Abstract. Four experiments investigated activation of semantic information in action preparation. Participants either prepared to grasp and use an object (e.g., to drink from a cup) or to lift a finger in association with the object’s position following a go/no-go lexical-decision task. Word stimuli were consistent to the action goals of the object use (Experiment 1) or to the finger lifting (Experiment 2). Movement onset times yielded a double dissociation of consistency effects between action preparation and word processing. This effect was also present for semantic categorizations (Experiment 3), but disappeared when introducing a letter identification task (Experiment 4). In sum, our findings indicate that action semantics are activated selectively in accordance with the specific action intention of an actor.

3.1 Introduction

In the area of motor control, many sophisticated models have been developed during the last couple of decades that specified the parameters of control for making object-oriented hand movements (Rosenbaum, 1991). However, a long neglected issue concerns the role of semantic knowledge in the process of action planning and control (see Creem & Profitt, 2001). That is, we do not only attune our motor system to the physical properties of a stimulus, but we also use our knowledge of what to do with an object and how to use it.

Recently, several behavioral and neuroimaging studies demonstrated that the visual perception of graspable objects and preparing for action are mutually dependent processes. For example, it has been shown that passive observations of tools evoke neuronal activation in different cortical motor areas (Martin, Wiggs, Ungerleider, & Haxby, 1996; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Chao & Martin, 2000) and facilitate motor responses that are consistent with these objects (Tucker & Ellis, 1998; Ellis & Tucker, 2000). Interestingly, other studies assume effects of a reversed directionality, that is, they assume effects of action on perception (e.g., Müsßeler & Hommel, 1997; Wohlschläger, 2000; Müsßeler, Steininger, & Wühr, 2001; Creem-Regehr, Gooch, Sahm, & Thompson, 2004). Several studies, for instance, showed that the planning or preparation of a motor action is able to facilitate visual processing, such as the detection of a visual stimulus that is consistent with the intended action (e.g., Craighero, Fadiga, Rizzolatti, & Umilta' 1999; Bekkering & Neggers, 2002; Hannus, Cornelissen, Lindemann, & Bekkering, 2005).

Despite the increasing evidence of the direct coupling between visual perception and action in motor control, the underlying mechanisms and representations are not well understood (see Hommel, Müsßeler, Aschersleben, & Prinz, 2001 for recent review and theoretical considerations). In particular, not much is known about the role of semantic knowledge in action planning. Several neuropsychological studies have shown that there are patients with apraxia who have a selective deficit in object use but spared semantic knowledge about those objects (e.g., Buxbaum, Schwartz, & Carew, 1997; Rumia'ti, Zanini, Vorano, & Shallice, 2001). On the other hand, patients have been reported with semantic loss but with the ability to manipulate objects accordingly (e.g., Buxbaum et al., 1997; Lauro-Grotto, Piccini, & Shallice, 1997). This indicates that the two domains, action planning and semantic knowledge, are at some level independent from each other and that the accessibility of conceptual knowledge is not necessarily required for an appropriate object-directed action. Comparable findings led Riddoch, Humphreys, and Price (1989) to conclude that there is a direct route from vision to action that bypasses semantics. This notion received additional support from experiments with neuropsychological intact adults (Rumia'ti & Humphreys, 1998). Interestingly, however, a recent study by Creem and
Proffitt (2001) indicated that action planning and semantic processing cannot be considered under all circumstances as two independent processes. They found in a dual-task experiment that normal subjects often used inappropriate grasping for household tools when object grasping was paired with a semantic dual task, but less so when paired with a visuospatial dual task. As the authors argued, this finding indicates that semantic processing is involved when preparing to grasp a meaningful object. The notion of the important role of functional knowledge in object-directed motor action is also supported by behavioral and developmental studies in children and adults indicating that in our everyday life, we build up strong associations between objects and hand shapes (Klatzky, Pellegrino, McCloskey, & Doherty, 1989; Klatzky, Pellegrino, McCloskey, & Lederman, 1993) and the purpose or function for which objects are typically used (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; McGregor, Friedman, Reilly, & Newman, 2002).

The importance of semantics for action is furthermore reflected by the results of behavioral studies that showed that semantic properties of distracting words (Gentilucci, Benuzzi, Bertolani, Daprati, & Gangitano, 2000; Gentilucci & Gangitano, 1998; Glover & Dixon, 2002; Glover, Rosenbaum, Graham, & Dixon, 2004) or objects (Jervis, Bennett, Thomas, Lim, & Castiello, 1999) influenced the kinematics of reach-to-grasp movements. For instance, Gentilucci et al. (2000) reported that Italian words denoting *far* and *near* printed on to-be-grasped objects had comparable effects on movement kinematics as the actual greater or shorter distances between hand position and object. Glover and Dixon (2002) reported that maximum grip aperture was enlarged when subjects grasped an object with the word *large* printed on top, as compared to grasping of an object with label *small*. Another effect indicating an interaction between semantics and action was reported by Glenberg and Kaschak (2002). They instructed their participants to judge whether sentences were sensible by making a motor response that required moving toward or away from their bodies and found faster response latencies when the sentence implied an action in same direction (e.g., “Close the drawer”, which implies an action away from the body) as the direction of the required motor response (e.g., moving their hand away from their body to indicate “yes”). According to the authors, this directly supports the notion that language comprehension is grounded in bodily actions.

The studies previously mentioned nicely demonstrate the impact of semantic information on the action system, showing the readiness in which semantic content, for example, from words, may interfere with and influence ongoing behavioral performance. It is typically not the case that mere activation of semantic information will in itself result in the execution of a stereotypical action, however (with the exception of patients that display utilization behavior; Archibald, Mateer, & Kerns, 2001). Rather, human behavior, in unaffected cases, shows the ability to withstand many of the automatic tendencies or affordances that
may be present in the environment and to control action selection in accordance with immediate and long-term behavioral goals (Norman & Shallice, 1986; see Humphreys & Riddoch, 2000; Rumiani et al., 2001 for neuropsychological cases in which there is a deficit in supervisory attentional control).

Although it is clear that executive processes that regulate the coherence of goal-directed behavior over time, must at some point, modulate the influence of action semantics on behavior, the exact interaction between the two mechanisms remains to be determined. One possibility is that semantic information on the functional use of objects is activated automatically upon presentation of those objects and that the control mechanisms for action subsequently select the most favorable course of action from the available alternatives (Buxbaum, 2001). Another possibility is that the activation of semantic information is selectively modulated in accordance with the behavioral goals of the task that the person is involved in. In this case, the semantic properties of the object will not be activated in full, but only those aspects that are relevant for the ongoing task. This hypothesis would be consistent with a selection-for-action viewpoint (Allport, 1987) in which information, whether perceptual or semantic, is selected in accordance with the action intention of the person that is about to act. In partial support for this possibility, electrophysiological studies indicate that providing subjects with specific task instructions to attend and respond to certain object properties, determines the type of semantic information that is activated to those objects (Coltheart, Inglis, Cupples, Michie, Bates, & Budd, 1998).

Whereas interactions between perception and action have been studied in both directions (effects of perception on action and influence of action preparation on perception; see information previously mentioned), there have been hardly any studies that looked into the influence of action preparation on the level of semantics. In the present study, we attempt to learn more about the activation of semantic information in the course of action preparation and tested the hypothesis that semantic action knowledge is activated in accordance with the specific action intention of the actor.

Traditionally, language tasks have been used to investigate semantics. A typical finding is that the semantic context (e.g., provided by a prime word) facilitates the processing of semantically related words (for review, see Neely, 1991). Priming effects have often been studied with a lexical-decision task in which participants have to judge whether a visually presented letter string is a lexically valid word or not. The semantic priming effect is very robust and has been supposed to occur automatically (Neely, 1991). It is plausible to assume that semantic preactivation is not restricted to the linguistic domain (e.g., from prime word to target word). Semantic effects have been reliably found between linguistic and nonlinguistic stimuli (e.g., Lucas, 2000; Van Schie, Wijers, Kellenbach, & Stowe, 2003). Additionally, priming studies have indicated facilitation
for a variety of prime-target relations, including script relations, functional relations, and perceptual relations (overview in Lucas, 2000).

To investigate effects of action preparation on semantics, four experiments were conducted in which the preparation of an action provided the semantic context for a subsequently presented word. In all experiments, participants prepared a motor action (e.g., drink from a cup) and delayed its execution until a word appeared on a screen. In Experiment 1, participants were required to execute the action (go) if the word was lexically valid, but withhold from responding if a pseudoword was presented (no-go). The size of interference between action preparation and lexical decision was estimated by comparing the movement onset times in trials with action-consistent words (e.g., mouth) and action inconsistent words (e.g., eye). To ensure that the expected action word-processing interaction depended on the relation between prepared action and processed words and not on the sequence of the presented stimuli (i.e., picture-word priming, cf. Vanderwart, 1984; Bajo & Canas, 1989), a control condition was introduced in which participants were required to perform simple finger-lifting movements instead of grasping responses. Assuming that the semantic concepts associated with the goal location of the object use are only activated with the preparation to grasp the objects, interactions between action planning and word processing were only expected in the grasping condition. The preparation of finger-lifting responses, however, should not activate these semantic concepts.

3.2 Experiment 1

The aim of Experiment 1 was to investigate the activation of action semantics in association with action preparation. We required our subjects either to grasp and use one of two objects (cup or magnifying glass) or to lift one of two fingers related to the object positions. Subsequently presented words in a go/no-go lexical decision task (Gordon, 1983) determined whether the prepared motor action should be executed (go) or not (no-go). In line with the hypothesis that action semantics are activated conform the action intention of the subjects, we expected faster responses in the object grasping condition for trials, in which words were consistent with the goal location of the object use, as compared to trials with inconsistent words. In contrast, no latency differences between consistent and inconsistent words were expected for finger lifting responses.
3.2 Experiment 1

3.2.1 Method

Participants

Twenty-four students (18 females and 6 males) from the University of Nijmegen took part in the experiment. All were right-handed and Dutch native speakers.

Setup

Figure 3.1 illustrates the experimental setup. In front of the participants, we placed a computer display and a touch sensitive response box with markers to indicate and control the starting position of the right hand. Additionally, a cylindrical cup without any handle (diameter 7.5 cm, height 10.0 cm) and a round magnifying glass (diameter 7.5 cm) with a handgrip (length 9.0 cm) were situated on the table, both at a reaching distance of 33 cm. To keep the object positions constant we used a desk pad with drawings of the object contours. The object positions (left side/right side) were counterbalanced between the participants.

Procedure

All participants were randomly assigned to one of two action conditions (object grasping or finger-lifting). At the beginning of each trial, a picture of one of the two objects appeared on the screen for 500 ms. In the object-grasping condition, participants were instructed to prepare actions associated with these objects. None of these actions was described verbally, nor were actions or their endpoints mentioned in the task instructions. Instead, the experimenter performed the associated actions in presence of the subject to instruct the required motor
responses at the beginning of the experiment. For example, if a cup was shown, the required action was to grasp the cup and to bring it to the mouth. The motor response associated with the magnifying glass was to grasp the object and move it to the right eye. By contrast, in the finger-lifting condition, the participants prepared a lifting of either the index or middle finger of the right hand depending on which side the depicted object was situated on the table. Importantly, the action in association with the object had to be delayed until the presentation of a word on the screen. After a variable delay of 500 ms to 2,000 ms either a valid Dutch word or a pseudoword was presented for 1,000 ms. We instructed our subjects to initiate the prepared action as soon as the word was identified as a lexically valid word (go), and to place back the object after the action was finished. Whenever a pseudoword was displayed, participants were instructed to withhold from responding (no-go). In the object-grasping condition, a cross appeared on the screen 2,500 ms after word offset and extinguished when the subject returned the hand correctly to the starting position. Because the time needed to execute a simple finger movement is relatively short, the cross in the finger-lifting condition was presented 1,000 ms after word offset.

Stimuli and design

The target words used for the go/no-go lexical decision task were the Dutch words MOND [mouth] and OOG [eye] representing the goal locations of the action associated with the cup and the action associated with the magnifying glass, respectively. In addition, two unrelated filler words, DEUR [door] and TAS [bag], were selected to match the target words with respect to word category, word length (three or four letters, monosyllabic) and word frequency in written Dutch language (CELEX lexical database, Burnage, 1990). Thus, in go trials, the presented words were either consistent with respect to the prepared action, inconsistent with the action (that is, associated with the other object), or unrelated fillers. Additionally, five legal pseudo-words were constructed for the no-go trials. These were derived from the targets by replacing all letters (vowels by vowels and consonants by consonants) so that the syllable structure and the word length were identical to those of targets. All pseudo-words obeyed the Dutch phonotactics.

Thus, there were two action conditions (object grasping and finger lifting) varied between subjects. Each condition consisted of 96 target trials (50% action consistent words, 50% action inconsistent words), 48 filler trials, and 30 (17.2%) no-go trials (2 objects × 5 pseudo-words × 3 repetitions). All trials were presented in a randomized sequence. The experiment lasted about 30 minutes.
3.2 Experiment 1

Data acquisition and analysis

To record hand and finger movements we used an electromagnetic position tracking system (miniBIRD 800™, Ascension Technology Corporation). In the object grasping condition, three sensors were attached to the participants’ thumb, index finger, and wrist of their right hand. Only two sensors, one attached to the right index finger and one to the middle finger, were needed in the finger lifting condition. Sensor positions were tracked with a sampling rate of 103.3 Hz.

Movement kinematics were analyzed off-line. We applied a fourth-order Butterworth lowpass filter with a cut-off frequency of 10 Hz on the raw data. Two criteria were chosen to detect onsets and offsets of the reach-to-grasp and finger lifting movements. An onset was defined to be the first moment in time when the tangential velocity exceeded the threshold of 10 cm/s and remained above this level for the minimum duration of 400 ms (object grasping condition) or 50 ms (finger lifting condition). For the offsets, we used the reversed criteria, taking the time of the first sample where the velocity decreased below the threshold for the predefined time.

The time differences between word onset and hand movement onset (determined by the wrist sensor) were used to calculate response latencies in the object grasping condition. We additionally calculated the following kinematic parameters of the first movement after word presentation: reach time, peak velocity, and percentage of time to maximum grip aperture with respect to reach time (TMG). In the finger lifting condition the analysis was restricted to the response latencies determined by the onset of the first finger movement after word presentation. All trials with incorrect response (i.e., incorrect lexical decisions and wrong actions) or with response latencies more than 1.5 standard deviations from each participant’s mean were excluded from the statistical analysis (cf. Ratcliff, 1993).

A type I error rate of $\alpha = .05$ was used in all statistical tests reported in this chapter. Given $\alpha = .05$ and $n = 12$ participants in both action conditions, contrasts between consistent and inconsistent trials of the size $d'_3 = .9$ (cf. Cohen, 1977) could be detected with a probability of $(1 - \beta) = .81$ for object grasping as well as for finger lifting$^1$.

3.2.2 Results

For both action conditions, the percentages of correct lexical decisions to Dutch words (hits) were greater than 98.4%. No false alarm responses occurred. Wrong

$^1$All statistical power analyses reported here were performed using the G*Power 2 program (Erdfelder, Faul, & Buchner, 1996)
actions (i.e., lifting the wrong finger or grasping the wrong object) occurred in less than 1% of all hit trials.

The response latencies to target words (i.e., consistent and inconsistent words) and filler words did not differ significantly, neither for object grasping, $t(11) = -2.00, p > .05$ nor for finger lifting, $|t(11)| < 1$. For further analyses we focused on the contrast between consistent and inconsistent trials.

The mean response latencies to target words in the lexical decision task are shown in Figure 3.2. A mixed-model analysis of variance (ANOVA) with one between-subject factor (action condition: object grasping or finger lifting) and one within-subject factor (word consistency) was computed. The data showed an overall trend for the factor word consistency, $F(1,22) = 3.91, p = .06$. Most important, the interaction between the two factors was significant, $F(1,22) = 4.72, p < .05$. Post-hoc 2-tailed $t$-tests showed that for object grasping the latencies to consistent words (521 ms) were shorter than to inconsistent words (538 ms), $t(11) = -3.35, p < .01, d' = 1.36$ (cf. Cohen, 1977), whereas no significant difference was observed in the finger lifting condition (consistent: 493 ms vs. inconsistent: 492 ms), $|t(11)| < 1$.

For the object grasping condition, we calculated the kinematic parameters reach time, peak velocity and the percentage of time to maximum grip aperture (TMG). They were entered separately into three 2 (object) × 2 (word consistency) repeated measures ANOVAs (see Table 3.1). When grasping the cup, peak velocity was slower, $F(1,11) = 12.58, p < .01$, and TMG was later, $F(1, 11) = 15.04, p < .01$, as compared to trials in which the magnifying glass was grasped. The reach times didn’t differ significantly. More important, no effects of the word consistency were found in any kinematic variable, all $F < 1$. 
3.3 Experiment 2

Table 3.1: Means of the Kinematic Parameters Reach Time (RET), Peak Velocity (PV), and Percentage of Time to Maximum Grip Aperture with Respect to Reach Time (TMG) in Experiment 1 as a Function of the Word Consistency.

<table>
<thead>
<tr>
<th></th>
<th>Cup</th>
<th>Magnifying Glass</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consistent</td>
<td>Inconsistent</td>
<td>Consistent</td>
<td>Inconsistent</td>
</tr>
<tr>
<td>RET (ms)</td>
<td>592</td>
<td>597</td>
<td>585</td>
<td>582</td>
</tr>
<tr>
<td>PV (cm/s)</td>
<td>123.9</td>
<td>123.4</td>
<td>137.1</td>
<td>137.7</td>
</tr>
<tr>
<td>TMG (%)</td>
<td>76.5</td>
<td>75.8</td>
<td>51.8</td>
<td>50.6</td>
</tr>
</tbody>
</table>

3.2.3 Discussion

In summary, response latencies to words consistent with the action goal of the movements were faster if object grasping was prepared. On the contrary, no consistency effects were found when subjects prepared for finger lifting. This dissociation suggests that the action word-processing interaction did not merely arise from presenting the object pictures or from attention being selectively directed to one of the two objects. Both action conditions were identical in these aspects. We can also exclude the alternative explanation that simple picture-word priming (cf. Vanderwart, 1984; Bajo & Canas, 1989) caused the response latency differences, because pictures and words were identical in both conditions. Rather, the results suggest that action-specific semantic information was selected in association with the action goal of the movement that was prepared. Only when subjects had the intention to grasp and use the objects, a relative advantage was found for words that specified the goal location of the object use. Furthermore, the absence of priming effects in the finger-lifting condition argues against the hypothesis that action semantics are activated automatically and independent from the behavioral goal upon the presentation of objects.

Nevertheless, there is a possible alternative account for the lack of response latency differences in the finger-lifting condition. In Experiment 1, the preparation of simple finger movements appears much easier than the preparation of reach-to-grasp movements, which are motorically more complex. As a consequence, participants may have been more efficient in cognitively separating action preparation and word recognition tasks, resulting in the absence of an action word-processing interaction for the finger-lifting condition.

3.3 Experiment 2

Experiment 2 was conducted to exclude the possibility that the differences in the motor complexity in the two action conditions (object grasping and finger lifting) may have affected interactions between action preparation and lexical decision.
In order to test that the effects reported in Experiment 1 were independent of movement complexity and the result of an interaction between the semantic representations involved in motor preparation and word processing, we sought to reverse the pattern of effects between the two conditions. Instead of using words related to the goal locations of grasping movements, we presented the Dutch words for left and right, as representatives of action features believed to be important in the finger-lifting condition. We hypothesized that these spatial descriptions were much more relevant for the finger-lifting condition than for the object-grasping condition. In other words, we predicted an action word-processing interaction primarily for the finger-lifting condition and much smaller or no effects for object grasping.

### 3.3.1 Method

**Participants**

Again, twenty-four students (16 females and 8 males) from the University of Nijmegen were tested. All were right-handed and Dutch native speakers.

**Setup and procedure**

The experimental setup and procedure was the same as compared to Experiment 1.

**Stimuli and design**

For the go/no-go lexical decision task we used as consistent and inconsistent words (target words) the Dutch words for the spatial relations left and right (i.e., LINKS and RECHTS). The unrelated filler words were BLAUW [blue] and SCHOON [nice, clean], selected to match target words in word category, word length (i.e. number of letters and syllables) and word frequency in written Dutch language. For the no-go trials, five legal pseudo-words with the same word lengths and syllable structure as the target words were constructed from the targets by replacing all letters. The experimental design was identical to Experiment 1.

**Data acquisition and analysis**

Data acquisition and analysis was unchanged. Also, the statistical power to detected consistency effects was identical to those in Experiment 1.
### Table 3.2: Means of the Kinematic Parameters Reach Time (RET), Peak Velocity (PV), and Percentage of Time to Maximum Grip Aperture with Respect to Reach Time (TMG) in Experiment 2 as a Function of the Word Consistency.

<table>
<thead>
<tr>
<th></th>
<th>Cup</th>
<th>Magnifying Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consistent</td>
<td>Inconsistent</td>
</tr>
<tr>
<td></td>
<td>Consistent</td>
<td>Inconsistent</td>
</tr>
<tr>
<td>RET (ms)</td>
<td>628</td>
<td>635</td>
</tr>
<tr>
<td></td>
<td>637</td>
<td>638</td>
</tr>
<tr>
<td>PV (cm/s)</td>
<td>128.6</td>
<td>127.6</td>
</tr>
<tr>
<td></td>
<td>141.2</td>
<td>143.0</td>
</tr>
<tr>
<td>TMG (%)</td>
<td>77.7</td>
<td>78.5</td>
</tr>
<tr>
<td></td>
<td>41.0</td>
<td>38.7</td>
</tr>
</tbody>
</table>

### 3.3.2 Results

Hit rates for both action conditions were higher than 98.8%. No false alarm responses occurred. The percentages of wrong actions were 2.8% for object grasping and 0.8% for finger lifting. In both action conditions, response latencies to filler words were statistically not different from the latencies to target words, both $|t(11)| < 1$.

Mean response latencies to target words in the lexical decision task are shown in Figure 3.2 on page 46. The $2 \times 2$ (action condition) mixed-model ANOVA yielded no main effects. Again, a significant interaction between word consistency and action condition was found, $F(1, 22) = 10.48$, $p < .001$. Interestingly, in the finger lifting condition response latencies to inconsistent words (524 ms) were longer than to consistent words (504 ms), $t(11) = 2.82$, $p < .05$, $d' = 1.15$. However, no significant differences were found in the object grasping condition (consistent: 520 ms vs. inconsistent: 514 ms), $t(11) = 1.58$, $p > .05$.

The three two-factorial repeated measures ANOVAs (object $\times$ word consistency) of the kinematic parameters revealed that grasping the cup led to slower peak velocities, $F(1, 11) = 8.43$, $p < .05$, and later TMG, $F(1, 11) = 30.02$, $p < .001$ (see Table 3.2). However, there was no influence of the word consistency on any kinematic variable, all $F(1, 11) < 1$.

### 3.3.3 Discussion

In summary, consistent with the results of the previous experiment, Experiment 2 showed an action word-processing interaction using the spatial descriptions *left* and *right*. Again, no effect of the word consistency was found in the analysis of kinematics. Importantly, however, in contrast to the first experiment, consistency effects were now present in the finger-lifting condition, whereas the response latencies in the object-grasping condition were unaffected by the word meaning. Overall, there is a double dissociation of effects between Experiment 1 and 2, which indicates that the action word-processing interac-
3 Action and Semantic Processing

tion cannot be explained by the complexity of the motor response. Rather, the results of Experiment 1 and 2 are consistent with the hypothesis that action semantics were specifically activated in association with the action intended by the subject.

Although it is difficult to imagine an explanation for the action word-processing interaction without including semantics, there is a possibility that the repeated use of the same words in the experiment may have led participants to perform the lexical-decision task on the basis of the visual word forms alone, without involving semantics. To control for this possibility and to provide further support for the idea that the interaction between action preparation and word processing critically depends on semantic processing, two additional experiments were performed, in which we introduced a semantic categorization and a letter identification task.

3.4 Experiment 3

In order to better understand the nature of the action word-processing interaction, we introduced a semantic categorization task instead of a lexical-decision task for the current experiment. We cannot exclude the possibility that the participants in the first two experiments did read the words, but relied only on the visual word forms and did not process words to a semantic level. Clearly, a semantic categorization task cannot be performed without deep semantic processing. Thus, Experiment 3 allows collecting further evidence for the assumption that the relevant processing level for the action word-processing interaction is the semantic processing level.

3.4.1 Method

Participants

Fifteen students (13 females and 2 males) from the University of Nijmegen participated in Experiment 3 in return for 4 Euros or course credits. All were right-handed and Dutch native speakers.

Setup and procedure

The experimental setup was the same as in Experiment 1. Only, instead of using a touch sensitive response box, we implemented an online control function in the motion tracking software to control whether the hand was positioned correctly at the beginning of each trial. A white and tangible circle (3 cm) on the desk pad served as marker for the initial position.
3.4 Experiment 3

**Table 3.3:** Word Stimuli Used in Experiment 3 (Semantic Categorization Task, SC Task) and Experiment 4 (Final Letter Identification Task, FLI Task).

<table>
<thead>
<tr>
<th>Word Stimulus (Dutch)</th>
<th>English Translation</th>
<th>Stimulus Category</th>
<th>Experiment 3 (SC Task)</th>
<th>Experiment 4 (FLI Task)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mond</td>
<td>mouth</td>
<td>target</td>
<td>target</td>
<td>target</td>
</tr>
<tr>
<td>oog</td>
<td>eye</td>
<td>target</td>
<td>target</td>
<td>target</td>
</tr>
<tr>
<td>heup</td>
<td>hip</td>
<td>filler</td>
<td>no-go</td>
<td>filler</td>
</tr>
<tr>
<td>rug</td>
<td>back</td>
<td>filler</td>
<td>filler</td>
<td>filler</td>
</tr>
<tr>
<td>nek</td>
<td>nape</td>
<td>filler</td>
<td>no-go</td>
<td>no-go</td>
</tr>
<tr>
<td>buik</td>
<td>stomach</td>
<td>filler</td>
<td>no-go</td>
<td>filler</td>
</tr>
<tr>
<td>mug</td>
<td>mosquito</td>
<td>no-go</td>
<td>filler</td>
<td>filler</td>
</tr>
<tr>
<td>mier</td>
<td>ant</td>
<td>no-go</td>
<td>no-go</td>
<td>no-go</td>
</tr>
<tr>
<td>eend</td>
<td>duck</td>
<td>no-go</td>
<td>filler</td>
<td>filler</td>
</tr>
<tr>
<td>kat</td>
<td>cat</td>
<td>no-go</td>
<td>no-go</td>
<td>no-go</td>
</tr>
<tr>
<td>vis</td>
<td>fish</td>
<td>no-go</td>
<td>no-go</td>
<td>no-go</td>
</tr>
<tr>
<td>hond</td>
<td>dog</td>
<td>no-go</td>
<td>filler</td>
<td>filler</td>
</tr>
</tbody>
</table>

The procedure was basically identical to Experiment 1. That is, each trial started with a picture of one of the objects, which indicated the action to prepare. After a variable delay a word appeared, which triggered the action initiation. In contrast to the previous experiments, a semantic categorization task was used for the go/no-go decisions. Participants were instructed to decide whether the displayed word represents a human body part or an animal. In the case of a body part the prepared action had to be initiated immediately; in the case of an animal no response was required. The semantic categorizations had to be performed as fast and accurate as possible. Since the aim of this experiment was to replicate the action word-processing interaction in object grasping, we could refrain from varying the type of action. Thus, all participants were required to prepare and execute reach-to-grasp movements to use the objects.

**Materials**

The twelve Dutch words that were used for the semantic categorization task are printed in Table 3.3. As in Experiment 1, the words *MOND* [mouth] and *OOG* [eye] were the target words, which were consistent or inconsistent with respect to the goal location of the prepared action. Additionally, we used four action unrelated words, all members of the natural category of the *human body* as filler words and six members of the natural category of *animals* as no-go stimuli. Both categories were part of the supracategory *natural* and were chosen so that they were roughly comparable in category size. All words were selected to match the two target words with respect to word length (3 or 4 of letters and
Figure 3.3: Mean response latencies in Experiment 3 (semantic categorization task) and in Experiment 4 (final letter identification task) as a function of the factors action condition and word consistency. Error bars represent the 95% within-subject confidence intervals (cf. Loftus & Masson, 1996).

monosyllabic), word category and word frequency in written Dutch language (cf. CELEX lexical database, Burnage, 1990). Both target words were repeated 20 times in combination with each of the two object pictures indicating the respective action. In order to obtain an equal amount of trials with target words and filler words, the four fillers were presented ten times per object. All six no-go stimuli were repeated four times per object.

The experiment consisted of 80 target trials (50% action consistent words, 50% action inconsistent words), 80 filler trials and 48 (23.0%) no-go trials. All trials were presented in a randomized sequence. The experiment lasted about 40 minutes.

Data acquisition and analysis

Data acquisition and analyses of latencies and kinematics were as described in Experiment 1. Given $\alpha = .05$ and $n = 15$ participants, consistency effects of size $d_3' = .8$ could be detected with a probability of $(1 - \beta) = .82$.

3.4.2 Results

The percentage of correctly categorized body-parts (hits) was 98.2%. Incorrect categorizations of animals (false alarms) occurred in average in less than 1% of all trials. Incorrect actions were observed in less than 1% of the hit trials. Response latencies to action-unrelated filler words (499 ms) were slower than to target words (482 ms), $t(14) = -6.10, p < .001$. This difference is not surprising, because filler words were presented less frequently than target stimuli.

Mean response latencies to consistent and inconsistent target words for the semantic categorization task are shown in Figure 3.3. As expected, the responses to action-consistent words (474 ms) were significantly faster as compared to action-inconsistent words (490 ms), $t(14) = 2.37, p < .05, d_3' = 0.87$. 
Table 3.4: Means of the Kinematic Parameters Reach Time (RET), Peak Velocity (PV), and Percentage of Time to Maximum Grip Aperture with Respect to Reach Time (TMG) in Experiment 3 as a Function of the Word Consistency.

<table>
<thead>
<tr>
<th></th>
<th>Cup</th>
<th>Magnifying Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consistent</td>
<td>Inconsistent</td>
</tr>
<tr>
<td>RET (ms)</td>
<td>522.1</td>
<td>522.0</td>
</tr>
<tr>
<td>PV (cm/s)</td>
<td>117.6</td>
<td>117.1</td>
</tr>
<tr>
<td>TMG (%)</td>
<td>76.1</td>
<td>76.5</td>
</tr>
</tbody>
</table>

The 2 (object) × 2 (word consistency) repeated measures ANOVAs of the reach time, peak velocity, and percentage of time to maximum grip aperture (TMG) yielded no influence of word meaning on any kinematic variable, all $F(1,15) < 1$ (see Table 3.4). Merely effects of the objects were present, that is, grasping the cup led to slower peak velocities, $F(1,15) = 7.97, p < .05$, and later TMG, $F(1,15) = 5.72, p < .05$.

3.4.3 Discussion

The aim of the present experiment was to provide further evidence for a semantic nature of the action word-processing interaction observed in Experiment 1. Unambiguously, the categorization task in the present experiment required deep semantic processing and the low number of errors in this task indicates that semantic processing was indeed successfully performed by the participants. Similar to the results of Experiment 1 response latencies were faster for conditions in which the word semantics were consistent with the prepared action, without there being any effects in movement kinematics. The results of Experiment 3 indicate the reliability of the action word-processing interaction and support our assumption that the effect reflects an interaction at a semantic level.

Still, one additional test may be applied to strengthen the present conclusions. If the interaction between action preparation and word processing indeed critically depends on semantic processing, the effect should disappear under conditions where the activation of word semantics is not required to solve the task.

3.5 Experiment 4

Previous studies using a word-to-word priming paradigm have shown that the semantic priming effect is reduced or eliminated when participants perform a letter identification task on the prime word (prime-task effect, e.g., Henik, Friedrich, Tzelgov, & Tramer, 1994; Stolz & Besner, 1996). Similarly, Stroop interference
can be reduced or eliminated when only a single letter is colored instead of the whole word, as in the standard version of the task (Besner, Stolz, & Boutilier, 1997). In both tasks, allocating attention to low-level features of the word is assumed to hinder semantic processing.

In the present experiment, we transferred this logic to the paradigm involving action preparation and word reading. We used the same experimental procedure and the identical stimulus set as in Experiment 3, although, the go/no-go criterion was whether a given letter was present in the final position of the word form. If the observed consistency effects require semantic processing, the response latency differences should disappear or become significantly smaller using a low-level letter-identification task.

3.5.1 Method

Participants

Twenty right-handed and Dutch native speaking students (14 females and 6 males) from the University of Nijmegen were tested.

Procedure

The experimental setup and procedure was identical to Experiment 3. The only modification was that the go/no-go decisions were based on the final letter of the word that was presented. To be precise, participants were instructed to initiate the prepared action as soon as possible only if the word ended with either the letter “D” or “G”, and not to respond if the word ended with any other letter.

Materials

The same twelve Dutch words as in Experiment 3 were used for the letter identification (see Table 3.3 on page 51). Again, the two goal locations of the actions MOND [mouth] and OOG [eye] served as target words. Four action unrelated words (filler words) also ended with a “D” or a “G” and served as go stimuli. The remaining six words, which did not end with “D” or “G” served as no-go stimuli. The frequencies of presentation of targets, fillers, and no-go stimuli were the same as described in Experiment 3. Thus, there were 80 target trials (50% action consistent words, 50% action inconsistent words), 80 filler trials and 48 (23.0%) no-go trials. All trials were presented in a randomized sequence. The experiment lasted about 40 minutes.
Table 3.5: Means of the Kinematic Parameters Reach Time (RET), Peak Velocity (PV), and Percentage of Time to Maximum Grip Aperture with Respect to Reach Time (TMG) in Experiment 4 as a Function of the Word Consistency.

<table>
<thead>
<tr>
<th></th>
<th>Cup</th>
<th>Magnifying Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consistent</td>
<td>Inconsistent</td>
</tr>
<tr>
<td>RET (ms)</td>
<td>508.0</td>
<td>508.3</td>
</tr>
<tr>
<td>PV (cm/s)</td>
<td>118.8</td>
<td>118.6</td>
</tr>
<tr>
<td>TMG (%)</td>
<td>70.1</td>
<td>70.7</td>
</tr>
</tbody>
</table>

Data acquisition and analysis

Data acquisition and analyses of latencies and kinematics were as described in Experiment 1. In order to interpret a potential non-significant result, as hypothesized, an a priori power analysis was performed. Given $\alpha = .05$ and $(1 - \beta) = .80$, $n = 20$ participants were needed to detect a consistency effect with somewhat smaller size ($d'_3 = .7$) than the effects in the first three experiments.

3.5.2 Results

The percentage of correct identifications of the final letter “D” and “G” (hits) was greater than 98%. False alarms occurred in less than 1% of all trials, wrong action in less than 1% of the hit trials. Response latencies to filler words (475 ms) were longer than to targets words (459 ms), $t(19) = 5.33$, $p < .001$, which reflects the fact that filler words were presented less often than target words.

Mean response latencies to target words for the final letter identification task are shown in Figure 3.3 on page 52. Importantly, there was no statistical difference between the response latencies to consistent words (457 ms) as compared to inconsistent words (462 ms), $t(19) = 1.29$.

Again, the three kinematic parameters were analyzed with separate 2 (object) $\times$ 2 (word consistency) ANOVAs (see Table 3.5). Grasping of the cup led to later TMG, $F(1, 19) = 6.80$, $p < .05$. No effects were observed in peak velocities and reach times. As in the three experiments before, we did not find effects of the word meaning on any kinematic variable, all $F(1, 19) < 1.4$.

3.5.3 Discussion

In summary, no reliable action word-processing interaction was observed with the letter identification task. There were no significant differences in response latencies for action-consistent words as compared to inconsistent words. Because the statistical power was satisfactory, we can exclude the presence of an interaction between action intention and word semantics in the present experiment. These results are in line with our assumption that when semantic processing is
3 Action and Semantic Processing

not required for the go/no-go task, no action word-processing interaction can be observed. Although some degree of automatic semantic processing of word forms cannot be excluded in the letter identification task, when attention was directed to low-level features of the target words, the interaction effects disappeared. Accordingly, the activation of semantic representations from the visual word form seems to be a prerequisite for the observed interaction, which emphasizes the semantic nature of the action word-processing interaction effect.

3.6 General Discussion

The results of the present study demonstrate an interaction effect between processes involved in action preparation and processes involved in word reading. Response latencies were sped up if words presented in a go/no-go decision task were consistent with the features of a concurrently prepared action. In Experiment 1, when subjects prepared to grasp the objects, reaction times were faster when words consistently described the goal location (i.e., mouth or cup) of the prepared action. When subjects prepared finger-lifting movements on the basis of the object positions instead of performing object-directed actions, however, reaction time effects were found to disappear. These results suggest that functional semantic information regarding the purpose or action goal for which an object is typically used does not become activated automatically upon presentation of the object, but only when subjects intend to use the object with that specific purpose.

Experiment 2 further supported the hypothesis that semantics are activated in association with the action intention of the actor and ruled out possible alternative explanations for the difference between the two action conditions in Experiment 1. Changing the words to describe relevant action features for the finger-lifting condition (left and right) resulted in an action word-processing interaction for this condition, whereas no effect was found in the condition in which subjects grasped and used objects. Both the dissociations between conditions within each experiment and the reversal of effects between experiments are consistent with our hypothesis that action semantics about objects are selectively activated and depend on the actor's intention.

Experiments 3 and 4 further supported the suggestion that the action word-processing interaction critically depends on the depth of semantic processing required by the go/no-go task. In Experiment 3, in which subjects made semantic decisions about word category instead of the lexical decisions, the action word-processing interaction between the two tasks was found unchanged. As Experiment 4 demonstrates, however, the mere presentation of a visual word form is obviously not sufficient to cause this effect, which indicates the semantic nature of this effect. Therefore, we consider the use of a secondary language
task as a successful approach to investigate semantic action representations and the use of functional object knowledge in the context of action preparation.

In line with the results of Experiments 3 and 4, which show that the activation of semantic concepts was critically involved in establishing the interaction between the two tasks, contemporary models of motor control (Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001; Glover, 2004) suggest that conceptual knowledge is involved in the selection of appropriate action plans. Consistent with this notion, recent experiments in the field of motor control demonstrated that presentation of irrelevant semantic information (via words) has a direct impact on movement kinematics of reach-to-grasp actions (Gentilucci & Gangitano, 1998; Gentilucci et al., 2000; Glover & Dixon, 2002; Glover, 2004). For example, Glover and Dixon (2002) reported that maximum grip aperture was enlarged while grasping an object with the word label *large* as compared to grasping an object with the word label *small*. Interestingly, Glover et al., (2004) reported an automatic effect of word reading on grasp aperture using words for objects that either afford a large grip (e.g., *apple*) or a small grip (e.g., *grape*). In both studies, Glover and colleagues performed a detailed analysis of the movement kinematics, which showed that word semantics affected the motor action only very early in the movement. As the hand approached the target, the impact of word semantics was found to decline continuously. In line with these results, the authors concluded that semantic information interferes only with motor planning but not with motor control once the action is initiated. This view is consistent with the present findings in which word meaning only affected reaction times but not the online control of movement execution. Concerning the absence of kinematic effects, our study notably differs from earlier studies on semantics in motor action. To be precise, in our paradigm, it was required to prepare the action before word onset and to execute it after word processing. In other words, motor action and word reading did not take place at the same time. This may explain the absence of kinematics effects in the present study and suggests that the reaction time differences reflect effects in the word-processing performances caused by action preparation.

Although the absence of kinematic effects is consistent with the assumption that actions were prepared effectively, an alternative account that may partly explain our results is that, instead of preparing a motor response, participants represented the upcoming motor task verbally in short-term memory and recalled these verbal descriptions for the grasping or finger-lifting actions after picture onset. It must be emphasized, however, that in the present study, subjects were never instructed in words such as “grasp the left object and bring it to the mouth.” Instead, subjects just saw the relevant actions once before the experiment started. Furthermore, the short reaction times, minimal error rates, and absence of kinematic effects in all experiments indicate that subjects prepared the upcoming actions well before word onset and do not suggest that
participants memorized the motor task verbally and prepared the action only after word onset. This assumption is also supported by several studies on motor control (e.g., Rosenbaum, 1983; Leuthold, Sommer, & Ulrich, 2004), which indicate that, in delayed response conditions, subjects tend to prepare the motor response as far as possible in advance instead of maintaining cueing information in memory or recalling the task instruction. In light of these arguments, we consider the verbal working memory explanation to be unlikely, and we favor the interpretation that effects reflect semantic overlap between action preparation and lexical semantics.

Hommel and Müßeler (2006) recently investigated the effects of action preparation on the perception of directional words (i.e., left and right). They required their participants to prepare either a manual left-right keypress response or to say “left” or “right.” Later, they briefly presented a directional word. In contrast to the present paradigm, the words had to be recalled after executing the prepared response. Under these conditions, planning vocal actions impaired the perception of directional words, but, interestingly, the preparation of manual responses did not affect word processing. Although it might be difficult to compare accuracy effects in an unspeeded identification task with reaction time effects in a lexical-decision task, these results seem to be in contradiction with the results of the present study. One possible explanation for this discrepancy is that in the study of Hommel and Müßeler (2006), participants were required to maintain a short-term memory representation of the presented words, which was not the case in the present study. According to the feature-integration approach (Stoet & Hommel, 1999; Hommel, 2004), attending a perceptual object as well as planning an action implies an integration of several activated feature codes into one coherent object representation or action plan. The mere activation of feature codes should facilitate processing of all events sharing these features. Once a feature code is integrated into an action plan or object representation, however, it is no longer available for another integration if needed for other cognitive processes. As a result, this process is assumed to be impaired. It has been suggested that the likelihood that a feature code becomes integrated depends on the relevance of the respective feature for the task. That is, unattended or task-irrelevant features may become activated but not integrated into one or more bindings (Hommel, 2004). In line of this reasoning, in the study of Hommel and Müßeler (2006, Experiment 3A), feature integration of the word semantics was required to maintain a short-term memory representation. In the present study, however, semantic features were activated but were not integrated into a short-term memory representation, which had to be maintained while acting. Consequently, we found that the semantic congruency between the two tasks did not result in an inhibitory effect, but in a facilitation of word processing.

Several studies have shown that action preparation as well as action execution can influence visual perception (Craighero et al., 1999; Müßeler & Hommel,
3.6 General Discussion

For example, Craighero et al. (1999) required their participants to prepare an action (i.e., to grasp a bar with a specific orientation) but to delay action execution until the appearance of a visual stimulus. Interestingly, they found that movements were initiated faster when the orientation of the go stimulus was consistent with the orientation of the to-be-grasped object. In the same study, consistency effects were found when after preparation of a hand movement, participants were instructed to inhibit the prepared grasping movement and to respond with a different motor effector. Craighero et al. (1999) concluded that the mere preparation of an action is capable to facilitate the processing of visual stimuli if it contains features that are consistent with the preactivated action plan.

In addition to and consistent with the reported perceptual effects of action preparation, the current study suggests that the principles of selection for action are also operational at the level of semantics. Our data suggest that functional semantic information about objects is activated in association with the action intention of the subject. For example, although cups are typically brought to the mouth for drinking, we assume that the concept of mouth is activated stronger when there is the intention to bring the object to the mouth as when some other response is required. In fact, our results suggest that the goal location of the object use is not activated when there is no specific intention to interact with the object. That is, when subjects received the instruction to perform finger-lifting movements, the facilitation of words, which are consistent with the goal locations of the object use, was absent. These results suggest that functional semantic information about how to respond to objects requires motor processing in order to become activated. A theoretically comparable idea in the field of perception and action is expressed by the premotor theory of visual attention (Rizzolatti, Riggio, & Sheliga, 1994), which suggests that allocating visual attention in space involves covert activation of the eye movement system. In this perspective, action preparation no longer just facilitates the selection of perceptual information, but perceptual processes themselves require motor support. A similar mechanism might, in theory, be applicable also to the activation of semantic representations. That is, functional semantic information about the use of objects may require activation of motor representations to enable the semantic information to be addressed. Similar proposals have been made with respect to visual semantic knowledge about the appearance of objects (Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; van Schie, Wijers, Mars, Benjamins, & Stowe, 2005). Lesions in visual areas of the brain (occipitotemporal area) sometimes not only result in perceptual deficits, but may also impair the activation of knowledge about the visual properties of objects (review in Humphreys & Forde, 2001). Comparable ideas have been expressed with respect to functional semantic knowledge in which lesions in motor areas of the brain are held responsible for subjects’ impairments to represent the functional
properties of objects (review in Saffran & Schwartz, 1994). A growing number of neuroimaging studies furthermore affirm the idea that visual and motor representations support semantic knowledge about the use and appearance of objects (e.g., Pulvermüller, 1999; Tanel, Kemmerer, Adolphs, Damasio, & Damasio, 2003). One advance of the present study is that it provides behavioral support for existing neuropsychological and neuroimaging results, which suggest that accessing functional semantic information about objects involves an activation of specific motor representations.

Whereas an increasing amount of research is directed at the use of motor representations for semantics, the reverse relationship concerning the use of semantic information for actions has received much less attention. As a consequence, the contribution of semantics for use of objects is still not fully understood (see Rumiati & Humphreys, 1998; Creem & Proffitt, 2001; Buxbaum et al., 1997). For example, neuropsychological studies (e.g., Buxbaum et al., 1997; Riddoch et al., 1989) and behavioral studies with time-limited conditions (Rumiati & Humphreys, 1998) suggest that semantic knowledge can be bypassed when selecting an action as response to objects. This shows that an involvement of semantics in action planning is not obligatory and has led Riddoch et al. (1989) to conclude that a direct route from vision to action exists in addition to a semantic route. Nevertheless, some experimental findings support information-processing models for action, which propose that access to stored semantic knowledge about an object is utilized to generate correct object-directed actions (MacKay, 1985). For example, a recent study of Creem and Proffitt (2001) shows that semantic processing is required when grasping ordinary household tools appropriately for their use. They observed that subjects’ grasping was frequently inappropriate when the motor task was paired with an additional semantic task but not when paired with a visuospatial task. In congruence with these findings, the present study demonstrates the important role for functional semantic knowledge in action preparation and provides evidence for the notion that action semantics are routinely activated with the preparation and execution of goal-directed actions.

In addition to the rather general conclusion that semantics are involved in object use, the results of the present study clearly indicate that action semantics are activated selectively in accordance with the actor’s specific intention. In other words, depending on the person’s current behavioral goal, different functional object properties become relevant and activate as a result of different aspects of semantic action knowledge. This conclusion does not contradict the results of neuroimaging experiments that find motor areas activated to the presentation of manipulable objects (Chao & Martin, 2000; Creem-Regehr & Lee, 2005) or the findings of behavioral studies suggesting that the mere perception of tools automatically potentiates components of the actions they afford (Tucker & Ellis, 1998; Ellis & Tucker, 2000). In contrast to these studies, however, the present study points out the modulating role of action intentions on the activation of action knowledge related to an object in a functional-relevant way.
In conclusion, the advance that is made with the present paradigm is that we were able to establish a measure of semantic action knowledge as it is activated in the process of action preparation. Our finding of an action word-processing interaction suggests that the selection-for-action hypothesis is not just restricted to the domain of perception and action, but it is to be extended to the field of semantics. This insight certainly calls for further investigation. More scientific interest into the area of semantic action knowledge is expected to increase our understanding of the cognitive mechanisms that underlie the planning and control of motor actions.
3 Action and Semantic Processing