Processing Differences of Effector-Related Nouns and Verbs: Discussing Effector-Specific Compatibility Effects

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Abstract

According to the experiential-traces account, which is part of the embodied cognition framework, language comprehension is based on the reactivation of experiential traces that stem from experiencing the corresponding objects, states, or events. Behavioural research finds support for this theory in interactions between language and motor processing. While this so-called action-compatibility-effect is often found for sentences and nouns, the evidence in case of action verbs seems unclear. Although neuropsychological studies found that information encoded in action verbs gets reactivated, a behavioural study found no compatibility effect. To further address this issue, we investigated effector specific compatibility effects in three experiments by comparing results of a lexical-decision task with those of a Stroop-like task. We found effector specific activation for action verbs only with a lexical-decision task. This supports the view, that verbs and nouns are processed differently. To activate the effector specific information in action verbs, deeper processing is needed.

Keywords: Embodied Cognition; Experiential Traces; Action Verbs; Lexical-Decision Task; Stroop-Task

Processing Differences of Effector-Related Nouns and Verbs: Discussing Effector-Specific Compatibility Effects

Today, theories concerned with language comprehension are typically categorized in amodal vs. embodied accounts. According to the amodal view, language is seen as a separate module in our brain that functions mostly independently from action and perception (Fodor, 1983; Masson, 2015). According to the embodied view, in contrast, comprehension is based on our bodily experiences with our environment (Barsalou, 1999, 2008). Within the last decades, the embodied account of language comprehension gained a lot of support (for reviews, see Barsalou 2008; Fischer & Zwaan, 2008; Horchak, Giger, Cabral, & Pochwatko, 2014; Jirak, Menz, Buccino, Borghi, & Binkofski, 2010). One well-known and rather specific account in this framework is the theory of experiential traces from Zwaan and Madden (2005). According to this account, every interaction with the environment leaves an experiential trace in our brain. Because linguistic labels often co-occur with the objects, situations, and events they refer to, the corresponding experiential traces eventually become associated. As a result, when later processing the linguistic label in isolation, the associated experiential traces stemming from interacting with the referents of the linguistic labels become re-activated. In its strongest version, this account of language comprehension thus suggests that comprehension is based on the reactivation of experiential traces. For instance, when we hear or read the word *football*, the different experiential traces associated with footballs become re-activated, including traces stemming from seeing a football, feeling a football, kicking a football, hearing a football match etc. All these re-activated traces together make up the meaning of the word und thus promote comprehension.

Empirical evidence for this account comes from neuropsychological, as well as behavioural studies. For instance, in neuropsychological studies it has been found that the comprehension of action sentences and single action verbs involves similar sensorimotor brain circuits that are also activated during the interaction with the referred objects, situations, and events. More specifically, the respective studies found that the areas of the motor and pre-motor cortex associated with different effectors (i.e., mouth/*chew*, leg/*kick*, hand/*grab*) are automatically activated when people hear language referring to these body parts. This pattern was similar to the activation resulting from the actual execution of the respective actions (Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, Hummel, & Härle, 2001; Tettamanti et al., 2005), and thus supports the view that sensory-motor processes are automatically activated even during a passive reading or a passive listening task. Although some concerns about the precise location and functional overlap of motor and language functions exist (e.g., Klepp et al., 2014; Postle, McMahon, Ashton, Meredith, & Zubicaray, 2008), the above mentioned findings provide evidence for an early, and likely automatic, involvement of the motor system in the processing of action-related language (Vigliocco, Vinson, Druks, Barbar, & Cappa, 2011).

Behavioural studies on embodiment typically focus on interactions between language and motor processing. Such interactions are typically taken as strong evidence for an embodied view of language comprehension. One example is the so-called action-sentence-compatibility effect (ACE) first observed by Glenberg and Kaschak in 2002. In their study, participants read sentences and judged their sensibility by moving their arm away or towards their body. Responses were faster if the movement direction implied by the sentence matched the response movement (e.g., *You opened the drawer* and a movement towards the body) compared to when there was a mismatch (e.g., *You closed the drawer* and a movement towards the body). These results are well in line with the assumption that participants reactivated the implied movements when processing the sentences which in turn primed the response movements in the matching conditions (Glenberg & Kaschak, 2002). Such compatibility effects between language and motor processing were shown in different studies by using different kinds of paradigms and materials. Zwaan and Taylor (2006), for instance, found a compatibility effect for clockwise vs. counter-clockwise rotations. Scorolli and Borghi (2007) found compatibility effects for movements with the arm vs. the foot. Shebani and Pulvermüller (2013) found that memory for arm- vs. leg-related words is impaired when participants move the respective body parts.

An unsolved question remains whether compatibility effects of this type are ascribable to sentence comprehension or single word comprehension. The original ACE (Glenberg & Kaschak, 2002) was based on sentences, and the same holds true for the studies extending the ACE (e.g., de Vega, Moreno, & Castillo, 2013; de Vega & Urrutia, 2011). However, in one of the experiments by Zwaan and Taylor (2006), sentences were presented word by word (e.g., *To quench/his/thirst/the/marathon/runner/eagerly/opened/the/water bottle*) showing a compatibility effect specifically on the verb of the sentence (i.e., *opened*). This suggests that the compatibility effect is not due to a sentence wrap-up, but rather depends on the word, which defines the action, namely the verb of the sentence.

To further address this issue, Ahlberg, Dudschig, and Kaup (2013) investigated effector-specific compatibility effects during single word processing. In this study, we presented different kinds of effector-related words in a modified Stroop paradigm (Stroop, 1935) that was already employed in other embodiment studies (e.g., Dudschig, Lachmair, de la Vega, De Filippis, & Kaup, 2012; Lachmair, Dudschig, De Filippis, de la Vega, & Kaup, 2011). In particular, we presented four different groups of German words, namely action verbs (e.g., *grasp* vs. *kick*), nouns directly related to the effectors and containing the lexemes *hand* or *foot* (e.g., *handbag* vs. *football*), and nouns referring to objects that are typically manipulated by the effectors (e.g., *cup* vs. *stirrup*), as well as a control group of up/down nouns referring to entities typically located in the upper or lower vertical space (e.g., *roof* vs. *root*). The task of the participants was to respond to the font colour of the words with either a hand button or foot pedal press, resulting in compatible (e.g., hand response on *grasp*/*handbag*/*cup*) and incompatible trials (e.g., hand response on *kick*/*football*/*stirrup*). For hand-related words and up-words, compatible conditions consisted of trials in which the correct response involved a key press with the hand. For foot-related words, compatible conditions consisted of trials in which the correct response involved the foot pedal on the ground. The results showed compatibility effects with shorter response times in compatible trials (e.g., hand response for *cup*; foot response for *stirrup*) than in incompatible trials (e.g., foot response for *cup*; hand response for *stirrup*) for all noun groups but not for the action verbs. This was surprising with the results of Zwaan and Taylor (2006) in mind, and also as neuropsychological studies (Hauk et al., 2004; Pulvermüller et al., 2001) focused on exactly these verbs to support an embodiment view of language processing.

In the current study, we aim at investigating why no compatibility effect was observed in our previous study for action verbs. We focus on four different possibilities. First, timing differences may be responsible for the null effect. Specifically, verbs cover a broader meaning than nouns (Gentner, 1981) and thus possibly require more processing effort in comparison to nouns. Maybe the processing of the nouns conflicted with response selection (hand vs. foot) because the meaning of the noun was available before the response could be selected. In contrast, because verbs require more processing effort, response selection may have taken place before the meaning of the verb was becoming available, thus explaining why the meaning of the verb does not affect response selection. To address this possibility, we conducted a more complex task in the current study (Experiment 1). Instead of using two effectors (right hand and right foot), we now used four effectors (right/left hand and right/left foot). This modification should give participants more time to process the words before selecting the response. Thus, verbs in this case may have been processed to such an extent that verb meaning and response selection come into conflict with one another. If this is the case, then we expect to find a compatibility effect also for the action verbs in this experiment.

Second, depth of processing may be responsible for the observed null effect for the action verbs. Possibly action verbs activate effector-specific information only in tasks that require lexical access and thus deeper processing than is required in a Stroop-like task focusing only on font colour. The results of a study by Mirabella, Iaconelli, Spadacenta, Federico, and Gallese (2012) are in line with this hypothesis. Their participants had to respond with a reaching movement of the left or right arm to action verbs and to refrain from moving, when abstract verbs were being shown. The authors found an interference effect with longer response times for hand- vs. foot-verbs. Interestingly, this interference effect disappeared when instead of the semantic task a Stroop-like task was administered. To investigate this possibility, we administered a lexical-decision task in the current study (Experiment 2). If a task requiring lexical access is needed to find compatibility effects for action verbs, we should find a compatibility effect for action verbs in this experiment.

A third reason for why we did not previously find a compatibility effect for action verbs may have to do with the fact that we presented more nouns than verbs in those experiments. Maybe this has led participants to focus on the nouns and to neglect verb processing. In the third experiment of the current study, we therefore only presented action verbs and manipulated the experimental task (Stroop-like vs. lexical-decision task) within participants. If the biased distribution of nouns and verbs in the experimental setup was responsible for the null-effect, then we should find a compatibility effect in both tasks in this experiment, in which only verbs were being presented. If the depth of processing explanation is correct, we should find a compatibility effect only in the lexical decision but not in the Stroop-like task.

Finally, a fourth possibility would be that action verbs are associated with very specific motor plans. Maybe the movement that an action verb refers to is so specific that it does not conflict with or facilitate a simple button or foot pedal press. If so, then we should not find compatibility effects in any of the three experiments in the current study, because response movements never directly match the specific actions that are associated with the respective action verbs.

Experiment 1: Stroop-Like Task with Four Effectors

In the first experiment, participants were presented with effector-related nouns and verbs written in one of four different colours as in the study by Ahlberg et al. (2013). Each colour was mapped to one of four effectors in a Stroop-like task: Correctly responding to the words required a hand or a foot button press on the left or right side, depending on the font colour of the stimuli. If reading an effector-related word activates the respective effector and thus primes responses with this effector or hinders responses with a different effector, then a compatibility effect should be observed in this experiment. More specifically, in case action verbs need more time than nouns to be processed before the respective effector is being activated, and if this is the reason why there was no compatibility effect in the previous study for action verbs, then there should now be a good chance to find such a compatibility effect in the current setup. The reason is that response selection in this task with four effectors is more complex and thus leaves more time for word processing prior to response selection.

Method

Participants. Forty-eight German native speakers, aged 18 to 26 years (7 male; M_{age} = 20.5 years, SD_{age} = 1.7 years) participated for course credit or financial reimbursement after signing a form of consent. The participants had normal or corrected-to-normal vision. We assessed handedness using a translated version of the Edinburgh inventory (Oldfield, 1971).

Forty-seven participants were classified as right-handed (*M* = 81.6; score range: +46.6 to +100), one participant was classified as left-handed (-62.5).

Materials and apparatus. We used the same stimuli as Ahlberg et al. (2013), namely 192 German nouns and verbs, subdivided into four different categories. The first group consisted of 64 hand- or foot-related action verbs (e.g., *grasp* vs. *kick*) originally taken from Pulvermüller et al. (2001). The second group (explicit nouns) consisted of 32 hand or foot related nouns including the lexemes *hand* or *foot* (e.g., *handbag* vs. *football*). The third group (associated nouns) consisted of 32 hand- or foot-related nouns without the lexemes *hand* or *foot* that referred to objects that are typically manipulated with the hand or the foot (e.g., *cup* vs. *stirrup*). The fourth group consisted of a shortened set, namely 64, of up/down words (e.g., *root* vs. *roof*) from the study of Lachmair et al. (2011). This group was included in the original study by Ahlberg et al. (2013) as a control group[1], and – for the sake of comparability – was included in this study as well. However, as the two sets of words in this group do not systematically differ with respect to effector-specificity, we will not include these words in our analyses but rather treat them as filler items.

Stimuli were presented in the colours blue (rgb 0, 0, 255), orange (rgb 255, 128, 0) brown (rgb 140, 80, 20), and lilac (rgb 150, 0, 255) on a white background in centre position on a CRT-screen in Type Size 12 in Courier New bold. Each colour occurred equally often and the colour assignment to the effectors was counterbalanced across participants, resulting in 24 different experimental versions.

[1] Based on the literature, one would expect that up-words are responded to faster with the hand (up-response) than with the foot (down-response) and vice versa for down-words. This was indeed what was found in the study by Ahlberg et al. (2013), and thus allowed to demonstrate the functionality of the experimental setup.

In contrast to the study of Ahlberg et al. (2013), in which the participants stood in front of the computer with a height-adjustable table, in this experiment the participants sat in front of the computer. As can be seen in Figure 1, responses were recorded via four buttons (two for the feet and two for the hands) on two keyboards with a constructed overlay. One of these was placed on the table and the other one was placed on the ground. This setup would not have been possible in a standing position, because it would not have been possible to use both feet for responding. The experiment was programmed with E-Prime® (Psychology Software Tools Inc., http://www.pstnet.com/E-Prime/e-prime.htm).

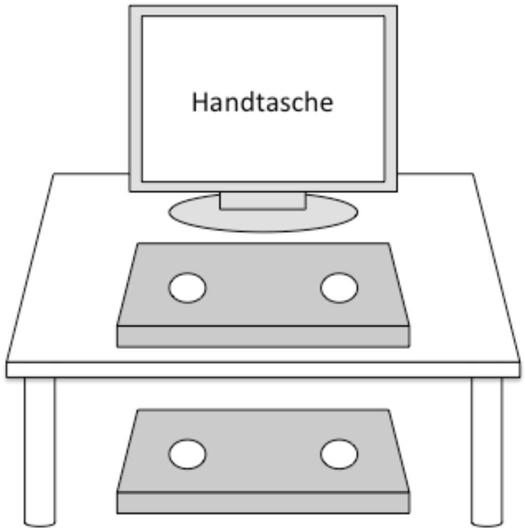

Figure 1. Experimental setup. Two keyboards with a constructed overlay served as response devices. Participants pressed the two buttons on the table with their left and right hand, respectively. The two buttons on the ground recorded responses with their feet. Participants took of their shoes and wore foot covers during the experiment.

Procedure and design. Each trial started with a fixation cross, displayed in the centre position of the screen for 800 ms. Afterwards the stimulus was presented until the participant responded. Between trials a white screen was shown for 1000 ms.

Every word was presented four times, resulting in a total amount of 768 trials, subdivided into 4 experimental blocks. The experiment started with a practice block, in which 16 stimuli were presented two times each in different colours. These stimuli were not presented in the experimental blocks. In contrast to the experimental blocks, the participants received accuracy feedback during the practice block.

Participants were instructed to respond to the font colour as quickly and accurately as possible. For each participant, each of the four colours was mapped to one effector. The mapping of colours to response directions was balanced across participants: All possible mappings occurred equally often.

The design was a 3 (word group) x 2 (response compatibility) within-subjects design. The dependent variable was the latency of the button press.

Results and Discussion

One participant was excluded from the data analysis due to an error rate above 15%. Mean error rate after exclusion was 4.9%. We excluded error and practice trials. In addition, responses deviating by more than 3 *SD*s from the mean for each participant and condition (word group x response compatibility) were excluded, which reduced the data by 1.8%. Mean response times of the remaining trials are displayed in Figure 2.

The analyses revealed a significant main effect for compatibility, $F(1, 46) = 10.23$, $p = .003$, $\eta_p^2 = .182$, and a response compatibility-by-word group interaction, $F(2, 92) = 5.25$, $p = .007$, $\eta_p^2 = .102$. There was no main effect of word group, $F(2, 92) = 0.02$, $p = .982$, $\eta_p^2 < .001$.

Separate analyses for the three word groups revealed significant effects for the two effector-related noun groups (explicit nouns: $F(1, 46) = 8.45$, $p = .006$, $\eta_p^2 = .155$; associated nouns: $F(1, 46) = 9.23$, $p = .004$, $\eta_p^2 = .167$) but no significant compatibility effect for the action verbs $F(1, 46) = 0.06$, $p = .809$, $\eta_p^2 = .001$.

This experiment was a replication of the study of Ahlberg et al. (2013), with the main difference being that four instead of two effectors were involved in the experimental task. We replicated the main results of that study, namely finding compatibility effects for the two effector-related noun groups (explicit nouns and associated nouns). Most importantly, the action verbs in the current experiment again did not show a compatibility effect, although the mean response times were 240 ms longer than in the prior study, indicating that we indeed accomplished our goal of making the task more complex. Thus, simply making the response selection more complex to give the language processing system more time to process the verbs before response selection did not lead to a compatibility effect for action verbs. Possibly, action verbs are not processed deeply enough to activate the corresponding effector if the task does not require lexical access. This possibility will be investigated in Experiment 2.

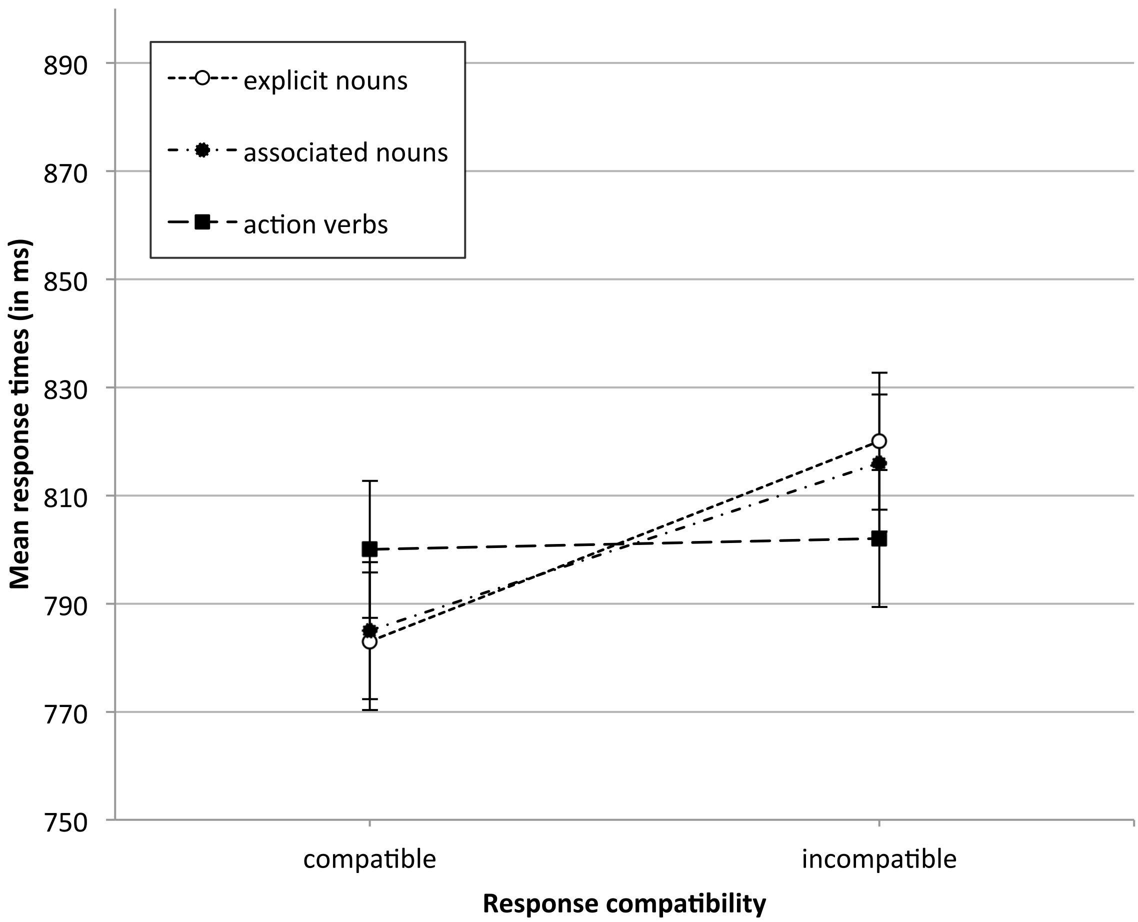

Figure 2. Mean response times of correct responses as a function of response compatibility and word group. Error bars represent 95% confidence intervals (as per Masson & Loftus, 2003).

Experiment 2: Lexical-Decision with Two Effectors

In Experiment 2, we wanted to find out whether a compatibility effect would be observed for action verbs if the experimental task required lexical access. Maybe action verb meaning is too complex to be assessed automatically. In the present experiment, we presented participants only with two word groups, namely the explicit nouns and the action verbs. If our hypothesis is correct, and the meaning of action verbs is only processed deeply enough for compatibility effects to occur if the task requires lexical access, then we should now find compatibility effects for both word groups, the explicit nouns as well as the action verbs. In order to keep the conditions as similar as possible to the original experiment by Ahlberg et al. (2013), participants were now responding in a standing position.

Method

Participants. Twenty-four native speakers of German, aged 18 to 44 years (2 male; M_{age} = 23.3 years, SD_{age} = 5.9 years) participated for course credit or financial reimbursement after signing a form of consent. All participants had normal or corrected-to-normal vision. We also assessed handedness using a translated version of the Edinburgh inventory (Oldfield, 1971). All participants were classified as right-handed (M = 88.5; score range: +62.5 to +100).

Materials and apparatus. Materials were made up of the explicit nouns (32) and the action verbs (64) from Experiment 1 as well as 96 pseudo words (e.g., *zalmen*, *Hestgeleur*). The pseudo words were generated with the help of the pseudo word generator *Wuggy* on the basis of our stimuli (Keuleers & Brysbaert, 2010). Stimuli were presented in centre position on a CRT-screen in Courier New type size 12 bold.

Responses were recorded via a PST Serial Response Box, Model Number 200A with a foot pedal. The Experiment was programmed with E-Prime® (Psychology Software Tools Inc., www.pstnet.com/E-Prime/e-prime.htm). The participants stood in front of a height-adjustable table, CRT-screen as well as response box situated on it, with the possibility of leaning against the wall with their back. Prior to the experiment, the height of the screen was adjusted such that stimulus words were presented at eye-level of the participants. The foot pedal was adjusted and fixed in a proper distance to the participant. Every participant reacted with his or her dominant side of the body.

Procedure and design. Each trial started with a fixation cross, displayed in centre position of the screen, lasting 800 ms. Then the stimulus was presented until response. Between trials a white screen was shown for 1000 ms.

Participants were asked to perform a lexical-decision task. For half of the participants the response mapping was hand button press in case of “yes” and foot pedal press in case of “no” for the first and the third block of the experiment and the reversed response pattern for the second and fourth block of the experiment. The remaining participants received the reversed order instructions. We measured the response times in this lexical-decision task.

Every word was presented four times, resulting in a total amount of 768 trials, which were subdivided into 4 experimental blocks. At the beginning of each block the instruction changed and therefore each block started with a practice block, in which 22 words (11 words as well as 11 pseudo words) were presented. These stimuli were different from the experimental stimuli. In contrast to the experimental blocks, the participants received feedback about response accuracy during the practice blocks.

The design was a 2 (word group) x 2 (response compatibility) within-subjects design. The dependent variable was the latency of the button or foot pedal press, respectively.

Results and Discussion

The results were analysed as in Experiment 1. Practice trials, error trials, and pseudo word trials were excluded from further analyses. Mean error rate was 4.8%. Responses deviating by more than 3 SDs from the mean for each participant and condition (word group x response compatibility) were excluded. This reduced the data by 1.8%. Mean response times are displayed in Figure 3.

The analyses revealed a significant main effect for word group, $F(1, 23) = 56.67$, $p < .001$, $\eta_p^2 = .711$, and response compatibility, $F(1, 23) = 14.31$, $p < .001$, $\eta_p^2 = .384$. There was no significant interaction effect, $F(1, 23) = 0.23$, $p = .635$, $\eta_p^2 = .010$. The separate analyses for the two word groups revealed significant compatibility effects for both groups (explicit nouns: $F(1, 23) = 16.57$, $p < .001$, $\eta_p^2 = .419$; action verbs: $F(1, 23) = 6.34$, $p = .019$, $\eta_p^2 = .216$).

In this experiment, we now indeed for the first time in our lab found a compatibility effect for action verbs. In our view, the reason most likely has to do with the experimental task administered in this experiment. Whereas in previous experiments our experimental tasks varied in complexity but always focused on superficial properties of the linguistic stimuli (namely font colour), the task in the present experiment required lexical access and thus deeper processing of the presented words. Thus, the results of the present experiment are nicely in line with the hypothesis that effector-related action verbs do not automatically activate the respective effector but only do so when participants are forced to access their mental lexicon. However, before jumping to this conclusion, some alternative explanations need to be ruled out that take into account differences between this experiment and Experiment 1. First, in this experiment, participants saw more verbs than nouns which might have biased participants towards a deeper processing of verbs. Second, in this experiment, participants were standing in front of the computer screen whereas in Experiment 1 they were sitting. Although we do not consider it likely that standing or sitting makes a difference for effector-related compatibility effects, we nevertheless consider it helpful to see whether action verbs also lead to a compatibility effect with participants in a sitting position. In Experiment 3, we therefore presented sitting participants only with action verbs and manipulated task

(Stroop-like vs. lexical-decision task) within participants. This allows us to directly investigate the hypothesis that the relevant factor for obtaining an effector-related compatibility effect for action verbs is indeed the experimental task.

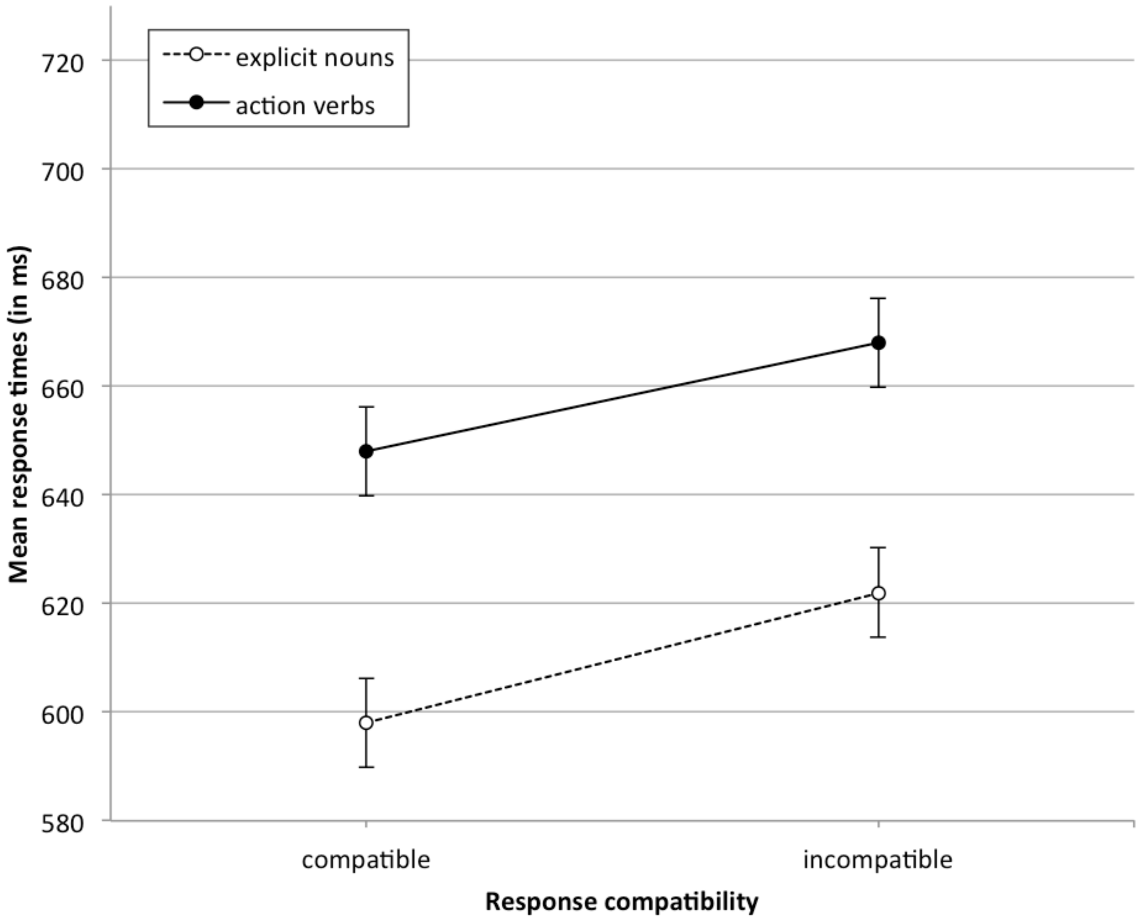

Figure 3. Mean response times of correct responses as a function of response compatibility and word group. Error bars represent 95% confidence intervals (as per Masson & Loftus, 2003).

Experiment 3: Task Manipulated Within Participants

In this experiment, we presented only the action verbs and manipulated the experimental task in a within-subject design. Each participant performed both tasks, half of the participants started with the Stroop-like task and the other half started with the lexical-decision task.

Method

Participants. Forty-eight native speakers of German, aged 18 to 33 years (11 male; M_{age} = 22.9 years, SD_{age} = 3.5 years) participated for course credit or financial reimbursement after signing a form of consent. All participants had normal or corrected-to-normal vision. The handedness of the participants was assessed using a translated version of the Edinburgh inventory (Oldfield, 1971). All participants were classified as right-handed (*M* = 80.7; score range: +50 to +100).

Materials and apparatus. In this experiment, we combined the Stroop-like task and the lexical-decision task in one experiment. We presented only the action verbs of Pulvermüller et al. (2001), the same as in the first two experiments.

In the Stroop-like task, stimuli were presented in the colours blue (rgb 0, 0, 255), orange (rgb 255, 128, 0), brown (rgb 140, 80, 20), and lilac (rgb 150, 0, 255) on a white background, in centre position in type size 12 in Courier New bold. In the lexical-decision task, stimuli were presented in black on white background, centre position in Courier New type size 12 bold.

We used the same setup for both tasks. Stimuli were presented on a CRT-screen and the participants sat in front of the computer. Responses were recorded via a PST Serial Response Box, Model Number 200A with foot pedal. The experiment was programmed with E-Prime® (Psychology Software Tools Inc., www.pstnet.com/E-Prime/e-prime.htm).

Procedure and design. The two tasks were completed after one another. The order was balanced across participants, half of them started with the Stroop-like task and the other half started with the lexical-decision task.

In the Stroop-like task, the general procedure was the same as in Experiment 1. Every word was presented four times, resulting in a total amount of 256 trials, which were subdivided into 4 experimental blocks. The experiment started with a separate practice block, in which 10 stimuli were presented two times each in different colours.

In the lexical-decision task, the general procedure was the same as in Experiment 2. Here the words were presented twice, distributed over two blocks, resulting in 256 trials in total. The practice block consisted of 10 words and 10 pseudo words and was presented right before the start of each block. For half of the participants the response mapping was hand button press in case of “yes” and foot pedal press in case of “no” for the first block of the experiment and the reversed response pattern for the second block of the experiment. The remaining participants received the reversed order instructions.

The design was a 2 (task) x 2 (response compatibility) within-subjects design. The dependent variable was the latency of the button press.

Results and Discussion

Results were analysed as in the two experiments before. We excluded all error trials and pseudo word trials. Mean error rate was 4.5%. Responses deviating by more than 3 SDs from the mean for each participant and condition (task x response compatibility) were excluded from further analyses. This reduced the data by than 1.7%. Mean response times are displayed in Figure 4.

The analyses revealed significant main effects of task, $F(1, 47) = 60.90$, $p < .001$, $\eta_p^2 = .564$, and response compatibility, $F(1, 47) = 10.14$, $p = .003$, $\eta_p^2 = .177$, as well as a task-by-response compatibility interaction, $F(1, 47) = 5.44$, $p = .024$, $\eta_p^2 = .104$.

The separate analyses for the two tasks revealed a significant compatibility effect for the lexical-decision task, $F(1, 47) = 9.67$, $p = .003$, $\eta_p^2 = .171$, while there was no compatibility effect in the Stroop-like task, $F(1, 47) = 1.26$, $p = .268$, $\eta_p^2 = .026$.

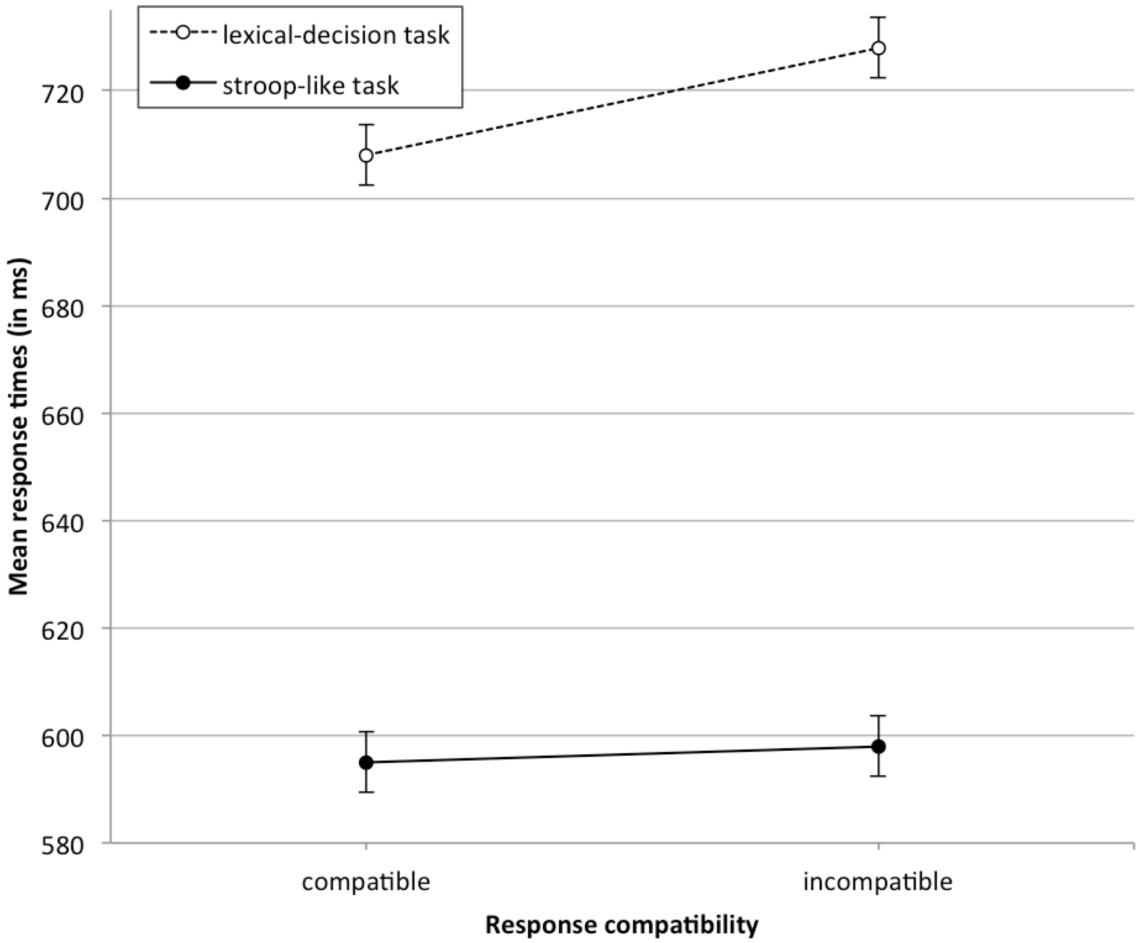

Figure 4. Mean response times of correct responses as a function of response compatibility and conducted task. Error bars represent 95% confidence intervals (as per Masson & Loftus, 2003).

These results clearly support the hypothesis that the experimental task is the critical factor for finding an effector-related compatibility effect. In addition, this experiment rules out the idea that effector-related compatibility effects for action verbs are only found in standing position, and also that these effects depend on a material set in which verbs are overrepresented. If the former had been true, we should not have found a compatibility effect in either of the tasks. If the latter had been true, we should have found a compatibility effect in both tasks. The observed interaction of compatibility and task clearly speaks against these possibilities.

Taken together, our results from the three experiments suggest that nouns and verbs are processed differently: Whereas nouns show effector-specific compatibility effects independent of the task, verbs only show these effects in a task that requires participants to pay attention to lexical factors. The question arises, how these differences come about. In principle it seems possible that the observed differences indeed reflect inherent differences between the processing of verbs and nouns. However, in principle it is of course also possible that the observed differences do not reflect differences between nouns and verbs per se, but rather differences that are specific to the particular sets of words used in our study. We therefore analysed the words used in our study with respect to several factors that might explain the observed differences. We will present these analyses in the next paragraph.

Properties of our Stimulus Sets

An overview of the properties of the different word groups used in our study can be found in Table 1. We included information on word length, word frequency, mean bigram frequency, number of orthographical neighbours, imageability ratings, as well as co-occurrence values with the words *hand* and *foot*. Word class frequencies were retrieved from the “Wortschatz Portal” of the University of Leipzig (http://wortschatz.uni-leipzig.de). Mean bigram frequencies and the number of orthographical neighbours were determined according to Coltheart (Coltheart, Davelaar, Joasson, & Besner, 1977) based on data retrieved from the “dlexDB” corpus (http://dlexdb.de; Heister et al., 2011). Imageability ratings were obtained from Köper and Schulte im Walde (2016). In addition, we determined co-occurence values between each of our stimuli and the words *hand* and *foot*, respectively, based on Latent Semantic Analysis (LSA) (Günther, Dudschig, & Kaup 2015). The connected semantic space *sdewac_hafu* can be found at: http://www.lingexp.uni-tuebingen.de/z2/LSAspaces/.

As can be seen in Table 1, nouns and verbs do indeed differ with respect to a number of variables. Nouns are longer compared to verbs ($t(126) = 4.09$, $p < .001$) and show a higher imageability rating ($t(126) = 2.56$, $p = .012$). Verbs on the other hand are higher in frequency ($t(126) = 4.34$, $p < .001$), higher in bigram frequency ($t(126) = -9.21$, $p < .001$), and they do have more orthographical neighbours than nouns ($t(126) = -4.16$, $p < .001$). No difference between nouns and verbs was observed regarding their co-occurrence with the words *hand* and *foot*, respectively ($t(125) = -0.87$, $p = .385$). We will come back to these differences in the General Discussion.

Table 1

Comparison of the properties of the different word groups.

Properties	Action verbs	Explicit nouns	Associated nouns
Length	6.89 (1.20)	8.22 (1.79)	8.03 (2.39)
Word frequency	12.95 (2.85)	14.97 (2.97)	15.31 (2.79)
Mean bigram frequencies	301,075.95 (94,736.96)	142,136.26 (74,860.13)	181,552.45 (71,075.42)
Orthographical neighbours	12.25 (9.47)	4.09 (10.67)	6.16 (9.15)
Imageability	5.74 (1.00)	5.88 (0.85)	6.45 (0.81)
Co-occurrence with *hand/foot* (LSA)	0.50 (0.12)	0.46 (0.23)	0.48 (0.16)

Note. The table contains means with the respective standard deviation in parentheses below.

General discussion

In the embodied cognition literature, action-related compatibility effects are usually interpreted as positive evidence for the embodied cognition account. Such compatibility effects were reported for sentences as well as for individual words. Thus, the typical assumption is that processing words or sentences referring to particular actions leads to an activation of experiential traces stemming from performing the respective actions in the past, which then explains why performing a particular action after reading linguistic material describing a matching or mismatching action is facilitated or hindered, respectively. With respect to verbs describing actions that are performed with a particular effector, the results however are mixed. While neuropsychological studies found strong evidence for the embodiment account by investigating action verbs, the evidence from the behavioural research side remains rather puzzling. Ahlberg et al. (2013), for instance, found effector-specific compatibility effects for effector-related nouns but not for effector-related action verbs. More specifically, participants in this experiment responded to the font colour of an effector-related word (e.g., *cup*, *kicking*) by pressing a button with their hand or their foot. Responses in compatible trials (e.g., hand response after reading a hand-related word) were faster than responses in incompatible trials (e.g., foot response after reading a hand-related word) but only for nouns (e.g., *cup*) not for verbs (e.g., *grasp*).

The present study investigated effector specific compatibility effects for different types of effector-related nouns and verbs. In particular, we aimed at finding out, why the study by Ahlberg et al. (2013) did not show effector-specific compatibility effects for verbs but only for nouns. In the first experiment, we investigated the hypothesis that verbs need more processing time than nouns before effector-specific information becomes available and thus only show effector-specific compatibility effects if enough time elapses between word presentation and response selection. To investigate this hypothesis, we employed a more difficult Stroop-like task than in the original study, namely one involving four instead of two effectors (right/left hand and right/left foot). As expected the mean response time in this study increased. However, we still only observed effector-specific compatibility effects for nouns, not for verbs, which speaks against the idea that timing differences are responsible for the different results obtained for nouns and verbs.

In the second experiment, we investigated the hypothesis that action verbs activate effector-specific information only in tasks that require lexical access and thus deeper processing. To investigate this hypothesis, we presented participants with effector-related nouns and verbs but this time in a lexical-decision task. In line with our hypothesis and in line with the results of a study investigating hand responses only by Mirabella et al. (2012), we now did find effector-specific compatibility effects for nouns as well as for verbs. To obtain further information with regard to the assumption that task is the relevant factor, we directly compared a Stroop-like task with a lexical-decision task in our third experiment, in which we presented participants only with effector-related action verbs. In line with the predictions, we found an interaction between compatibility and task. Action verbs only showed effector-related compatibility effects when processed in a lexical-decision task not when processed in a Stroop-like task, not requiring participants to access their mental lexicon. Together the results of the three reported experiments thus suggest that there is a difference between noun and verb processing in the sense that nouns but not verbs automatically activate effector-specific information. For verbs, participants need to be forced to access their mental lexicon before any evidence can be found that they indeed activated effector-related information.

Of course the question arises why the effects for verbs are task dependent whereas those for nouns are not. There are many differences between nouns and verbs that could be made responsible for the observed differences. For instance, nouns are mostly learned before verbs (Gentner, 1982) and might, therefore, have more experiences connected to them than verbs. Also, different brain regions are involved in the processing of nouns and verbs (Damasio & Tranel, 1993; Gleichgerrcht et al., 2016; Preissl, Pulvermüller, Lutzenberger, & Birbaumer, 1995). Finally, verbs cover broader meaning than nouns (Gentner, 1981) and effector-specific information might therefore get lost in the shuffle of features that are relevant to the meaning of an effector-related action verb, at least in a task that does not even require reading the word like the Stroop-like task employed in the present experiment.

Additional explanations are suggested when considering the differences between nouns and verbs presented in Table 1. We consider it unlikely that the higher frequency class of the verbs, their higher mean bigram frequency, or the shorter length is responsible for the observed differences. If at all, this should have facilitated deeper processing of the verbs compared to the nouns and thus have increased the possibility that word meaning influences responding even in a task where accessing the meaning of the word is task-irrelevant (as in our Stroop-like task). In contrast, differences with respect to the number of neighbours or imageability could well have contributed to the observed differences between nouns and verbs in our study. As mentioned above, our verbs were characterized by a higher number of orthographic neighbours compared to our nouns. Possibly, these neighbours interfered with processing of the action verbs and thus delayed lexical access (Boot & Pecher, 2008; Perea & Roser, 2000). In the Stroop-like task this then may have reduced the possibility of finding an influence of the meaning of the words because response selection may have preceded lexical access. This explanation is in line with the observation in Experiment 2 that response times were longer in the lexical decision task for verbs compared to nouns. However, this explanation seems to stand in conflict with the results of Experiment 1. Making the task more complex (and thereby giving participants more time to process the words before responding) did not lead to a significant compatibility effect for the action verbs, and explanations based on simple timing issues are therefore unlikely. Consequently, we are left with the difference between nouns and verbs regarding imageability. Possibly, the higher imageability ratings for the nouns reflect the activation of more intense experiential traces during noun compared to verb processing. This may then have supported effector-specific compatibility effects in nouns compared to verbs in our study. In principle it even seems possible that this is not a property of our specific sample but rather a general difference between nouns and verbs. In fact, the difference in imageability is well in line with the above mentioned hypothesis that verbs generally cover broader meaning than nouns (Gentner, 1981). To clarify this issue, future studies would be needed in which sets of effector-specific nouns and verbs are being compared that are matched regarding imageability.

Conclusion

In this study, we found clear evidence for effector-specific compatibility effects for single word reading both with nouns referring to objects that are typically manipulated with either the hand or the foot, as well as for verbs referring to an action that typically involves either the hand or the foot. As such, the current study provides evidence for the embodied cognition account, assuming that readers activate experiential traces when reading words or sentences that stem from prior interactions with the referents of the linguistic expressions. Our results, however, also show differences between effector-related nouns and effector-related action verbs. Whereas for nouns, effector-specific compatibility effects were automatic and task independent, the same effects for action verbs were task dependent and only showed when the task required accessing the mental lexicon. Future studies are needed to investigate the exact mechanisms that are responsible for these processing differences between nouns and verbs.

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