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Effector-specific motor activation modulates verb production

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HIGHLIGHTS

- ► Effector-specific activation of the motor system supports word comprehension.
- ► We investigated effector-specific modulations of verb production.
- ► Participants completed a blocked naming and motor suppression task.
- ► Response times indicated that information about the effectors was activated.

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ABSTRACT

Language comprehension studies have demonstrated that effector-specific activation of the motor system supports the representation of word meaning. The aim of the present study was to test whether motor activation is also relevant for verb production. In the first part of the experiment, participants named photographs of actions either in effector-homogeneous blocks, with all actions involving the same effector, or effector-heterogeneous blocks, with actions involving different effectors. Action-naming latencies were longer in homogeneous blocks, indicating the activation of effector information. In the second part of the experiment, the same participants named action pictures in random order, while performing a motor task with either their hand or foot. The motor task caused interference for action-picture naming: latencies were longer when the effector of the depicted action was congruent with the effector of the action used in the motor task. While these results do not exclude the existence of abstract semantic representations, they indicate that effector-specific effects found in language comprehension extend to language production.

1. Introduction

According to the grounded cognition hypothesis, our perceptual and motor system is used to represent semantic information during language processing [4]. While understanding nouns modulates early visual processing regions [14], comprehending verbs involves motor representations [12]. Behavioral studies have shown that several action parameters, such as direction, rotation, force, or effectors used, are affected by information provided in sentences [9]. Neural evidence for an involvement of the motor system during language comprehension comes from neurocognitive studies that show somatotopic activations of the motor cortex during verb comprehension. Understanding action verbs such as 'kick' or 'throw' activates those parts of the motor cortex that initiate action in these effectors [12]. Furthermore, transcranial magnetic stimulation (TMS) pulses to specific areas in the motor cortex selectively impair processing of verbs that refer to actions carried out with this effector [7,19]. Taken together, behavioral and neurocognitive studies provide compelling evidence that understanding a verb results in rapid (re-)activations of aspects of motor control, most importantly involving the effector with which an action is carried out [11,19].

The aim of the present study was to extend the idea that language utilizes representations that are grounded in action to the domain of language *production*. Previous verb-production studies were concerned with abstract representation of action features [22]. Studies in the embodied-cognition literature have also used oral responses [21,23], not to study production but to avoid confounds in paradigms in which comprehension processes were investigated. If effector-specific activations underlie the representation of verb meaning, they should also have an impact on language production. We used a variant of the blocked-naming paradigm and a motor-suppression task to test this hypothesis. In the standard version of the blocked-naming paradigm, participants

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name pictures of objects either in homogeneous or heterogeneous blocks. Homogeneous blocks contain pictures from one semantic category (e.g., furniture) that are repeated a number of times within one block. Heterogeneous blocks contain pictures from different semantic categories. Typically, semantic relatedness between pictures produces interference, and picture naming is prolonged in semantically related, homogeneous contexts, especially for later repetitions [1,2,15]. In the variant of the blocked-naming paradigm employed here, participants named action pictures either in homogeneous blocks that contained pictures of actions carried out with the same effector, or in heterogeneous blocks that contained pictures from different effectors. If action representations are activated during language production, we expected prolonged reaction times in the homogeneous condition. In the motor-suppression task, the same pictures had to be named in random order, but this time participants also had to move either their hands or feet during the production task. In the variant employed here, participants made self-paced finger tapping or foot-rocking movements. On the hypothesis that the language production and motor planning access the same resources, we expected the type of movement (hand- or foot-movement) to interact with the kind of action depicted in the picture (hand- or foot-actions). Specifically, we expected prolonged reaction times when the depicted action was performed with the same effector that was used in the motor-suppression task.

2. Materials and methods

Forty students from the University of Münster, aged between 19 and 36, participated in the study after giving informed consent to the experimental procedure. Participants with more than 15% naming errors were excluded, so that 34 participants remained in the blocking- and 28 in the action phase. One participant was retained in the action phase but had to be excluded from the blocking-phase analysis, due to more than 15% errors. Removing this participant altogether did not affect the results.

24 full-color photographs of every-day actions without background served as targets. Eight actions were face-related (eyes and mouth; e.g., for *singing* [singen]: a man standing in front of a microphone), eight hand-related (e.g., for *painting* [malen]: a young boy painting with crayons in an album), and eight foot-related (e.g. for *marching* [marschieren]: an English royal guard lifting one leg). Included actions could be goal-directed or not. Pictures were taken from a database (hemera photo objects), and selected on the basis of a pre-test that ensured that pictures were good representations of the action and clearly associated to activity in only one effector system. Materials were pretested in thirteen students from the same pool as the main experiment. Due to coding problems, we could not ascertain whether participants took part in both the pre-test and the experiment. But as recruiting for the reaction-time experiment began 6 months after the pre-test, it is unlikely that the pre-test affected the reaction-time results. As part of the pre-test, participants rated 125 pictures and line-drawings on different scales. We selected items that were (a) good illustrations of the action, as measured on a five-point scale, and (b) were performed with a specific effector. For (a), we took the mean rating of how good the picture illustrated the action, and only included items with a mean score higher than 3. For (b), we computed a score that reflected whether an action was performed with a single or more effectors. The rated involvement of the other two effectors was subtracted from the rating for the target-effector (e.g., hand-activation = hand-rating − (foot-rating + face-rating)).

In the main-experiment participants first completed the blocked-naming task, in which they named pictures of actions in homogeneous or heterogeneous blocks. After a break, they completed the motor-suppression task. This fixed order of tasks was chosen to disguise the manipulation in the blocked-naming task.

The blocked-naming task consisted of twelve different experimental blocks, six homogeneous and six heterogeneous, each block contained 32 pictures. Homogeneous blocks included eight same-effector pictures that were pseudo-randomly repeated four times within a block (each picture was presented once before any picture was repeated). Heterogeneous blocks were created by pseudo-randomly selecting items from the verb categories (one item at a time was taken from each of the verb categories). The heterogeneous blocks contained two pictures from one verb category, and three pictures from the other two categories. The number of items from a specific category was balanced across blocks. Again, each picture was shown once before any picture was repeated. Blocks were presented in pseudo-random order (each block type was presented once before any block type was repeated, and no block was repeated immediately), and balanced across subjects. All pictures appeared 16 times, eight times in homogeneous and eight times in heterogeneous blocks.

During the motor-suppression task, participants named each picture four times in completely randomized order, while moving either their hand or feet. Participants were randomly assigned to either the hand- or foot-group. Participants in the hand-group made a self-paced tapping movement with their right hand, while they named the pictures. Participants in the foot-group moved a foot rocker with both feet, while they named the pictures.

Each trial started with the presentation of a fixation-cross in the middle of the screen, for 300 ms. A target picture replaced the fixation-cross and stayed on the screen until a response was given. The next trial started 500 ms after the response.

The data were analyzed using linear mixed-effects models, with crossed random effects for subjects and items to analyze the reaction times [3]. These analyses replace the traditional separate per-subject and per-item analysis, as they allow the simultaneous modeling of subject-and item-effects. *p*-Values were based on Markov-chain Monte Carlo sampling [3]. Whenever these analyses revealed significant main effects or interactions with the experimental variables, follow-up analysis were done with fewer variables to investigate the source of the effect. The software R [20] with the lmer package [5] was used for analysis.

3. Results: blocked naming task

Responses were coded for errors, voice-key failures, and erroneous or disfluent utterances. Erroneous trials were removed (8% of all trials), as were responses faster than 250 ms or slower than 1500 ms (9% of all trials). No reliable differences in error rates between conditions, and no speed-for-accuracy tradeoffs were observed.

We fitted a linear mixed-effects model with *half* (first vs. second), *blocking* (homogeneous vs. heterogeneous), and their interaction as fixed-effects and subjects and items as random effects to the data (Table 1). The factor *half* was included to investigate the development of interference during blocked naming [1]. Inspection of this model indicated no main effects, but a significant interaction between the two factors, $B = -18.91$; SE $B = 5.87$; $p_{MCMC} < 0.01$.

Analyzing the first and second half separately showed that the difference between the homo- and heterogeneous blocks emerged only in the second half of each block, $B = -23.84$; SE $B = 3.97$; $p_{MCMC} < 0.001$. No such differences were found in the first half of the blocks, $B = -5.67$; SE $B = 4.34$; $p_{MCMC} > 0.1$, (see Fig. 1). Thus, interference developed during homogeneous blocks [15].