Lexical Processing Drives Motor Simulation

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Abstract

While growing evidence suggests that sentence understanding engages perceptual and motor systems for the purpose of mentally imagining or simulating the content of utterances (Barsalou 1999) it is not known whether processing words alone does the same. We investigated whether making a decision about the form of a word would lead to activation of motor mechanisms, using a modified version of the Action-sentence Compatibility Effect (Glenberg and Kaschak 2002). Fluent signers of American Sign Language (ASL) were shown pairs of ASL signs which were either identical or not. Critical signs involved hand motion forward or backward, relative to the body. Subjects indicated whether the two signs were the same or different with a manual response requiring their hand to move either forward or backward - thus in a direction either compatible or incompatible with the direction of motion denoted by the sign. Results demonstrated a compatibility effect - literal and metaphorical motion signs facilitated response motion in the same direction, suggesting that mere phonological processing of a lexical item with motion meaning engages the motor system. The same experiment, performed with non-signers yielded no such effect, demonstrating that the effect was not simply the result of perceptual processing of the form of the sign. These results support an embodied view of linguistic processing where the content of language about motor actions is simulated using parts of the cognitive system responsible for actually performing the described actions.

Keywords: mental simulation; American Sign Language; motor control; lexical processing, Action-sentence Compatibility Effect

Introduction

If one were charged with the duty of building a human being from scratch, one would have to give it a motor system with which to act upon the world. To facilitate thinking about acting, one might configure this motor system such that, when necessary, it could be run without sending sufficient output to the relevant effectors for them to actually move - thus allowing the same system used for action execution to internally simulate acting for the purpose of reasoning. Finally, if one wanted to bestow upon one's creation the capacity to communicate about acting on the world, a particularly parsimonious solution would be to hook the communication system into the motor system. In such a system, acts of communication would begin with the speaker internally recreating a motor experience, followed by the selection and production of language appropriate to evoke a similar experience in the mind of the understander.

Remarkably, the demands of effective communication about action seem to be met in humans by this very solution (Barsalou 1999, Zwaan 1999, Glenberg and Robertson 2000, Bergen et al. 2004, Bergen and Chang 2005). Mounting evidence demonstrates that finely detailed perceptual and motor processing is automatically and unconsciously evoked during language processing (Stanfield and Zwaan 2001, Glenberg and Kaschak 2002, Zwaan et al. 2002, Richardson et al. 2003, Bergen et al. 2003, Bergen et al. 2004, Kaschak et al. 2004, and Matlock To Appear). This constitutes broad evidence for the view that language understanders make use of perceptual and motor simulation to gain deep understanding of language, even when performing tasks that do not directly ask them to perform imagery.

The last decade has witnessed an explosion of evidence demonstrating that the motor system is critically engaged during behaviors that are related to motor control, but involve no actual motion on the part of the relevant individual. Much of this work has developed from the discovery of "mirror neurons" in monkeys (Gallese et al. 1996, Rizzolatti et al. 1996) - neural circuits that become active during either the execution <u>or</u> perception of specific motor control events, like grasping and reaching. The work has since been extended to humans, where neural imaging and behavioral methods have demonstrated that different overlapping regions in pre-motor cortex become active when subjects execute and perceive actions produced by the mouth, leg, and hand, respectively (Buccino et al. 2001), and similarly that executing actions and recalling those actions also activate common areas in motor and parietal cortex (Nyberg et al. 2001).

In addition to execution, perception, and memory of motor actions, recent work has begun to investigate whether language about actions is processed using action-specific areas of the motor system. Pulvermüller et al. (2001) and Hauk (2004) found that when subjects performed a lexical decision task, verbs associated with different effectors led to different paths of processing in motor cortex. These findings were further corroborated by Tettamanti et al. (m.s.) who showed that passive listening to sentences describing mouth, leg and hand motions also activated different parts of pre-motor cortex, along with BA 6, BA 40 and BA 44.

Two principal lines of behavioral investigation have also demonstrated a role for the motor system in language processing. The first (Glenberg and Kaschak 2002) has demonstrated that processing sentences denoting motion involves activation of motor programs for hand action in the same direction as the described motion. The second (Bergen and Wheeler 2005) has demonstrated that processing sentences which verbs of hand motion involves activation of motor programs for hand shape.

In Glenberg and Kaschak (2002), it was demonstrated that a sentence sensibility task could evoke motor imagery strong enough to prime actual motor action. In this paradigm, participants judge the acceptability of sentences describing movement toward or away from the body (i.e. "Put your finger under your nose" vs. "Put your finger under the faucet"). To respond 'yes' (sensible) or 'no' (not-sensible), they are asked to press a button that is either further away or closer to their body. The critical condition was measured by comparing the reaction times to the 'yes'-is-near and 'yes'-is-far responses. Glenberg and Kaschak found that participants were slower to respond when the direction of the action in the sentence was opposite to the direction their hand had to move in order to press the 'yes' button. They named this the Action-Sentence Compatibility Effect, or ACE (Glenberg and Kaschak 2002).

In subsequent work, Bergen and Wheeler (2005) have similarly found that language describing physical actions made using specific hand shapes, like a fist versus an open palm, facilitates performing the same action. In their study, subjects again judge the sensibility of sentences, though the critical condition is found in the fine motor detail implied in the verbs, such as 'punch' (clenched fist) and 'pat' (open palm). To investigate their hand shape compatibility effect, subjects responded 'sensible' versus 'not sensible' by using a fist or an open palm to hit the large response button. Bergen and Wheeler found that participants were faster to respond 'sensible' when the hand shape of the action in the sentence was the same as the hand shape they had to make when pressing the response button. Thus, Bergen and Wheeler (2005) show that not only hand motion, but also fine details of hand shape are also encoded in our language understanding.

This speeding up of actual motor action by previously processed language about similar actions is straightforwardly interpreted as indicating that during sentence processing, language understanders automatically and unconsciously activate motor representations corresponding to the described actions. Thus, the current state of knowledge about motor activity in language processing is that words about actions interfere with processing images of similar actions, and at the level of the sentence, processing language about actions appears to critically engage the motor system. The next logical step in the investigation of motor imagery in language comprehension is thus to apply the methods that have previously demonstrated a role for the motor system in sentence processing to the study of lexical processing.

To this end, we begin in a language rich in motor activity, American Sign Language (ASL), because the pervasive iconicity of signs expressing motor events, as compared with spoken languages, could increase the likelihood that lexical access drives motor imagery when understanding language. Signed languages are profoundly iconic, especially when it comes to representations of space (Taub 2001). In spoken languages, movements of the tongue and other parts of the vocal tract constitute the speech gestures. These phonological movements generally do not iconically represent spatial aspects of events denoted by the words they occur in, though the sounds produced by these gestures may be acoustically iconic through sound symbolism or onomatopoeia (Ohala 1997). Signed languages, on the other hand, use 'phonological' movement consisting of hand, arm and upper body movements, all of which can be used to iconically represent motion events. Thus, if there are any languages in which lexical access directly drives motor imagery, a spatially iconic one like ASL is likely to be one.

To investigate the extent of motor imagery in lexical meaning, we adapted the Action-Sentence Compatibility Effect (ACE) methodology (Glenberg and Kaschak 2002) to suit word processing. Recall that the ACE methodology presents subjects with sentences to read and make a meaningfulness judgment on. In order to explore whether simply accessing a lexical item also yields motor imagery, the design was modified somewhat. Rather than direct subjects' attention to meaning, we instead had subjects perform a lexical matching task, in which they saw two signs in sequence and were asked to simply judge as quickly as possible whether they were the same sign or not. With this design, any motor interference would arise not from task-imposed interpretation of sign meaning, or from the construction of an interpretation for a whole sentence, but rather would be exclusively an automatic product of the lexical item presented.

Method

Following Glenberg and Kaschak (2002), signs fell into one of two conditions - those denoting motion forward (i.e. away from the body) and those denoting motion backwards (i.e. towards the body). The subjects were to respond affirmatively or negatively, by performing a hand movement that was either in the same or the opposite direction as the denoted movement. If subjects display motor priming effects even when performing this task, which could be successfully performed solely through visual perceptual means since the two signs in the matching condition were identical, then this would indicate the automaticity of the motor imagery mechanism.

The signs denoting forward motion and those denoting backwards motion were split into two groups. The first denoted literal motion of the arm and hand, like CATCH and BOWLING (both of which look iconically like the denoted actions), and will be referred to as semantic or sem signs. The second set denoted metaphorical motion, like TELL (in which the index finger moves forwards from under the chin to indicate transfer of information in the form of language) or YESTERDAY (in which the hand moves backwards to indicate the past), and will be identified as metaphorical or met signs. Using signs with forwards or backwards semantics, however, is complicated by the pervasiveness of spatial iconicity in ASL. Nearly all forward signs, like BOWLING and GIVE and backward signs like CATCH and EAT are phonologically encoded using physical motion of the arm and hand in the corresponding direction. As a result, any motor priming effects observed could potentially result from the processing of the phonology of the signs, and not their semantics.

To deal with this possibility, we included a final set of signs that were phonologically directional but whose semantics was totally unrelated - even through metaphor - to that same motion. An example is the sign for GIRL, in which the thumb moves forward away from the face, but its meaning does not reflect this directional element in any way. Other examples include ABUNDANT (forward), HOME (backward) and MISTAKE (backward). These signs will be referred to as phonological or phon signs. If an observed compatibility effect obtains for the sem and met signs as well as for the phonological signs, then this would confirm the possibility that it is the phonology and not the semantics that is responsible for the effect. However, if the effect is present for signs encoding motion but not for those that only had 'phonological' motion, then this would indicate that the effect results from semantic access.

Subjects

Two groups of subjects participated in the same experiment. The first group consisted of forty-six ASL signers. The second group consisted of forty-two non-signers. The signers were residents of Oahu and were compensated with ten dollars. The non-signers were students at the University of Hawai'i at Mānoa and received credit in an undergraduate linguistics course for their participation.

Materials and Design

Subjects were tested on sixty-six different signs, consisting of twenty-two phon signs, twenty-two met signs and twenty-two sem signs. Half of each of these three groups of signs were phonologically encoded with hand movement forward, away from the body and half had the hands move backward, toward the body. The major axis of motion for all signs was forward or backward, though some were angled slightly to the right or left. (We chose forward and backward motion as opposed to rightward and leftward motion because the direction of the latter set depends on the signer's handedness.) These signs were obtained with permission from the MSU American Sign Language Browser (http://commtechlab.msu.edu/sites/aslweb/). During the experiment, signs consisted of a movie composed of four frames, which was found to suffice to clearly display each unidirectional sign.

There were two lists, identical except for the order of their two blocks. In addition, each list had two variations. In the first variation of each list, the first block had the 'same' button in a location that required movement forward, and the second block had the 'same' button in a location that required backward movement. In the second variation of each list the location of the 'same' button was reversed. Thus, the first block had the 'same' button in a location that required backward movement, and the second block had the 'same' button in a location that required forward movement.

Thus, there were a total of four versions of the experiment. Each subject was randomly assigned to one of these versions. The task required subjects to determine whether two ASL signs, which they saw in sequence, were the same sign or different signs. Subjects first saw a fixation cross. At this point they pressed and held down the 'go' button, the 'h' key on an attachable keyboard that was rotated 90-degrees clockwise from normal so that the long axis extended outwards from the subject. After pressing the 'go' button the subject saw, in sequence, a blank screen (100msec), the first sign (first frame 150msec, second frame 100msec, third frame 100msec, fourth frame 100msec), followed by a visual mask (1000msec), then the second sign (first frame 150msec, second frame 100msec, third frame 100msec). Subjects did not release the 'go' key until they were ready to respond. The last frame of the second sign remained on the screen until the subjects lifted their finger off the 'go' button to hit the 'same' key or the 'different' key (either the 'a' key or the ''' key, depending on the condition). The keyboard was positioned such that hitting the 'a' key would require moving the arm forward, whereas hitting the ''' key would require moving backward. The 'same' and 'different' keys were switched halfway through the experiment such that subjects would have a chance to respond in both directions. For the critical signs, the answer was always 'same'.

Thus, independent variables were the direction of the hand movement - forward or backward (sign direction), whether the signs had semantic direction of movement or not (sign type) and whether the response was a forward or backward movement of the hand (hand motion). The dependent variables were time to let go of the 'go' key (release time) and time to press the 'same' button (response time).

For the nonmatching sign pairs, phon signs were randomly matched with met and sem signs which moved in the same direction, met signs were matched with phon and sem signs and so on. The reason nonmatching sign pairs encoded movement in the same direction was to ensure that subjects couldn't distinguish matching from nonmatching signs simply on the basis of directional cues.

These twelve groups (6 groups matching and 6 nonmatching) were randomized within their groups, then halved and split into two lists. Each list was then split into two blocks, one appearing first and the other appearing last in the first version and vice versa in the second version. This gave a total of 66 sign pairs (33 matching and 33 nonmatching) for the first block and 66 sign pairs for the second, leading to each list, and thus, each version, containing a total of 132 sign pairs. Thus, each subject saw each phon, met and sem sign appear as the first sign in a pair only twice in the experiment, once in a matching sign pair and once in a nonmatching sign pair. All signs within blocks were presented in random order.

Procedure

The experimental procedure consisted of a practice session, which used six signs which did not encode direction forward away from or backward toward the body, each presented in a matching and nonmatching condition, as described above for the main session. During the first half of the practice session, subjects were given feedback as to whether they had correctly judged whether the signs were the same or different. At the end of the practice, subjects were informed their score. If they scored better than 80% they were allowed to start the main session; otherwise the practice session was repeated.[1]

After the first half of the main session, subjects were given their accuracy score, and then the screen froze and the labels on the 'a' and '" buttons were switched. Subjects were given a second practice session with the new orientation of 'same' and 'different' buttons, followed by the second half of the main experiment.

Subjects in both groups were explicitly told not to lift their finger off of the 'go' button until they were ready to answer. The experiment took twenty to thirty minutes to complete.

Results

Nineteen ASL signers were eliminated since they were left handed, had less than five years of ASL experience, had reaction times (RTs) over three standard deviations from the mean or performed at less than 80% accuracy (either on their own account or because of instrument failure). Of the remaining twenty-seven signers, seventeen were women and ten were men, with an age range from 19 to 68 years of age. Sign pairs were eliminated for being over three standard deviations above the mean response RT. These were AFFECTION/EMBRACE, BINARY and GOOD-LUCK.

In the group of nonsigners, three subjects were eliminated due to either computer malfunction or time constraints on the subject's schedule, requiring early termination of the program. All subjects' RTs were within three standard deviations from the mean. Of the remaining thirty-nine subjects, twenty-one were women and eighteen were men, with an age range from 18 to 24 years old. Items found to have average RTs three standard deviations above the mean (CHOKE and LEISURE) were eliminated from the analysis. For both groups of subjects, all item RTs per subject over three standard deviations from the mean for that subject were replaced by the value three standard deviations above the mean, resulting in changes in less than 1% of the data.

Glenberg and Kaschak's original work on the ACE found significant compatibility effects on release times. The release RTs for signers were analyzed with a 3 (sign type) x 2 (sign dir) x 2 (hand motion) repeated measures ANOVA.

The results show a main effect on release time of sign direction, $F_1(1,26) = 18.0$, $p < 0.01$, with backward signs having longer release RTs. Unlike Glenberg and Kaschak, our data showed no significant ACE (sign dir x hand motion) for release RTs, $F_1(1,26) = 0$, $p = 0.99$, and no significant three way effect (sign type x sign dir x hand motion), $F_1(2,52) = 1.92$, $p = 0.16$.

[1] As pointed out by a reader, this may have been a confounding factor, since some subjects had more practice time than others.

However, we did find the predicted effect on response time, the time it took subjects to press the 'same' button. Response times were analyzed with a 3 (sign type) x 2 (sign dir) x 2 (hand motion) repeated measures ANOVA. The results for subjects show no significant main effects. In terms of two way effects, the interaction between sign direction and hand motion (the ACE) was found to be significant, $F_1(1,26) = 4.12$, $p < 0.05$. The three way interaction was not significant.

In order to investigate whether signs that denoted motion differed from those that did not, we performed separate 2 (sign dir) x 2 (hand motion) repeated measures ANOVAs for the combined group of met and sem signs on the one hand and a separate one for phon signs on the other. The results showed that the ACE (interaction of sign direction and hand motion) was significant for sem and met signs combined for subjects, $F_1(1,26) = 9.29$, $p < 0.01$, and for items, $F_2(1,40) = 4.07$, $p = 0.05$. The ACE for phon signs, by contrast, was not found to be significant, $F_1(1,26) = 0.53$, $p = 0.48$. This is illustrated in Figure 1.

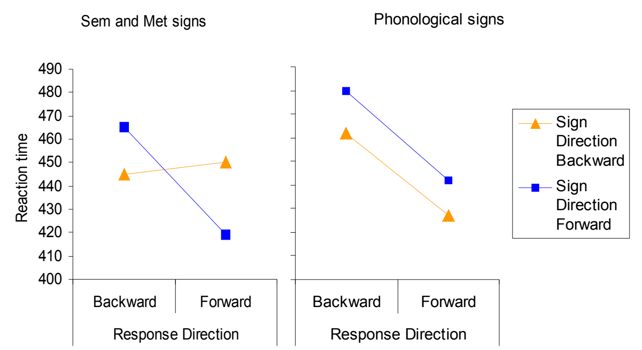

Figure 1: ASL signers response RTs for sem and met signs (significant interaction) versus phon signs (no interaction)

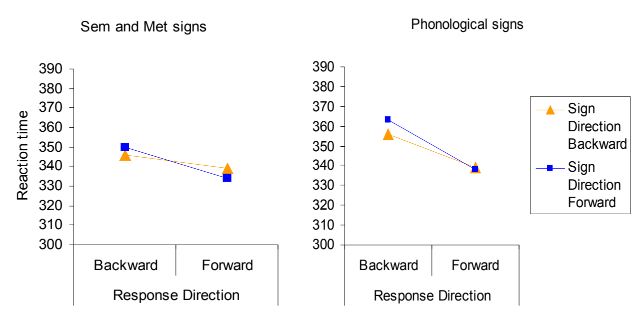

Figure 2: Response RTs for non-signers show no ACE.

These results show a significant interaction effect between sign direction and response direction (the ACE), which is apparently specific to signs that denote literal or metaphorical motion, but is not shown by signs that only phonologically encode motion without any motion semantics. To determine whether these findings might result from other phonological properties of the signs themselves, or whether they are in fact due to activation of motor systems during word processing by fluent signers, we investigated whether the same ACE would show up in subjects who had no experience with ASL.

The results of a 3 (sign type) x 2 (sign dir) x 2 (hand motion) repeated measures ANOVA of response times showed no significant main effects or interaction effects. However, a four-way repeated-measures ANOVA in-cluding language - signer or non-signer - as an independent variable demonstrated a significant effect of language; signers responded more slowly than non-signers $F_1(1,64) = 12.77$, $p < 0.01$. The results for non-signers are illustrated in Figure 2.

Discussion

Signers took longer to press a button indicating that two signs were identical when the action they had to perform was incompatible with the action described by the sign. This effect appears to hold for signs denoting literal or metaphorical motion (sem and met signs), but not for signs with no motion semantics (phon signs), which eliminates the possibility that the effect results simply from the visual perception of the phonological motion encoded in the signs themselves. Further evidence that it is semantic processing, rather than visual processing that yields this compatibility effect comes from the absence of an effect in nonsigners. If it were just observing an action that was priming performing a similar action in this task, nonsigners should have displayed a significant interaction between sign direction and response direction, which they did not.

This observed ACE in ASL within a sign matching task constitutes two important advances in the study of how motor systems are engaged by language processing. First, it provides evidence that sentence sensibility tasks, which require subjects to pay close attention to sentential meaning, aren't required for the motor system to be engaged in language processing. Even in a lexical matching task, where subjects can simply look at the form of the two signs to determine whether they are identical or not, there is nonetheless motor activity, as evidenced by the priming of similar physical actions. This speaks to the automaticity of motor imagery, as it occurs even when superficial visual processing would suffice.

Second, the fact that this effect was observed in a lexical matching task, and not one that uses sentences as stimuli argues for a role for motor activation in lexical processing, not just sentence processing. This supports the findings from previous work on lexical semantics (Bergen et al. 2004) arguing that the meanings of action words are at least in part calculated on the basis of activation of motor systems.

In terms of the particular method used, it seems that alongside an Action-Sentence Compatibility Effect there is an Action-Word Compatibility Effect, at least in ASL. A notable difference between the two effects lies in the fact that in Glenberg and Kaschak's (2002) study, the ACE was demonstrated in release times, whereas in the current study it was in evidence in response times. One explanation could lie in the difference in the two tasks. Since Glenberg and Kashack's study involved sentence sensibility judgments, subjects had to perform phonological and relatively deep semantic processing before they could lift their finger. Thus, in a sentence sensibility task, the ACE could already be detected in the time to release the button. In our task however, where subjects had to decide if two signs were the same or not, subjects responded much more quickly. It could be that the semantic processing performed on the signs in our experiment occurred after the release, and thus appears in the response times (see Vitevitch and Luce 1999 for discussion of the sublexical and lexical stages of word recognition; Pylkkanen and Marantz 2003 discuss different stages in brain activations during word recognition). The cognitive load of semantic processing could also explain the relatively shorter response RTs for nonsigners, who did not perform semantic processing, than signers.

One tangential finding of potential interest was the longer release RTs for backwards signs. Several possible explanations present themselves. First, backwards signs have their critical location information encoded at the end of the sign, where the movie stops. This could require longer processing time in sign recognition tasks. In addition, some of the backwards signs cover shorter distances compared to forward signs. This leads to less spatial information, and quicker signs, which also may slow sign comprehension. It could be that these factors also lead to the apparently smaller number of backward signs in the lexicon.

Conclusion

This investigation of lexical processing in ASL has provided evidence supporting an embodied view of language understanding. In a sign matching task, it was shown that motor action was affected by the lexical semantics of signs in citation form. It has been suggested by a number of authors that simulated motor activity is the actual mechanism by which language about action is understood (Barsalou 1999, Zwaan 1999, Glenberg and Robertson 2000, Bergen and Chang 2005). In accordance with this proposal, ASL signers appeared to mentally access meanings of literal and metaphorical signs using motor imagery that relies on the same neural structures responsible for actual movement. The results seen here for automatic activation of motor imagery during the processing of words denoting motor actions supports this embodied view of word meaning and highlights the importance of low-level body and brain systems in language use.

The impact of this research lies in its implications for the importance of automated motor programs in cognitive development. Language tasks in particular and perhaps reasoning tasks in general all require activation of motor systems for understanding. In addition, this motor understanding isn't only limited to language about physical motion events, as can be demonstrated in work by Lakoff (1987) which shows that our conception of abstract concepts often depends on motor-based metaphors (i.e. 'Time passes quickly'). To this extent, recent findings on the pervasive effects of both visual and motor imagery lead us to conclude that our conceived realities, specifically as expressed through language, are inseparable from our bodily experiences, giving us a neurological explanation for our uniquely human perception of the world.

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