Effector specific response activation during word processing

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Abstract

Theories of embodied cognition suggest that sensorimotor processes are involved in language comprehension processes. Recent studies suggested that sentences referring to actions that involve a typical effector (e.g. "*He kicks the ball*") can systematically activate motor cortex areas that are involved in performing such actions (Hauk, Johnsrude & Pulvermüller, 2004). In behavioral studies, there is mixed evidence regarding the effects of effector-specific words on corresponding actions. In the current study, we investigated the effect of four word groups on subsequent motor responses involving the hand or the foot. The four word groups were (a) action verbs (e.g., *kick*, *grasp*) (b) nouns containing the lexeme 'hand' or 'foot' (e.g., *handball*, *football*) (c) nouns referring to objects that are typically manipulated by hand or foot (e.g., *cup*, *shoe*), and (d) as control items, nouns that have a spatial association with the upper or lower space (e.g., *eagle*, *root*) and which are known to activate locational information in paradigms where no reading is required. We found strong effector-specific compatibility effects revealing a facilitation effect in all noun-groups. Surprisingly, this effect was not present for the action-verbs. Implications of these findings will be discussed.

Keywords: Embodied Cognition; Language Comprehension; Effectors

Introduction

Many of our daily activities involve language. We speak, we listen to people speaking, we read or we write at various occasions every day. However, in research on language processing there is still no agreement on theoretical assumptions concerning the processes and representations that are involved in language processing. For a long time, the propositional, amodal theory of language comprehension was the predominant view (Kintsch & van Dijk, 1978; Kintsch 1988; McKoon & Ratcliff, 1992). According to this view, the result of language comprehension is a meaning representation in an amodal propositional format that captures the content of the linguistic input and integrates it with the reader's background knowledge which is also available in this format. Typically, embodied models of language understanding are viewed as the counterpart to these amodal theories of language processing (Barsalou, 1999). The main assumption of this approach is that language processing is closely connected to other cognitive systems, such as perception and action. There is a tremendous number of empirical studies providing evidence for the embodied view of language comprehension (for an overview, see Jirak, Menz, Buccino, Borghi & Binkofski, 2010). However, in many cases the individual results are somewhat inconsistent, and cannot be integrated into a coherent processing model. As a result, important theoretical questions concerning the embodied view are still unsolved, as for instance the question whether all kinds of sensorimotor activations are functionally relevant for comprehension or in contrast sometimes constitute a kind of epi-phenomenon. Before turning to these important issues, research first needs to investigate in more detail the individual phenomena, with the goal of arriving at more definite conclusions concerning the boundary conditions for the observed effects. In the present study, we aim to address the question, whether motor activation occurs in a specific manner when processing action related verbs (e.g., *kick*, *grasp*), or nouns referring to objects that are typically manipulated with the hand or the foot (e.g., *brush*, *shoe*).

Evidence for an embodied view of language understanding has been reported in behavioral and neuroimaging paradigms. In the behavioral domain, observed interactions between language and visual-processing, and between language and motor processing are typically taken as strong evidence for an embodied model of language comprehension. For example, Zwaan, Stanfield and Yaxley (2002) reported that sentence processing can activate very specific visual representations. In their study, participants had to process sentences such as "The girl saw the egg in the frying pan" and subsequently respond to pictures of the target entity (egg). The pictures could either match the shape of the entity described in the sentences (e.g., a fried egg sunny side up) or mismatch the shape (e.g., an unbroken egg). Responses were faster in the matching than in the mismatching conditions, suggesting that readers had available a visual representation of an egg in the frying pan when reading the corresponding sentence.

Evidence for the reactivation of *motor* representations during language comprehension was reported by Glenberg and Kaschak (2002) in the so-called action sentence compatibility effect. In their study, participants had to read sentences and judge the 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 toward the participants) compared to when there was a mismatch (e.g., “You closed the drawer” and a movement away from the participants). These results suggest that participants reactivated the described movements when processing the sentences and thus primed the response movements in the matching conditions.

Interestingly, if language understanding indeed relies on motor activation and the reactivation of experiential traces, these language-action compatibility effects should occur in a very specific manner. In other words, reading sentences such as “He throws the ball” versus “He kicks the ball” should result in rather distinct activation in the motor cortex. That is, when processing sentences such as “He throws the ball” hand related motor areas should be active, whereas when processing sentences such as “He kicks the ball” foot related motor areas should be involved. Indeed, Hauk, Johnsrude and Pulvermüller (2004) reported in an fMRI study such effector-specific motor activation during language understanding (for an EEG study, see Pulvermüller, Härle & Hummel, 2001). They compared the brain areas activated while performing finger, feet and tongue movements with the activation in a passive reading task of face-, foot- and arm-related sentences. This study revealed clear activation in the motor cortex and in the primary motor cortex during language processing, with the activation being similar to the conditions where the participants actually performed the corresponding actions.

In addition to neuropsychological studies, some behavioral studies reported evidence for effector-specific motor activation during language processing. Marino, Gough, Gallese, Riggio and Buccino (2011) investigated the effects of words on hand movements. Their stimuli consisted of Italian nouns referring to concrete objects, which were both hand- or foot-related, and abstract entities. Participants had to decide whether a presented word referred to a concrete object (e.g., *pencil*) or whether the word referred to an abstract content (e.g., *jealousy*). Only in case of concrete objects, participants had to press the response key with their index finger. In case of abstract words, they had to withhold responses. Additionally, participants had to wait with their response until a go-signal was delivered, and this could occur early or late after word presentation. The results showed that participants (all right-handed) responded slower with their right-hand to hand-related words compared to foot-related words. In contrast, with their left hand, they were faster to hand-related words than to foot-related words. Those effects were only found in the early go-signal condition. Marino et al. (2011) explained those results with a left hemispheric specialization for language processing. In case of right hand responses, interference took place due to the left hemisphere being activated by both, language processing and motor response activation, whereby they compete for common resources. The authors argued that this kind of interference was not present for left hand responses because the motor activation took place in the right hemisphere and thus did not overlap with activation from language processing. The authors themselves state that this explanation cannot account for the facilitation effect of the left hand, because no difference between hand and foot-related words would be predicted.

Scorolli and Borghi (2007) also reported influences of sentence understanding on effector-specific behavioral responses for sentences that imply the usage of a specific effector (e.g. hand vs. mouth). Their participants had to judge the plausibility of sentences with nouns and verbs that refer to objects and actions associated with specific effectors, e.g., *to unwrap* vs. *to suck the sweet*. In the first block, hand and mouth sentences, and in the second block, hand and foot-sentences were tested. Half of the participants had to react by saying “yes” into a microphone and the other half had to press a foot-pedal. As predicted, they found match effects with mouth- and foot-responses for mouth- and foot-sentences, but not for hand sentences However, Scorolli and Borghi (2007) did not differentiate between word-based and sentence-based effects, thus leaving open whether the reported compatibility effects were triggered by single words or the processing of the whole sentence.

In summary, there is evidence supporting the hypothesis that language can activate effector-specific motor processes, but at the same time it seems difficult to come up with a consistent explanation regarding the underlying mechanisms causing facilitation or interference. We therefore consider it worthwhile to investigate this issue in a very basic behavioral paradigm with the focus being on the influence of single words on responding.

In the current study, we will investigate whether processing of single nouns and verbs with an association to the effectors hand and foot, will result in effector-specific compatibility effects if implemented in a task that does not require active reading. This task will be an alternated version of the original color-naming experiment conducted by Stroop (1935). In our experiment, all words will be presented in a color, and the color will determine the response effector, either hand or foot. According to the Stroop literature any meaningful word can potentially cause interference in a color-response task because word-processing is seen as more automatic and faster than responding to the word color (for a review, see MacLeod, 1991). Importantly, interference should only be found if automatic word processing interacts with the required response and can result in response conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001). For example, in case of action verbs (e.g., *kick*), this word might automatically activate effector-specific responses (e.g., foot responses) and thus facilitate compatible responses or interfere with incompatible responses (e.g. hand responses).

Indeed, there is a debate regarding the automaticity of effects reflecting interactions between language processing and motor responses. For example Bub and Masson (2008) only find an effect of words on subsequent reaching tasks if the words have to be actively processed by the participants.

In our study, we compare four different kinds of word categories: First, action-verbs, using the stimulus-set of Pulvermüller et al. (2001). Second, nouns directly related to one specific effector, involving the lexeme ‘hand’ or ‘foot’ (e.g., *handball* vs. *football*). Third, nouns referring to objects that are typically manipulated by hand or foot (e.g., *paint brush* vs. *stirrup*). Forth, nouns referring to objects with a typical location in the vertical space (e.g., *bird*, *root*). The fourth word category consists of a reduced set of up/down words used by Lachmair et al. (2011) and Dudschig et al. (2012, 2013). We will use those words as a control in our paradigm, because they can be expected to show strong compatibility effects with responses differing with respect to the vertical dimension (here: hand = up, foot = down) even in tasks that do not demand active reading. As described above, words will be presented in a color, and the color determines the response effector (hand vs. foot). We predict compatibility effects for all word categories, with possibly stronger effects for the verbs, as well as possibly for the nouns involving the lexemes ‘hand’ and ‘foot’.

Method

Participants were presented with words displayed in one of four colors in each trial. Their task was to respond to the font color. Depending on the color, they either pressed a key with their hand which was located at chest height or a pedal with their foot which was located at the ground.

Participants

A total of 30 students (9 males) of the University of Tübingen, aged from 19 to 34 years (*M* = 22.8 years, *SD* = 3.5) participated in this study. Twenty-three of the students were right-handed and 7 were left-handed. All participants had normal or corrected-to-normal vision; none of them had impaired color-vision. They were asked to fill in a form of consent before doing the experiment and received course credit for their participation.

Apparatus and stimuli

Stimuli were presented in center position on a CRT-Monitor in size 12 Courier New 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 with the possibility of leaning against a wall with their backs. Prior to the experiment, the height of the table and with it the monitor was adjusted such that stimulus words were presented at eye-level of the participants. The foot pedal was also adjusted and fixed in a proper distance to the participant. The response box was situated on the table. Every participant reacted with their dominant body side.

We used 192 German nouns and verbs as stimuli, which could be subdivided into four groups: (a) The verbs were adapted from Pulvermüller et al. (2001) (N=64) consisted of 32 hand- and 32 foot-related action-verbs (e.g., *grasping* vs. *kicking*). (b) The “explicit nouns” group (N=32) consisted of 16 nouns containing the lexeme ‘hand’ and 16 nouns containing the lexeme ‘foot’ (e.g.; *handbag*, *footprint*). (c) The “associated nouns” group consisted of 16 nouns referring to an object that was typically manipulated with the hand and 16 nouns referring to an object that is typically manipulated with the foot (e.g., *cup*, *stirrup*). (d) Finally, the “up/down nouns” group (N=64) consisted of a shortened set of up/down words from the study of Lachmair et al. (2011) with 32 words referring to an entity typically located in the upper part of the world and 32 referring to an entity typically located in the lower part of the world (e.g., *root*, *roof*). See Table 1 for mean frequencies and mean length (number of characters) of the two sets in each group. Frequencies were retrieved from the “Wortschatz Portal” of the University of Leipzig (http://wortschatz.uni-leipzig.de).
Words were presented in the colors 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.

Table 1: Mean length and mean frequency of the two sets of words in each word group.

Word group	Length	Frequency (SE)
verbs (hand)	6.88	1073 (266)
verbs (foot)	6.91	8385 (3313)
explicit (hand)	9	1811 (1458)
explicit (foot)	7.4	1682 (1186)
associated(hand)	8.1	442 (133)
associated (foot)	8	367 (152)
up-down (up)	6.25	2734 (880)
up-down (down)	6.13	2747 (972)

Procedure and design

Each trial started with a fixation cross, displayed in the center of the screen for 800ms. Then the stimulus word was presented until response. Between trials a white screen was shown for 1000ms. Each word was presented 4 times, resulting in a total amount of 768 trials, which were subdivided into 4 experimental blocks. The experiment started with a practice block, in which 8 practice words were presented two times in different colors. Participants received feedback on speed and accuracy in the practice block (but not in the experimental trials). Reaction times were measured.

Participants were instructed to respond as quickly and accurately as possible to the font color of the word. The mapping of colors to response direction was balanced across participants: All possible color pairs occurred equally often.

For the analyses, we collapsed across the two compatible conditions in each group and the two incompatible conditions in each group. For hand-related words and up-words, compatible conditions consisted of trials in which the correct response involved a key press with the hand at chest height. For foot-related words and down-words, compatible conditions consisted of trials in which the correct response involved pressing the foot pedal on the ground.

The design thus was a 4 (word group) x 2 (compatibility of the response) design with repeated measurement on both variables.

Results

Responses faster than 200ms or slower than 2500ms, as well as errors were excluded from further analyses. This reduced the data by less than 5%. Mean error rate was 3.9%. Mean RTs are displayed in Figure 1.

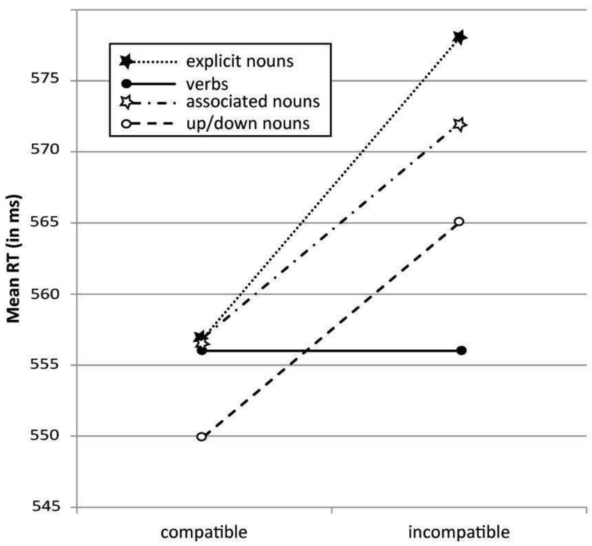

Figure 1: Mean response times of correct responses as a function of response compatibility and word group.

The analyses revealed a main effect of group, $F(3,87) = 5.3$, $p = .002$, a main effect of compatibility, $F(1,29) = 5.30$, $p = .006$, and a compatibility-by-group interaction, $F(3, 87) = 3.32$, $p = .024$. Separate analyses for the four word groups revealed significant compatibility effects for the three noun groups (explicit nouns: $F(1,29) = 7.42$, $p < .05$; associated nouns: $F(1,29) = 4.64$, $p < .05$; up/down nouns: $F(1,29) = 8.56$, $p < .01$) but no significant compatibility effect for the verb group ($F<1$).

To investigate the different compatibility effects in more detail we compared the different pairs of word groups with each other. The verb group differed significantly from all other groups with respect to the size of the compatibility effect (verbs vs. up/down nouns: $F(1,29) = 6.41$, $p < .05$, verbs vs. explicit nouns: $F(1,29) = 8.46$, $p < .01$, verbs vs. associated nouns: $F(1,29) = 4.63$, $p < .05$). The analysis revealed no significant difference between the different noun groups with respect to the size of the compatibility effect (all Fs < 1.04).

Discussion

In the present study, we investigated whether processing of single words with an association to the hand or foot results in effector-specific motor activation if implemented in a task that does not require active reading. Our results clearly show such effector-specific compatibility effects which is in line with the view that effector-specific information is automatically activated during word processing. Our results therefore fit well with the idea that readers re-activate experiential traces during word processing that stem from interactions with the respective referents of these words.

In our experiment we compared four different word groups. As predicted we observed compatibility effects for all noun groups. For the up/down nouns we had predicted such an effect because the two responses in this paradigm (hand vs. foot) differed with respect to the location of the response key in vertical space (up vs. down). In previous studies involving hand responses with up- versus down-keys strong compatibility effects were also observed, even in tasks that did not require active reading (Lachmair et al., 2011). Finding a compatibility effect with these nouns in the present paradigm shows that the up/down-effect generalizes to an experimental situation involving responses with different effectors. As such these results provide further evidence for the stability of this effect.

For the remaining two noun groups we had predicted compatibility effects on the basis of the view that readers activate experiential traces during word processing that stem from interacting with the objects these words refer to. If these objects are typically manipulated with one of the respective effectors, then this effector should be primed during processing and a response involving this effector should be facilitated. Interestingly, the observed compatibility effects were equally strong in these two groups, although the association with the effectors was linguistically specified in the explicit noun group but not in the associated noun group. Thus, if linguistic representations had played a prominent role during processing one could have expected stronger compatibility effects for the explicit noun group compared to the associated noun group. The fact that this was not observed can be taken as further evidence for an experiential-trace view of language understanding.

In contrast to our predictions, we did not observe compatibility effects for the action verbs. This is surprising for several reasons. First, in our view the association between these words and the two effectors seems particularly strong, and for this reason we had even expected to find the strongest compatibility effects in this group. Second, and more importantly, neuro-scientific studies involving the exact same set of stimuli repeatedly found evidence for an effector-specific activation during the processing of these words (e.g., Pulvermüller, et al. 2001). What then may be the reason for not finding effector-specific compatibility effects with verbs referring to actions that are typically performed with the hands or the feet? Several possibilities come to mind.

First, in German, nouns begin with a capital letter, but verbs do not. To present the words in their natural appearance, we presented the nouns with a beginning capital letter, and the verbs in small letters throughout. In principle it seems possible that this difference could account for the different results obtained with nouns and verbs in the present experiment, especially if one considers that active reading was not required by the experimental task. Maybe participants were more successful at ignoring the words when they homogeneously involved small letters than when there was a capital letter at the beginning. But this seems unlikely as the standard Stroop effect and several variants thereof have been observed in different sets of tasks, involving various types of word displays. Thus, we regard it as unlikely that the pure difference in word display, specifically concerning the first letter, can account for the differences between nouns and verbs in the present paradigm.

Another explanation for the missing influence of verbs on responding might be a different time course of verb processing in contrast to noun processing. We consider it conceivable that verbs require more processing effort than nouns, for instance due to differences in breadth of meaning (Gentner, 1981). If it takes relatively long to process verbs, then the information in the verb that potentially triggers the conflict may become active only after the response decision (responding with hand vs. foot) has already been made. This would explain why verbs did not influence responding. If indeed differences in processing times are responsible for the missing effects in verbs, we might find compatibility effects for verbs if a lexical-decision task was being employed instead of a Stroop color-response task (e.g., Mirabella, Iaconelli, Spadacenta, Federico, Gallese, 2012). Critically, in studies using verbs referring to upward or downward directed motion (e.g., *rise, fall*) similar effects were observed as in a study implementing nouns (e.g., *bird, ground*), even if implemented in a Stroop-like color-response paradigm (e.g., Dudschig, Lachmair, De Filippis, de la Vega & Kaup, 2012). Thus, a general difference between verb and noun processing cannot fully account for our findings.

Finally an alternative explanation may be that verbs referring to actions are associated with very specific motor plans. Maybe no compatibility effect was observed for the verb group because the overlap between the motor activation involved in understanding these words and pressing a key with the hand or the foot simply was not large enough. After all, a movement such as kicking is a quite different foot movement than pressing a foot pedal, and grasping is quite different from pressing a key with the index finger. If this hypothesis is correct, compatibility effects should be observed with verbs that refer to actions that are similar to the response actions in the experiment. Indeed, the embodied language processing account predicts that words become associated with experiential traces (e.g., Zwaan & Madden, 2005). Such an account would predict that experiential traces are rather specific, such that activating a specific effector might not be sufficient for facilitating language understanding.

In summary, our results provide clear evidence for effector-specific activation during single word processing in a very basic color-response paradigm. Especially, participants did not have to actively process the words' meaning and nevertheless subsequent responses were affected. However, this compatibility effect is limited to certain word categories and does not seem to occur in case of verb processing (e.g., *kick, grasp*). Our results suggest that conflict between words and effector-specific motor responses is not a general effect between words referring to foot or hand related entities and actions, but is rather specific to certain word categories. These results are of interest to both, the embodied language processing models (e.g., Glenberg & Kaschak, 2002) but also for the conflict monitoring model (e.g., Botvinick et al., 2001). Future studies will be needed to investigate whether difference in processing times are responsible for these effects, or whether the missing effect of action verbs on subsequent responses is due to the fact that very specific motor-plans are activated by the verbs.

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