives required for sentence processing and consciousness are formed through general neural processes involving decomposition of perceptual experiences through a system of simulated motor ontology.

Indeed, English verbs can be classified according to their visual axis of conceptual representation (Richardson et. al. 2001), and behavioral studies have shown that the axis of conceptual representation can interact with that of visual perception. After listening to a sentence with a given axis of representation (e.g., the vertically oriented sentence "The ship sinks in the ocean."), subjects were slower to identify a visual shape, circle or square, which flashed approximately 200 milliseconds thereafter in the matching visual axis (i.e., at the top or bottom of their visual field). Head-mounted eye tracking studies have also shown that visual attention is modulated by the axis of representation of referents described by fictive motion sentences (Richardson & Matlock In Press), as well as that of purely simulated visual imagery when viewing a blank screen and listening to short stories (Spivey & Geng 2001).

The present study works within this framework to make a case for the psychological reality of spatially oriented image schemata in English sentence processing.

Subjects viewed a blank computer screen and wore a head-mounted eye tracker while listening to sentences and viewing briefly flashed object shapes. Critical sentences were either vertically or horizontally oriented, and filler sentences either made sense or were nonsense:

(1) Vertical Sentence
"The cloud is floating through the sky."

(2) Horizontal Sentence
"The ox is pulling the plow."

(3) Normal Filler
"The wind is blowing the curtains."

(4) Nonsense Filler
"The blackboard is swimming the mile."

After hearing the sentence, and following either a short interstimulus interval (approx. 200 ms) or long interval (approx. 1000 ms), subjects were required to identify a visual shape, circle or square, which flashed for 200 milliseconds. Once they had identified the shape, subjects were also required to indicate whether or not the sentence made sense.

The independent variables were (i) match or mismatch of the representational axes of conceptual orientation and visual object placement; and (ii) short or long ISI type. Dependent variables were (i) reaction time for object discrimination; and (ii) reaction time for sentence meaningfulness discrimination. Eye movements were also tracked throughout the course of each trial.

Preliminary data from 6 subjects and 16 items indicate a trend toward significance for an interaction effect, $F(1,15)=2.203$, $p=0.157$. Shorter reaction times were found in the matching condition for short ISIs, and longer reaction times in the matching condition for long ISIs. This facilitation effect, with short ISIs, contradicts with the results reported by Richardson et al. (2003), who found interference effects in the matching condition for short ISIs. Based on these findings, I argue that both facilitation and interference effects are evidence for an interaction between conceptual and perceptual axis of representation, thus supporting the psychological reality of simulation in sentence processing. The distinction between facilitation and interference must, however, take into account the highly complex nature of the online construction of simulated representations, which can be modulated according to subtle differences in experimental tasks.

The eye-tracking data from this study also shows interesting preliminary evidence supporting the psychological reality of simulation. For example, when listening to sentences that involved upward-focused imagery (e.g., "The bird is flying over the building." or "The cloud is floating through the sky."), subjects consistently looked toward the top of their visual field when viewing the blank screen. Moreover, when presented with an image shape at the bottom of the screen, they continued to look upward. Presumably, subjects were able to identify the object correctly through their peripheral vision. Based on this, I propose that the quasi-blank-screen eye-tracking method described here could be a useful instrument for measuring the effects of a simulated image as a visually situated "imaginary competitor" that can distract attention away from a "real-world competitor" presented in another location.

This study, and other behavioral studies of visual directionality in simulation during sentence processing, have broader implications for theories of cognition. They suggest not only that simulation can inform understanding and reasoning, but that the dynamic time course of simulation can also modulate the perception of real-world objects by suppressing perceptual attention for the benefit of simulated attention.

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Embodiment of abstract concepts: Neurocognitive evidence from motor-meaning congruity and visual hemifield effects

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Abstract concepts present a challenge for embodied theories(1) according to which thoughts are perceptual simulations: how can we perceptually simulate things we can never perceive? Conceptual Metaphor Theory(2) points toward a potential solution. Linguistic metaphors (e.g., a long time, a high price, a deep mystery) suggest that many of our abstract ideas depend, in part, upon a few simpler concepts grounded directly in perceptuo-motor experience (e.g., experience with physical motion, force, and space). To the extent that perceptuo-motor schemas constitute the content of abstract concepts, these concepts can be instantiated by the same neural and mental structures that simulate perception and action in the physical world.

Yet, many embodied cognition researchers have marginalized the role of metaphor in the mental representation of abstract concepts, arguing instead that "a direct, non-metaphorical representation of an abstract domain is essential," and proposing that "perceptual symbol systems can represent all abstract concepts directly"(1). Here we argue that Conceptual Metaphor should be considered more central to embodied theories of abstract concepts, based on evidence that (i.) perceptuo-motor representations are automatically activated when we instantiate abstract concepts, and (ii.) these representations are perceptual simulations of the sort that embodied theories posit.

Experiment 1: Meaning and Motor Action. For Experiment 1, we created a Stroop-like 'motor-meaning congruity' task in which participants incidentally read abstract words referring to metaphorically spatialized concepts while moving marbles into boxes positioned so as to require schema-congruent or incongruent motor actions.

Colored boxes containing hundreds of marbles were stacked to the right left of the computer screen. 48 words appeared, one at a time, for 2000ms. If a word appeared in blue letters, participants moved one marble with each hand as quickly as possible into the blue box (which was on top for half of the Ss). Likewise, for words in red letters, participants moved marbles into the red box (which was on bottom for half of the Ss). Movements were cued only by color: word meanings were irrelevant. Unbeknownst to participants, half of their movements were schema-congruent (e.g., the word color cued movements to the top boxes during an 'upward' word like wealthy or joy), and half were schema-incongruent (e.g., word color cued movements to the top boxes during a 'downward' word like poor or misery). We reasoned that if spatio-motor schemas are automatically activated when people process abstract words - even if their meaning is task-irrelevant - then schema congruity should facilitate marble movements (an on-line effect), and should also facilitate subsequent memory for the stimulus words (an off-line effect).

Consistent with predictions, marble movements were fastest when the direction of movement was congruent with the spatial schema implied by the word (e.g., upward for genius; downward for gloomy; congruity effect=308ms, $t(17)=13.50$, $p<.0000001$). Furthermore, motor-meaning congruity during word presentation strongly predicted subsequent memory for incidentally encoded words in a surprise recognition memory test (congruity effect=40% accuracy difference, $t(17)=10.99$, $p<.0000001$). These on-line and off-line motor-meaning congruity effects suggest that spatio-motor representations are integral to abstract concepts, and are activated automatically, even when we process word meanings shallowly and incidentally.

Experiment 2: Hemispheric Laterality of Motor-Meaning Congruity

Experiment 1 results strongly support Conceptual Metaphor Theory, but do they necessarily support Embodiment Theory? Like many previous experiments, these results leave open a critical question: what is the nature of the 'spatio-motor representations' that underlie word meanings? In principle, these representations could be either modality-specific or amodal.

For Experiment 2, we used a visual hemifield (VHF) manipulation to distinguish these possibilities, adapting our Stroop-like motor-meaning congruity paradigm. Words were flashed (200ms) to the right or left side of a central fixation, sending information selectively to the left or

right hemisphere of the brain. Following Zwaan & Yaxley3, we reasoned that if motor-meaning congruity effects are merely due to lexical associations, or if mental representations of word meanings are amodal and proposition-like, then congruity effects should be greater for words flashed to the left hemisphere (rightVHF). Alternatively, if the spatio-motor representations underlying abstract word meanings are image-schematic simulations of our interactions with the physical environment, then congruity effects should be greater for words presented to the right hemisphere (leftVHF).

Results (N=24) showed motor-meaning congruity effects were dramatically greater in the right hemisphere, both by Ss and by items ($t1(23)=13.58$, $p=.000000001$; $t2(190)=49.61$, $p=.000000001$), as predicted by the Perceptual Symbols proposal. Few studies claiming support for Embodiment actually distinguish predictions of perception-based theories from amodal alternatives. For this VHF manipulation, however, the competing theories made contrasting predictions about the hemispheric laterality of congruity effects. Results suggest image-schematic perceptuo-motor simulations partly constitute the content of abstract concepts.

Conclusions. Much remains unknown about how perceptuo-motor representations structure abstract concepts, but Conceptual Metaphor Theory appears to provide at least part of the answer to the problem of mentally representing the imperceptible via embodied simulations.

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Powerful metaphors; The role of spatial schemata in representing the concept of power

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In language, the abstract concept of power is often expressed metaphorically, using the vertical dimensions up and down. For example, having a high position is equivalent to being powerful, one can climb up a company's hierarchy or be degraded to a lower function, and kings are typically addressed as Your Highness. According to the linguists Lakoff and Johnson (1980), this metaphorical representation of power in terms of verticality is more than just a linguistic phenomenon. They argue that metaphors provide grounding for abstract concepts by mapping them onto more concrete representations, which are structured by image schemas. Image schemas are dynamic patterns that emerge from experience with the world during perception, action, and interaction. They structure our experiences and can be reinstated to form representations of concrete as well as more abstract concepts (Johnson, 1987).

If people understand power metaphorically, by using the image schema of verticality, then a number of predictions follow. First, we expect that activating the up-down image schema affects processing of the concept of power. Evidence for this first hypothesis has been provided by Schubert (2005) and Giessner & Schubert (in press). The second, and stronger prediction, is that thinking about power automatically activates the underlying image schema. This prediction is addressed in the current study.

In this experiment, words referring to powerful and powerless people (such as king and servant) were presented visually, at the center of the computer screen. Participant decided whether each word referred to a powerful or powerless person. Directly following the power decision, a letter was presented either at the top or at the bottom of the screen, and participants identified the letter as quickly as possible. We expected an interaction effect of power and position, such that participants would be faster to detect letters at the top of the screen when preceded by a powerful word, whereas they would be faster to detect letters at the bottom of the screen when preceded by a powerless word. This result would show that thinking about power automatically activates the vertical image schema.

Method:

Participants. Thirty-eight psychology undergraduates took part in the study in return for course credit.

Materials. Sixty-four words referring to people, professions or social classes were selected. Half of the words referred to powerful people, the other half referred to powerless people. In addition to these words, twenty words were used as practice items.

Procedure. Each trial started with the presentation of a powerful or powerless word to which participants made a power judgment. Responses were recorded on a serial response box with five aligned buttons. Participants made a power decision by pressing the M-button for powerful words ("Machtig" = powerful) or the O-button for powerless words ("Onmachtig" = powerless). The response was followed by a 200 ms delay, after which the lowercase letter p or q was randomly presented at the top or bottom of the computer screen. Participants responded to the identity of the letter by pressing the P-button or Q-button. Following an incorrect response, feedback was presented. Following a correct response, a blank screen was presented for 500 ms. After an additional delay of 500 ms, the next trial was initiated.

The experiment started with two practice sessions, followed by two experimental blocks. Each critical item was presented twice, followed once by a letter at the top position and once by a letter at the bottom position.

Results. After correction for errors and outliers, the corrected average reaction times and error scores on the letter detection task were submitted to a 2 (power: powerful vs. powerless) x 2 (position: top vs. bottom) repeated measures ANOVA. There were no main effects of power or position, but the predicted interaction between power and position was significant: $F(1,39) = 10.25$, $p = .003$. Letters in the top position were discriminated faster when they were preceded by

a powerful word, whereas letters in the bottom position were discriminated faster when they followed a powerless word. The analysis of the error scores revealed no significant main effects or interaction effect, indicating that the effect found in the reaction times was not due to a speed-accuracy trade off.

Discussion. The results of the current study suggest that spatial attention may be influenced by the activation of the concept of power. Processing power-related words shifts attention into a metaphor-consistent direction (up or down), thereby facilitating detection of targets in that location. This suggests that the up-down image schema is automatically activated when processing power-related words.

The result corroborates earlier findings of the role of spatial metaphors in representing power (Schubert, 2005; Giessner & Schubert, in press) and other abstract concepts, such as valence (Meier & Robinson, 2004) and time (e.g. Boroditsky, 2000). Together, these studies show how abstract concepts are grounded in sensorimotor processing. As such, they are in line with an embodied view of cognition.

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Incremental interpretation of motor knowledge affects the time course of visual attention during situated comprehension

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Existing findings suggest comprehension of figurative language interacts with visual attention as reflected in total-sentence gaze measures (Richardson&Matlock, 2006). However, does this interaction extend to the comprehension of non-figurative action language, and what is its time course as the utterance unfolds? We addressed these two issues by examining whether the speed of an event - as described by an utterance / depicted in a scene - influences the time course of visual attention during situated comprehension.

To this end, we monitored participants' gaze in scenes while they listened to related motion sentences that described either fast ([1a]) or slow ([1b]) motion. Each utterance was presented with a scene depicting an agent either as rapidly ([A]) or slowly ([B]) moving on a path towards a goal. A pretest ensured gaze differences for [1a vs. 1b] did not result from plausibility differences. People were asked to attentively listen and to inspect the scenes.

If people – upon hearing the verb - rapidly use associated knowledge about event speed, and if the time course of visual attention is a function of interpreting utterance-mediated event speed, then we should find an earlier increase in eye gaze to the event goal for fast [1a] versus slow [1b] conditions. Similarly, if the depicted speed [A/B] rapidly informs interpretation, and if the time course of visual attention is a function of scene-based event interpretation, then we should see an earlier increase in gaze to the goal for motion [A] than static scenes [B].

Der Großvater [1a] hetzt eilig / [1b] hinkt müde in den Park.
The grandfather [1a] rushes hurriedly / [1b] limps wearily into the park.

[A] grandfather-rushing into-park
[B] grandfather-walking into-park

Analyses of data from 48 subjects for the verb/post-verbal region revealed effects of the utterance- but not scene-based speed manipulation: When verb&adverb described fast motion [1a], gaze to the goal (the park) began to rise during the verb and adverb compared with slow motion conditions [1b] ($ps < 0.01$). The fact that the "fast-motion" advantage was closely time locked to the verb/adverb, corroborates it is triggered by these words. Depiction of the event speed, in contrast, did not affect the time course of goal-anticipation, a finding that may result from unrealistic motion depiction (scene events were not dynamic in real time). Our findings show comprehension of (non-figurative) motion sentences incrementally modulates the time course of visual attention to mirror the interpretation of utterance-mediated events.

Modelling speech-gesture perception in type logics

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Coverbal gestures represent a pervasive way to enrich the information conveyed by verbal language. The relation between these two modalities has been described in terms of synchronisation patterns in McNeill92. What this work (and many inspired by it) lacks is a fully developed theory of joint gesture-speech perception (cf. Sowa06). The goal of the research described here is to test in a systematic way a number of suggestions advanced in the literature, that may form the core for a proper theory of multimodal perception. I intend to test these hypotheses employing two different analytical paradigms: a set of psychological experiments and a computational model. The plan is to conduct the two investigations in parallel, in order to construct incrementally the necessary evidences to proceed in both experimentations.

The psychological experiments devised for this research examine the role of synchronisation factors in the processing of multimodal utterances. The experiments are based on the response given by subjects to different "violations" to the synchronisation patterns already mentioned. From the first results, it has been possible to develop a preliminary version of the computational model, the main subject of this abstract. The model is based on the assumption that there are language-like (i.e. grammatical) relations governing the interaction between gesture and speech.

The approach followed at modelling the phenomenon is largely inspired by computational linguistics methodologies, and capitalise on the proposals of Johnston98, Johnston&Bangalore00 and Nigay&Coutaz95 among others. However the framework presented here tries to improve some of the features of the previous prototypes. In fact, many of the computational models proposed so far seem to imply an asymmetry between the structural and the semantic relations that link gesture and verbal language, e.g. keeping separated the construction of the two (see for example Johnston&Bangalore00) or ignoring the role of the structural component (Nigay&Coutaz95 is an example). At the same time the representational language tools developed by semantics studies (Lascarides&Stone06 proposes for example the use of Discourse Representation Theory to capture the semantics of gestures). These are two central deficiencies in current models that I try to address in my prototype.

Thus, I propose to employ Type logic categorial grammars (TLCs) as a basic formalism to reproduce the constraints imposed by structural and semantical relations (see Morrill94 and Moortgat97 for an introduction to TLCs). These relations are represented in gesture studies by temporal synchronisation (the temporal relation between the prosodic pattern of verbal language and the kinetic effort of each gesture) and semantic synchronisation (or compatibility principle). TLCs offer a particularly direct connection between the structural and semantical representations: linguistic resources are represented as functional terms build in a sort of directed lambda calculus, and are then mapped to "isomorphic" typed lambda terms, a standard semantic language. At the same time they are general enough to not impose any ad hoc structure on the type of data they treat.

The central innovation is the addition of another functional "direction" to the system, in order to model temporal synchronisation. Without entering in the details of the proposal, if we take the standard model theoretic perspective associated to TLCs, based on Kripke-like relational frames, it is possible to consider the set of all communicative resources that we want to take into account and sort it according to a natural partition: verbal language fragments, gestures and multimodal utterances. Then we can define two different relations that operate on this sorted set and represent respectively grammatical composition (the notion commonly used in linguistics, possibly enriched by e.g. prosodic cues) and temporal synchronisation. It is then possible to define a vocabulary of logical connectives, based on the functional paradigm and consistent with the relational structure we have defined. This language together with a small set of axioms that imitate the nature of the relations defined in the relational frame form a multimodal grammar, capable of reconstructing the "grammatical" links between the communicative resources we want

to analyse. As already stated, it is possible to map the grammatical analysis obtained through this extended version of TLCs to an "isomorphic" semantic language: we can employ a simple Montagovian approach to build a static interpretation of the message, or a more complex dynamic representation using some type of DRT as proposed by Lascarides&Stone06 (using for example the proposal of Muskens94, De Groote06 to encode DRTs into TLCs).

The final goal of this model to investigate and demonstrate the plausibility of some cognitive hypotheses that may form the heart for a theory of gesture-speech perception. The use of a computational paradigm such as TLCs is mainly justified by the fact that they do not impose any particular structure on the resources they can describe and allow for a strongly connected treatment of structural and semantic phenomena, a central feature of multimodal communication.

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Processing motor language affects unrelated motor tasks

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Several embodied theories of language processing (Zwaan & Madden 2005, Kaschak & Glenberg 2000, Bergen & Chang 2005) argue that understanding language about non-present entities and events entails performing mental simulations of the described scenes. Behavioral evidence using several different methods (Glenberg & Kaschak 2002; Bergen, Narayan, & Feldman 2003; Zwaan & Taylor 2006) has demonstrated that in processing language about actions, language understanders activate motor representations corresponding to those actions. All these methods ask participants to perform linguistic tasks, such as deciding whether sentences are meaningful or grammatical, reading words, or matching words to images. This type of evidence clearly shows that understanders perform mental simulation when performing linguistic tasks. But asking participants to reflect on language about action could artificially inflate their depth of semantic processing, and motor simulation could thus be present as a result of the experimental task. The study described below investigated whether language understanders automatically perform motor simulation when processing sentences about actions, even when performing a task that was completely unrelated to the language they were processing.

Our method was an adaptation of the Action-sentence Compatibility Effect (ACE) paradigm (Glenberg & Kaschak 2002, Bergen & Wheeler 2005, Borreggine & Kaschak 2006, Zwaan & Taylor 2006). In most ACE experiments, participants read sentences about motion towards or away from their body ("You handed Paula the napkin" versus "Paula handed you the napkin"), and then make meaningfulness or grammaticality judgments that require them to move their hand in a direction compatible or incompatible with the action described by the sentence. We modified this method, so that participants read sentences passively. Sentences were displayed one word at a time, in a rapid serial visual response presentation. Each word was centered on the screen and appeared for 250ms. Immediately after each sentence, participants performed an unrelated even-odd categorization task. For this task, participants saw a two-to-five character sequence of one of four standard ASCII symbols, %, #, $, *. For instance, stimuli looked like '# # #' or '% % % %'. Participants had to decide as quickly as possible whether there was an odd or even number of symbols. "EVEN" and "ODD" labels were placed on the "a" and " ' " buttons of a standard keyboard. The keyboard was then rotated 90 degrees so that the "a" button was farther away from the subject than the " ' " button. In order to see the sentences, subjects had to hold down the "h" button, and as a result, in order to make their "EVEN" or "ODD" responses, they had to move their hand either closer to their body or farther away from it. Response time was measured as the time from the presentation of the symbols until the "EVEN" or "ODD" button-press. Subjects were randomly assigned to conditions where "EVEN" or "ODD" was in the far or near position.

We prepared 70 critical sentences; 60 were the critical stimuli from Glenberg & Kaschak's (2002) original ACE study, and 10 were longer sentences of the following form: "You are shoving the food in the fridge in a rage." All sentences had a second-person subject performing an action and all used the present progressive tense. Half of the critical sentences denoted hand motion towards the body and half away from the body.

Response times were analyzed first with a three way (2*2*2) repeated-measures ANOVA, in which within-participants factors were compatibility (whether the sentence direction and the manual response direction were the same or not) and sentence type (original Glenberg & Kaschak (2002) sentences or new ones); the one between-participants factor was response condition (odd is away from versus towards the body). The analysis showed a significant main effect of compatibility, $F(1, 51) = 4.39$, $p = 0.04$. Subjects responded significantly faster if the direction of their hand motion was in the same direction as the direction of motion implied in the sentence they had just read.

In this study, we observed motor simulation effects even when the physical responses understanders made were unrelated to language processing. This finding suggests that language

users automatically activate motor systems when processing language about actions, regardless of whether or not they are performing a language-relevant motor task. While this does not imply that motor simulation is either necessary or sufficient for understanding language about actions, it does show that motor simulation is both robust and pervasive.

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The effect of simulated shape on eye fixation

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A number of studies on embodied language processing have demonstrated that the semantic content of uttered sentences is mentally simulated during comprehension (Barsalou et al. 1999). The same neural structures that process perceptual and motor experiences are implicated in understanding sentences with perceptual and motor content. Evidence for this comes from studies that demonstrate that implicit, modally based details not mentioned in sentences interact with subsequent tasks that involve the same perception or motor control (Kaschak et al. 2005, Glenberg & Kaschack 2002).

Work in simulation semantics has demonstrated that perceptual details such as implied orientation (Stanfield and Zwaan, 2001) and implied shape (Zwaan, et al 2002) of objects mentioned in sentences interact with tasks that require the processing of shape or direction. Subjects take longer to identify whether an object was mentioned in a preceding sentence if the object is subsequently presented in a different shape or orientation to that implied by the sentence. These and other reaction time studies argue for the embodied, perceptual character of mental simulations. While other work in eye tracking and simulation (e.g. Spivey and Geng 2000) has also shown the relationship of implied direction on eye-motions on a blank-screen, it has had nothing to say about implied shape on fixation patterns to objects in a picture array. Since the reaction time experiments do not show how simulation interacts with eye-motions for implied shape, that is the focus of the current study.

This study aims is to test whether simulated details implicit in the meaning of a sentence affect patterns of eye fixation to objects within a visual display. Dahan and Tanenhaus (2005) demonstrated that object matching occurs at the level of visual features associated with prototypical shapes; competitor objects (a coiled rope) in the prototypical shape of a target object (a snake) attracted more fixation than unrelated distractors, (an umbrella, a sofa). However, the goal of current work is to demonstrate a corresponding effect with shapes implied by sentential meaning.

Subjects were presented with spoken sentences and a four-quadrant picture array while wearing an ASL head-mounted eye-tracker. Their task was to answer, by pressing YES/NO buttons, whether one of the pictures in the four-quadrant array was mentioned in the sentence that they heard. As in Dahan and Tanenhaus (2005), competitor objects were predicted to attract more fixation than unrelated distractors if they appeared in a shape consistent with the meaning. Thus, when a subject heard ìThe lime is in the Corona,î fixations to corresponding shape - a wedge-shaped half moon for instance - are predicted to be higher than fixations on unrelated objects. Reaction time was also a critical dependent measure, but unlike the Stanfield and Zwaan 2001 and the Zwaan et al. 2002 studies which presented pictures after the sentences, picture arrays were presented concurrently with audio stimuli, so we predicted an interference effect rather than a compatibility effect (Bergen 2007). The separate tasks of visually processing the same shape one is trying to simulate result in competition for the same neural resources if the tasks are performed at the same time, thus slowing down critical reaction times. Fixations were compared between conditions with target-shape match/mismatch as well as competitor-shape match/mismatch. Furthermore, overall target-fixation patterns were compared between conditions with or without the competitor.

A preliminary RT analysis for under ten pilot subjects has in fact shown this interference effect in reaction times to lean toward significance $F(1,8) = 3.251$, $p = .109$. When the target matched the implied shape, the RT is 2300ms; when the target mismatched the implied shape, the RT is 2194ms. As expected, an eye-fixation time analysis has shown longer fixations on target objects in the target-shape-mismatch condition; when objects appear in a different shape than that of a subjectís mental imagery, participants fixate longer on the anomaly, presumably because it takes them longer to judge it as the same object. Furthermore, while the presence of a competitor seems to have no effect on the task reaction time, it seems to matter in fixation. In

trials without a shape-matching competitor, fixations on the target are much longer than fixation on the targets with the competitors which suggests that competitors draw fixation away from the targets. This makes a case not only for mental simulation, but also that emergent, simulated details are embodied in patterns of eye fixation.

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Use of visual scene to facilitate spoken language comprehension

Pyykkönen, Van Gompel, & Hyönä

Research using the visual-world eye-tracking method has shown that when listening to sentences, people often direct their attention to entities in the visual scene that have not been mentioned yet (e.g., Altmann & Kamide, 1999; Kamide et al., 2003). The present two visual world experiments investigated whether anticipatory eye movements reflect linguistic predictions of the next word in the sentence or are due to a more general process: When people hear language they aim to understand it as fully as possible, and they use all possible information to facilitate processing. Thus, rather than looking at the object that is the most likely referent of the next word, people may direct their attention to new/non-salient information in the visual scene, because this facilitates comprehension more than directing attention to previously processed given information.

Evidence from corpora, production and comprehension experiments shows that with ditransitive verbs (which semantically require two objects, theme and recipient) like give people prefer the order "given before new" (e.g., Arnold et al., 2000; Bock & Warren, 1985; Clifton & Frazier, 2004). Thus, if eye movements to unmentioned objects reflect anticipations of the next word, people should fixate more on the child than the book during the verb phrase had given in (1), because the child is mentioned in the previous context (i.e., is given information). In contrast, if anticipatory eye movements occur because they facilitate processing of the unfolding utterance, people should look more at the book, because it is new and therefore requires more processing effort than the child.

(1) The child was lying in the play room of the nursery. The child was a little restless and naughty. That morning the nursery school teacher had given [the child the book/the book to the child] and read a couple of stories.

(2) The book was lying in the play room of the nursery. The book was a little old and tattered. That morning the nursery school teacher had given [the child the book/the book to the child] and read a couple of stories.

In Experiment 1 in English we presented both entities (book and child) in the context, where their relative salience was manipulated (The child was lying next to the bookÖ/The book was lying next to the childÖ). In Experiment 2 in Finnish only one of the entities was presented in the context (examples 1 and 2, above). Finnish was used in the follow-up experiment as it lacks definite and indefinite articles and allows including an adverbial phrase between verb and ditransitive structures (The nursery school teacher had given this morning the child the book). By adding an adverbial phrase between the verb and the objects provided a longer time window for analyses.

In both experiments, while participants were listening to the stories they were shown four pictures on the computer screen: pictures of a child, a book, a nursery school teacher and a play room in the examples (1) and (2). The eye movements to the pictures revealed that when people heard the verb given, they fixated significantly more on the non-salient than salient entity in Experiment 1 and more on the new entity than given entity in Experiment 2. These findings indicate that listeners' eye movements do not necessarily reflect the prediction of the next word, but are due to more general processes in which listeners look at objects that facilitate processing of the utterance most: Looking at the referents of new or non-salient words in the sentence facilitates processing more than looking at given, salient objects that have already been processed and are active in working memory.

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Individual experience affects mental simulation in sentence processing

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A range of studies using convergent methodologies (Stanfield & Zwaan, 2001; Zwaan et al. 2002; Richardson et al., 2003; Zwaan et al., 2004; Bergen et al., 2007) have shown experimentally that sentence understanders perform mental simulations of perceptual information. Mentally simulation plays a vital role in several theories of sentence processing (Glenberg & Kaschak, 2002; Bergen & Chang, 2005). However, inter-individual variability in the intensity and global character of this mental simulation has been largely unexplored. One dimension along which individuals vary, and which may be relevant to their mental simulations, is their experience with the domain described by language they are processing. Zwaan (1999) has argued that more experience with a domain allows the understander to construct richer mental simulations. We report on a study that correlates individuals' self-reported experience in a specific domain with the size of mental simulation effects when they process language about that domain.

Using a method adapted from Zwaan et al. (2004), participants listened to sentences over headphones and, 50 ms after offset of each, they saw two images presented for 500 ms on a computer screen, separated by a visual mask for 175 ms. Their task was to decide as quickly as possible whether the two images were the same or not and respond with a YES or NO button-press. All images were center-screen with the first image 225 by 225 pixels and the second either larger or smaller by 25 pixels along each dimension. This created the illusion of movement either away from or toward the sentential agent. Forty critical sentences were created involving a ball-related event (e.g. basketball, golf). Half involved movement of the ball toward and half away from the subject. In critical trials, the two images were of the ball mentioned in the sentence. We added a post-experimental questionnaire that asked participants to report on their imagery within the experiment as well as their experiences with sports. The critical question of interest was "How often do you watch sports?". Participants could select from among the following responses: "Every day", "Several times a week", "Several times a month", "Rarely", or "Never". We predicted that, as in previous work (Zwaan et al., 2004), participants would respond more quickly when the critical sentences were followed by matching images in the compatible direction (away or toward). Additionally, we predicted that this compatibility effect should be stronger in participants who had had more exposure to ball sports.

Participants were on average faster to respond when the sentence and object movement was compatible (772 ms) than when they were not (789 ms). A subjects analysis (a two-way repeated-measures ANOVA) showed this difference was significant through an interaction between the direction of motion implied by the sentence (towards or away) and the direction of apparent motion depicted by the images (towards or away): $F1(1,76)=6.56$; $p<.05$. In line with previous work, this indicates that linguistic input affects mental simulation. We then included "How often do you watch sports" responses as a covariate, encoding participants on a scale from 1 ("Every day") to 5 ("Never"). The three-way interaction among sentence direction, image direction, and sports-watching proved significant: $F1(1,76)=5.699$; $p<.05$. To investigate how the compatibility effect differed for people with more or less experience watching sports, we then divided subjects according to their sports-watching responses into High (1-3) and Low (4-5) watchers. There was a marginal interaction effect between sentence direction and picture direction for High watchers, $F1(1,35)=3.088$; $p=.088$, but no effect for Low watchers, $F1(1,40)=.084$; $p=.773$. Understanders who reported more experience watching sports showed stronger mental simulation effects when processing sentences about ball sports.

These results show that language-driven mental simulation can vary, depending on the understander's individual background. In this case, the more frequently subjects reported watching sports, the larger the perceptual compatibility effect they displayed. There are several ways to interpret these results. It could be that more experienced sports-watchers simply performed more visual simulation when processing these sports-related sentences. Or it could be (as suggested by Zwaan (1999)) that individuals who have more experience with an activity are

more likely to simulate it from a first-person perspective (the perspective that the design used in this experiment implicitly tests). The results from this experiment show that differences in an understander's experiences with events affect the mental simulations they perform during language understanding. This raises the possibility that other sorts of individual variation - from cognitive style to working memory span - might affect the character of the mental simulations they perform.

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What a moving dot can tell us about language

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The embodied theory of cognition (e.g. Barsalou, 1999; Glenberg, 1997; Stanfield & Zwaan, 2001) suggests that language comprehension is grounded in perception and action. This approach argues that perceptual and motoric experiences are stored in the brain as activation patterns (perceptual symbols) and these experiences are reenacted in the brain during language comprehension. Therefore, representations activated during language processing share characteristics with the representations activated during direct experience and bear an analogous relationship with the representation of those experiences (e.g. Zwaan, Madden, Yaxley, & Aveyard, 2004; Zwaan, Stanfield, & Yaxley, 2002; Zwaan & Yaxley, 2004).

A study carried out by Glenberg and Kaschak (2002) provided support for this theory. Participants had to judge whether sentences such as 'Open the drawer' made sense, by pressing a button requiring a motion either away or towards the body. The time to read the sentence and initiate the finger movement was longer when the direction of motion required for the button press was incongruent with the direction of motion implied by the sentence. Conversely, it was shorter when the directions were congruent. This effect was named the action-sentence compatibility effect (ACE).

To investigate this effect further, we asked whether words whose meanings imply directionality (e.g. 'rise' and 'sink') would affect smooth pursuit eye movements. Participants tracked a dot moving smoothly across a computer screen in one of four directions: Up, down, left or right. Motion verbs were presented auditorily during the movement. The present study has three advantages compared to the ACE study: First, smooth pursuit eye movements provide a continuous measure with good temporal resolution due to the online feedback system that constantly corrects the speed and positional errors of the eyes during pursuit (Lisberger & Westbrook, 1985), whereas the latency to execute hand movements does not. Second, eye movements are a more direct measure of the early effects language may hold over attention compared to hand/finger movements, as eye movements often accompany the shifts in visual attention that precede intentional action. Finally, when we open or close a drawer we necessarily enact a movement towards or away from the body (except in only rare circumstances), whereas when we observe an object sinking or rising we most likely only rarely make smooth pursuit movements as we observe the object - thus, an effect on smooth pursuit of motion verbs implying directionality that is congruent or incongruent with the direction of the pursuit would necessarily constrain any account of how language comprehension implicates the motoric system.

We observed that tracking performance (measured in terms of velocity and positional errors) was influenced by the directional properties of the verbs; the congruency of the direction implied by the verb and the direction of the moving dot influenced participants' ability to track the dot. This effect was particularly marked in the downward direction, and the onset of perturbation to the smooth pursuit occurred within the acoustic lifetime of the spoken verb.

How does language interfere with the functioning of the pursuit system? Possibly by modulating the attentional state during pursuit. There is evidence suggesting that language can interfere with eye movements towards objects that suddenly appear within the visual field (Salverda & Altmann, 2005). These language-induced shifts in visual attention are likely to be automatic, i.e. not under voluntary control. In the present study, the directionality of the verb may have influenced the extent to which attention was directed in a certain direction, so that the ability to detect the velocity and position of the pursuit target became impaired when attention was shifted in a direction that was congruent or incongruent with the motion of the target dot.

This study provides support for the embodied theory of language comprehension. Furthermore, it raises the question of whether it is the motoric action per se that has been affected in the reported ACE effect. Observing an object rising and having rising experiences oneself do not necessarily entail upward smooth pursuit eye movements, yet pursuit eye movements are influenced by the process of comprehending the word "rise". In other words, the

motoric experiences of pursuit eye movements cannot themselves be the perceptual symbols (cf. Solomon & Barsalou, 1997) activated as we comprehend the word "rise". The effect observed here and in the ACE study are more likely the results of the impact language has on some common mechanism (e.g. attention modulated by an allocentric representation of external space) that is related to both language and motoric actions. And instead of stored experiences of motoric actions, experiences of changes occurred within this mechanism are what become the proposed perceptual symbols that are essential for language comprehension.

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The role of sensory-motor information in early categories

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Recent brain imaging studies have demonstrated that motor information is involved in processing verbs and labels for tools. For example, premotor cortex is activated during comprehension of action sentences (Buccino et al., 2005), generation of action words (Oliveri et al., 2005), lexical decision tasks (Hauk & Pulvermuller, 2004), and naming of manipulable tools (Martin et al., 1999). Behavioral studies have demonstrated that subjects are slower in executing a motor task (such as pressing a button) when reading hand-related action words, due perhaps to interference between the motor schema activated by the action word and the motor schema involved in executing the motor response (Boulenger et al., 2006). Object recognition is also primed by visual depictions of hand positions that are consistent with the object's affordances (Tucker & Ellis, 1998).

But precisely what role does this motor information play in conceptual life? Do motoric primitives define categories and individuate concepts for verbs and tools? How might the role of motor information change over development? Prior developmental work has addressed parallel questions about the role of perceptual features in defining artifact concepts. Research has shown a developmental difference in children's use of perceptual information (such as object's shape, color, texture, etc.) versus abstract information (such as object's function) in categorizing novel objects. Smith and colleagues have observed that young children are more likely to extend novel words on the basis of perceptual features (such as object's shape) rather than abstract information (such as object's function) (Smith, Jones & Landau, 1996). However, recent evidence suggests that 3 year old children use perceptual features as a clue to the object's intended function (Diesendruck, Markson & Bloom, 2003) and, given sufficient time and complexity of objects, overcome the shape bias (Kemler-Nelson, 2000; 2004). These findings suggest that children may use perceptual information as cue to more abstract properties which underlie categorization.

There are three possibilities about the contribution of perceptual information to conceptual during development: (1) initially, sensory-motor representations are primary and later abstract representations emerge; (2) sensory-motor and abstract representations exist in parallel but sensory-motor information is more dominant initially and later recedes its role; (3) sensory-motor and abstract representations exist in parallel but abstract information always serves as the basis for conceptual tasks.

Our current work compares the use of motor information and function in the acquisition of novel tool categories in children. Five-year olds were asked to extend a novel word to new exemplars of tools which either required the same motor movement or had the same function as the standard. Children overwhelmingly used the tool's function as the basis for their categorization decisions (75% of function choices). Thus by five years of age, abstract information overrules motor information in the formation of novel tool categories.

Motor resonance during language comprehension

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Verbal descriptions of actions activate compatible motor responses (Glenberg & Kaschak, 2002). Previous studies have found that the motor processes for manual rotation are engaged in a direction-specific manner when a verb disambiguates the direction of rotation (e.g. "unscrewed;" Zwaan & Taylor, 2006). The present experiments contributes to this body of work by showing that (a) this effect is localized on a verb when it disambiguates an element of the action, (b) verbs that leave direction ambiguous (e.g. "turned") do not necessarily yield such effects, (c) a post-verbal adverb that maintains focus on the action (e.g. "slowly" or "quickly") can show the same effect, and (d) as meaning is integrated across sentences, motor resonance may occur as an element of the action (direction of rotation) is disambiguated . The findings are discussed within the context of discourse processes, inference generation, motor activation, embodied accounts of higher-order cognition, and mental simulation.

In all experiments, the same methodology was used. Participants read sentences by turning a knob continuously during the frame-by-frame presentation of a sentence. Words were presented in groups of one to three. Every five degrees of rotation caused a group of centrally-presented words to be replaced by the next group of words in the sentence. On critical trials, a sentence describing an act of manual rotation was presented. Using this method, we can determine the point within a sentence at which motor resonance occurs.

In the first experiment, we find motor resonance on verbs that disambiguate the direction of manual rotation (e.g. "turned down"). In addition, we find motor resonance on post-verbal adverbs that maintains focus on the action (e.g. "quickly" or "slowly"). In the second experiment, we find that the effect on adverbs does not occur if the sentence's content shifts focus (MacWhinney, 2005) to some other element of the referential situation (e.g. "happily" or "eagerly"). In the third experiment, participants read two sentences using the same procedure. The first sentence mentions an act of manual rotation (e.g. "He examined the pie through the microwave window and turned the timer.") but leaves the direction of rotation ambiguous. The second sentence disambiguates the direction of action on a word that is not the verb (e.g. The cooking time needed to be longer [or shorter]). We find that the effect does not occur for verbs that keep the direction of rotation ambiguous (e.g. "turned"); rather, motor resonance occurs surprisingly rapidly on the word that allows a disambiguating inference about the direction of rotation.

These experiments make two contributions to the literature on language processing. First, as a person comprehends text, she constructs a situation model of the described referential situation. In so doing, inferences are routinely drawn within and between sentences in order to construct a coherent representation that is being described in the discourse. Making such an inference about an action involves motor resonance that is compatible with the described action. Second, previous studies demonstrating the association between comprehending text about actions and action systems have primarily focused on verbs (Tettamanti, et al., 2005; Zwaan & Taylor, 2006). The present studies demonstrate that motor resonance can be associated with any word that maintains focus on an action or a word that disambiguates and element of an action that a protagonist performs.

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