

Comprehending sentences with the body:
Action compatibility in British Sign Language?

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Abstract

Previous studies show that reading sentences about actions leads to specific motor activity associated with actually performing those actions. We investigate how sign language input may modulate motor activation, using British Sign Language (BSL) sentences, some of which explicitly encode direction of motion, vs. written English, where motion is only implied. We find no evidence of action simulation in BSL comprehension (Experiments 1-3), but find effects of action simulation in comprehension of written English sentences by deaf native BSL signers (Experiment 4). These results provide constraints on the nature of mental simulations involved in comprehending action sentences referring to transfer events, suggesting that the richer contextual information provided by BSL sentences vs. written or spoken English may reduce the need for action simulation in comprehension, at least when the event described does not map completely onto the signer's own body.

Keywords: sentence comprehension; embodiment; sign language; motor simulation; action compatibility

Comprehending sentences with the body?

Action compatibility in British Sign Language

There is now a broad body of evidence supporting an embodied account of language; rather than being abstracted away from our bodily experience of the world, language comprehension takes advantage of many of the same systems engaged in bodily experience. This grounding of language in perception and action has been evidenced in a wide range of behavioral and neuroscientific studies (e.g. Barsalou, Simmons, Barbey & Wilson, 2003; Barsalou, 2008; Beauchamp & Martin, 2007; Gallese & Lakoff, 2005; Glenberg & Kaschak, 2002; Zwaan & Kaschak, 2008; for reviews see Meteyard, Rodriguez Cuadrado, Bahrami & Vigliocco, 2012; Fischer & Zwaan, 2008; Taylor & Zwaan, 2009). In a classic study of this type, Stanfield and Zwaan (2001) showed how sentence comprehension involves activation of specific imagery related to the perceptual and action properties of an event. Participants were presented with sentences which implied a certain orientation or configuration of an object (e.g., *John hammered the nail into the wall*) and were then presented with a pictured object (e.g., nail) and asked to verify whether that object had been mentioned in the sentence. Participants were faster to respond when the orientation of the object was consistent with the physical details of the events described by the sentence (as in a nail pictured horizontally rather than vertically facilitating response time, given that hammering a nail into a wall implies a horizontal orientation). As the object's orientation is only relevant when considering the bodily realisation of the action described in the sentence, such results suggest that sentence comprehension involves mentally enacting bodily activity. Neuroscientific studies have likewise pointed to the specific involvement of motor areas in understanding language related to action. For example, as found by Tettamanti, Buccino, Saccuman & Gallese et al. (2005) in an fMRI study, reading sentences describing actions using specific body parts (e.g. *I bite the apple, I kick the ball*) activates the area in the motor cortex related to physical use of that body part (e.g. mouth for *bite*, foot for *kick*; see Pulvermüller, 2013 for review).

The Action-Sentence Compatibility Effect (ACE), first demonstrated by Glenberg and Kaschak

(2002), provides further compelling evidence that we involve our sensori-motor systems in language comprehension by mentally simulating details of the actions and events encoded in language. In this study, participants were presented with written sentences that implied either motion toward the comprehender's body (*Andy delivered the pizza to you*) or away from it (*You delivered the pizza to Andy*). Participants were asked to judge sentence sensibility by responding with a button press that required movement of the arm either toward or away from the body. The results showed that participants initiated their responses faster when the motion implied by the sentence was congruent with the response direction (for example moving the arm away from the body in response to a sentence like *You delivered the pizza to Andy*). This was true not only of sentences implying transfer of concrete objects (like a pizza) but also of sentences that involved transfer of abstract entities (e.g. *You communicated the message to Adam*), further suggesting that even metaphorical transfer engages the effectors involved in concrete transfer events. Results such as these strongly suggest that our bodily systems are closely involved in language comprehension: if they were not, then details like the direction of movement necessary to press a button or the precise orientation of a pictorial stimulus should be irrelevant and should not affect sensibility judgments or content-matching judgments. Thus, these authors (and many others working in the same vein) have argued against amodal views of language processing, arguing instead for a far more central role of the body than had been previously considered in psycholinguistics (see Glenberg, Witt & Metcalfe, 2013 for a historical perspective).

Demonstrating that some aspects of language comprehension are embodied is only a first step, however. In order to understand how the body is involved it is important to establish the conditions under which embodied effects arise, and when they do not. As the evidence supporting sensori-motor system involvement in language comprehension accumulates, we must also address the question of how this embodiment comes about. How does language come to be grounded in our bodily experience and what are the mechanisms by which language processing engages the sensori-motor system (e.g., Perniss, Thompson & Vigliocco 2010)? Moreover, there is much debate about how embodiment effects may be modulated by context (e.g., Willems & Casasanto, 2011; Zwaan, 2014), and how effects may be

constrained by different properties of language. In this context, the strong role of action/motor simulation in sentence comprehension demonstrated by action-compatibility effects raises an interesting question with respect to the modality of language presentation.

To date, embodiment effects have almost entirely been studied looking at spoken/written language. However, in sign languages, the natural languages of deaf people, meaning is encoded through movement of the hands and arms through the space on and in front of the body. Thus, signers use the same effectors to produce language and to perform actions, and comprehenders use the visual modality to comprehend language, actions and events. Extending the investigation of embodiment to language expressed in the visual modality, where the same motor articulators that perform non-linguistic actions are used to encode actions linguistically, is an important step to understanding the nature of embodiment, and the conditions under which embodiment effects come about. The simulation effects observed in action sentence comprehension may well be modulated or constrained by inherent properties of language, particularly those related to language modality.

Moreover, the visual medium of sign language affords a high degree of iconicity, or resemblance between linguistic form and meaning. This potential is exploited particularly for encoding sensori-motor information, such that meanings related to action are expressed in highly iconic linguistic forms. Thus, in addition to engaging the same effectors needed to perform transfer events, many sign language verbs encoding transfer of the type studied by Glenberg and Kaschak (2002) explicitly realize directionality of motion in the event through a corresponding movement of the hands through space (i.e. toward or away from the body; Padden 1988). Figure 1 below shows the use of such a *directional verb* in British Sign Language (BSL). The verb POST-TO (or MAIL-TO in US English) moves toward the viewer/addressee's body (and away from the signer's own body) to encode the meaning "I post [something] to you". The opposite meaning "you post [something] to me" would be expressed by the signer moving his hands away from the viewer/addressee's body (and toward the signer's own body).



1p-POST-TO-2p (I post [something] to you)



2p-POST-TO-1p (You post [something] to me)

Figure 1: Left: two still frames from the BSL sign 1p-POST-TO-2p, which moves from the signer directly toward the addressee's body and indicates that the signer is posting something to the addressee. Right: two still frames from the BSL sign 2p-POST-TO-1p, which starts away from the signer's body and moves toward him, indicating that he is the receiving party and the addressee is the sender.

The behavior of directional verbs in BSL is closely related to the use of space for reference (Liddell 1990; Perniss 2012). In BSL, as in other sign languages, person reference is achieved by directing signs toward locations in the space surrounding the body that are associated with the entities being talked about (see Figure 2). Second person (*you*) is associated with a location directly opposite the signer, the canonical location of an addressee.¹ Third person (*he/she/it*) is associated with a location to the right or left of the signer. The body of the signer, specifically a location at the center of the signer's chest, is associated with first person (*I*). Points to the appropriate locations indicate the arguments, e.g. subject and object, of a predicate. Directional predicates can thus indicate arguments by physically moving between the locations associated with the arguments.²

¹ In actual discourse with both individuals present, 2nd person reference is achieved by pointing to the physical location of the addressee.

² This is a highly simplified description (for a more in-depth treatment see Sandler & Lillo-Martin 2006), but is adequate for the present purposes.

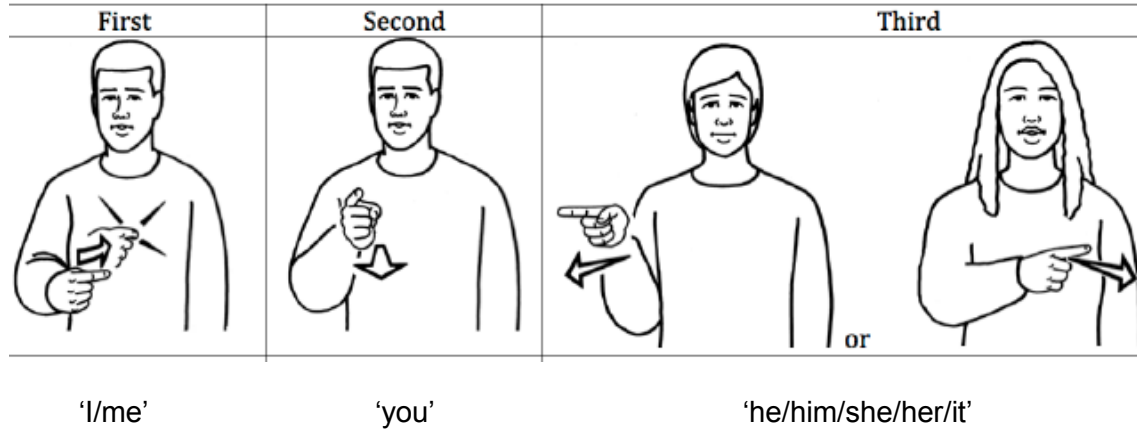


Figure 2. Pronominal pointing signs (from Johnston, 2013).

The use of a directional predicate in sentence context is illustrated in the BSL example sentence shown in Figure 3, which corresponds to English *James posts the box to you*. In the example, 3rd person reference to *James* is achieved in stills 2-3 of the figure, consisting of a sign for the letter 'J' (for James), in still 2, followed by a pointing sign to a 3rd person location to the right of the signer's body, in still 3. The predicate in stills 4-5 conveys the meaning *he posts to you*: starting at a location offset to the signer's right, corresponding to the 3rd person location previously specified, and then moving to the 2nd person location – outward from and opposite the signer's body – associated with the participant/addressee viewing the sentence. Thus, in the BSL version of *James posted the box to you*, participants see the predicate move toward them, in the same way as the actual event would involve movement toward them.



Figure 3: Panel A: Stills from an example BSL sentence with English glosses. (English translation: *James posted the box to you*.) The sentence includes the directional verb POST-TO that moves from the 3rd person to the 2nd person. The perceived motion in viewing the sentence is thus toward the

participant's/addressee's body. Panel B: Schematic illustrating the implied directional motion given the relative positioning of James and the second person ("you") in signing space. Compare it to the starting point of the verb POST-TO (fourth still in Panel A) which is offset to the signer's right, reflecting the location of the 3rd person referent in signing space.

However, not all BSL verbs express the direction of actions with movements mapping onto the directional events being described. In *non-directional* predicates, the form of the verb is the same regardless of the direction of the event (e.g. in the verb DEAL-CARDS, the hands represent dealing out a deck of cards from the front of the body as a card dealer would, regardless of who is dealing cards to whom). Here, argument structure is indicated not by means of the movement of the verb, but only by word order and overt pronominal points to locations associated with referents. An example of a BSL sentence with a non-directional predicate is provided in Figure 4.



CARDS 2p ("you") DEAL-CARDS JAMES 3p ("he")

Figure 4. Glossed example of BSL sentence with a non-directional verb. (English translation: *You dealt the cards to James.*) The verb is produced in the same manner regardless of who deals the cards to whom.

Finally, some directional verbs are only partly modified by their arguments. An example is the BSL verb AWARD which has optional subject agreement in BSL (see Padden, 1998; Meier, 2002; Lillo-Martin & Meier, 2011). When the awardee is 2nd or 3rd person, the starting point is on the signer's body regardless of the subject of the sentence, but the end point varies for 2nd vs. 3rd person recipients (both thus including movement away from the signer's body). An exception occurs when the awardee is 1st person, in which case the starting point is away from the body (varying in position for 2nd or 3rd person) and the sign moves toward the signer; see Figure 5 for illustrations of these

examples. With respect to directional motion we must consider such verbs carefully as the relationship between physical movement and direction of implied motion varies depending on the participants in the event.



Figure 5: Stills from examples of the BSL verb AWARD-TO, a directional verb only partly modified by its arguments. Upper left: (1p) AWARD-TO-2p: "I award [something] to you". Upper right: 2p-AWARD-TO-1p: "You award [something] to me". Lower left: (3p) AWARD-TO-2p: "[Someone] awards [something] to you": note the similarity to the example above it. Lower right: (2p) AWARD-TO-3p: "You award [something] to [someone]": 3rd-person reference is offset to the signer's right. The recipient of the award is marked in all four instances, but the subject of the sentence is marked only when the recipient is 1st person.

How might these characteristics of sign languages affect the way signers internally simulate actions in comprehending sentences referring to directional actions? One possibility is that they would not: effects of action simulation would be observed in signed sentence comprehension just as Glenberg and Kaschak (2002) found for written English. In this case, the specific characteristics of modality with respect to how transitive action sentences are encoded would not differentially affect sensori-motor system involvement in language comprehension. If comprehenders are mentally simulating the actions described, independently of the specific features of the linguistic forms used to describe them, the involvement of the motor system in comprehension should facilitate response planning when transfer events described in signed sentences are congruent to the direction of responses, and response compatibility effects should be observed regardless of sentence type.

A second possibility, however, is that the iconic, directional motion inherent in the linguistic (i.e. phonological) expression of some action verbs could modulate motor simulation in sentence comprehension compared to what has been found for English. In particular, for sentences containing directional predicates (as in POST-TO in Figures 1 and 3 above), phonological motion corresponds to the implied direction of the events. For sentences containing non-directional predicates (as in DEAL-CARDS in Figure 4 above), instead, the phonological motion is constant regardless of the implied direction. If signers' simulations during comprehension are not just related to the implied direction of the events, but also to the directional movement present in the language input, the magnitude of response compatibility effects should differ as a function of sentence type: greater for sentences with directional predicates and reduced or absent for sentences with non-directional predicates (although the example of AWARD-TO indicates that we need to be careful about the treatment of predicates that vary with respect to argument marking).

Finally, another possibility is that iconic characteristics of signed languages may eliminate the need for simulation. Zwaan (2014) proposes that the degree of simulation in language comprehension varies, depending in part upon how much information is available in the environment. For example, for demonstrations that are maximally embedded in the environment, the situation provides visibly present referents and actions, and thus the role of simulation in comprehension may be minimal (or absent). If less contextual information is provided by the environment (as would be the case for comprehending Glenberg & Kaschak's written English sentences about transfer events), more simulation may be required to fill in those details as part of comprehension. As signed languages exploit the visual-manual modality, expressing many characteristics of referents iconically (Taub, 2001) the need for simulation may be reduced or eliminated by contextual information provided to the comprehender not by the surrounding environment, but by visual-spatial properties of the language itself that provide information about referents, actions and events. If this is the case, motor simulation of the encoded event in comprehension may be reduced or eliminated.

These questions were partly addressed by Secora and Emmorey (2014) who conducted a

sentence judgment study in American Sign Language (ASL). Participants were presented with sentences that implied directional movement in ASL, and as in the previous studies in English, made sensibility judgments by moving their hand toward or away from the body. Two types of sentences were included: "two-person sentences" including directional verbs for which direction of movement varies depending on the verb's arguments (e.g. HAND-TO, as in "You hand me the coffee cup", gloss: COFFEE CUP YOU HAND-ME), and "one-person sentences" with non-directional verbs for which movement does not vary for different arguments (e.g. PUT-ON, as in "You put on glasses", gloss: GLASSES YOU PUT-ON-GLASSES).

Button release latencies were faster when response direction was congruent with the directionality implied by the event, but there was no congruence effect when congruence was recoded in terms of the direction of physical motion observed in the video clip. Secora and Emmorey concluded that comprehenders simulate actions while comprehending sentences in similar ways regardless of language modality, and that sign comprehenders do so without regard to the directionality that may be physically present in sign phonology, consistent with the first set of predictions we described. However, this general conclusion is not warranted from these data due to limitations in their experimental design and analysis. The crucial difficulty lies in the use of an incomplete factorial design: Secora and Emmorey report two primary analyses: one ANOVA testing response direction \times semantic congruence (whether the direction of movement implied by the event being described matches the response direction), and another testing response direction \times phonological congruence (whether the direction of the physical movement observed in the sign matches the response direction; Secora and Emmorey call this "perceptual direction"). For two-person sentences these two congruence measures are the same: as in the BSL verb POST-TO (Figure 1), the direction of physical movement observed by the participant corresponds to the direction of movement of the implied event. In contrast, the two congruence measures differed for one-person sentences. Semantically, the direction of movement implied by the verb PUT-ON-GLASSES will always be toward the signer's body; however, for the participant observing the sign, the motion will be away from the body.

The pattern of results Secora and Emmorey (2014) observed, semantic congruence effects but not phonological congruence effects, can then only be attributed to the one-person sentences. This is (somewhat) borne out by the marginal simple main effect of semantic congruence for one-person sentences. As the authors did not test for interactions involving sentence type, or report the simple main effect of congruence for two-person sentences, one might even conclude that action-compatibility effects are not observed for transfer events (two-person sentences in which semantic direction coincides with phonological direction), but are only observed for events involving one person performing a non-transfer, bodily action.

It therefore remains to be seen whether signers simulate directional actions while comprehending sentences referring to transfer events, and if so, whether the phonological characteristics of signed languages modulate action simulation. To address this, we used a fully crossed factorial design, manipulating the implied directionality of events, response direction and verb type entirely within-participants. Moreover, we manipulated the two directionality variables within items as well. First, we created pairs of sentences depicting the same event varying only in the implied direction (unlike Secora & Emmorey's design in which each event was depicted by only a single directional sentence). This allows us to tightly control other aspects of iconicity that might be present in sentences, thus creating as strong a possible contrast related to directional movement toward or away from the body. Second, we presented the same sentences to the same participants in different sessions in which the direction of response is varied. This allows us to explicitly test whether action compatibility effects are observed in BSL (a language historically unrelated to ASL), and if so, how they are affected by phonological movement in verbs referring to transfer events.

Experiment 1

In the first experiment, we designed a set of BSL sentences that depicted similar, but not identical transfer events to those of Glenberg and Kaschak (2002) in order to manipulate the number of directional vs. non-directional verbs that appeared in the sentences. In the present design, the action

compatibility effect, if present, should manifest in the form of a significant interaction between implied direction of the event described by the sentence and the response direction: faster responses when the two are compatible. If sentence type modulates action compatibility effects for transfer sentences, we should observe a three-way interaction (for example, interaction between sentence direction and response direction, only for non-directional verbs and not for directional verbs).

Method

Participants

16 deaf adult BSL signers (7 women, 9 men) were recruited from the greater London area. BSL Age of Acquisition ranged from 0-13 years (mean AoA 3.13; with 9 native signers who acquired BSL from birth). Participant age ranged between 19-59 years (mean age 34.69). All participants had normal or corrected to normal vision and were paid for their participation.

Materials

We constructed BSL sentences around events involving 16 directional verbs and 13 non-directional verbs, and moving between 2nd and 3rd person.³ For each verb we created four sentences, two sensible sentences (one depicting an event moving toward the body, one away from the body) and two nonsense sentences (one toward, one away). The structure of each sentence varied to some degree, and was decided on the basis of well-formedness among the alternatives; we gave this consideration precedence over achieving structural consistency across all the sentences (see Appendix 1 in the Supplementary Material file for English glosses of the sentences). Of the 16 directional verbs, four were inflected only for object and thus were invariant with respect to the direction of physical motion toward or away from the signer's body (these were AWARD, DELEGATE, FEEDBACK and INFORM). We labelled these as "partly-directional" and combined them with the non-directional verbs for analysis (because the movement of the verb was away from the signer's body regardless of the directionality of

³ Given constraints regarding the type of transfer verbs required, we were not able to fully balance the number of directional vs. non-directional verbs used in the final set of sentences.

the implied event): analyses thus compared the 17 verbs whose directional movement did not vary depending on the implied event, with the 12 verbs whose directional movement was consistent with the event. Each participant saw all four sentences involving a given verb, with materials divided into four blocks so that each verb occurred only once per block and so that conditions were approximately balanced within each block. Order of blocks and order of trials within a block were randomized for each participant. We treated nonsense sentences as fillers, only analyzing the effects of implied directional motion in sentences depicting real events.

Procedure

Participants sat directly opposite a computer screen (approx. 50 cm away) with a response box oriented sagittally in front of them with the nearest edge approximately 20 cm from their torso, and were told they would see BSL sentences addressed to them (see figure 6). Participants were prompted to press and hold the middle of five buttons on the response box upon the appearance of a fixation cross in the middle of the screen. Upon pressing the button, a video clip of a BSL sentence began to play, and continued to play as long as the middle button was held down. Participants judged the sensibility of the sentence by moving their finger to press a button either away from or toward their body from the middle button (i.e. to the nearest or furthest button on the response box, approximately 4 cm). Participants were told to respond as quickly and accurately as possible. We measured the time it took for participants to release the central button, thus tapping into the motor planning necessary to make their responses (see Borreggine & Kaschak, 2006). Key release times were measured from video onset. To control for variation in sentence duration between items, we presented the same sentence twice to each participant, once in each response direction condition. Participants came for two sessions on different days replicating the same procedure, which differed only in the direction of the response for sensible sentences (toward vs. away from the body) and the order of trials per session. The order of response per session (toward or away from the body for sensible sentences) was counterbalanced across participants. As a result, within a session, the correct response direction was known from the beginning of sentence onset, permitting response planning during the earliest stages of comprehension

(Borreggine & Kaschak, 2006).



Figure 6. One of the authors (D.V.) illustrates the experimental set-up, holding down the central button with index finger while the BSL video plays.

Results

We first checked the accuracy for each sentence and each participant before conducting the main analyses. Sentences were excluded from analysis if overall accuracy was less than 70% (both directional variants were treated as equivalent here); one pair of sensible sentences (verb SPRINT) did not reach this criterion. Four pairs of nonsense sentences also exhibited similarly low accuracy, as some participants came up with interpretations in which they could be considered sensible, but most were correctly rejected. After excluding these problematic items, all participants were over 80% correct (mean = 94.7%) and thus none were excluded. We also excluded individual trials on which there were errors⁴, and for which key release times were longer than 4000msec (the latter including only 0.48% of

⁴ We excluded errors for two reasons. First, on error trials, the relationship between sentence direction and response direction would be reversed, compared to the same item when the response is correct. This might be dealt with simply by recoding such trials to indicate the actual direction of response. However, this would not eliminate a second issue with errors: because the experimental sentences are all sensible, when an error occurs this indicates that the participant has judged a correct sentence as nonsensical for some reason. This calls into question what kind of motor simulations might be expected, compared to processing of a sentence that makes sense.

all trials). Analyses were conducted only on sensible sentences; nonsense items were treated as fillers.

We conducted 2x2x2 ANOVA (sentence direction x response direction x verb type: directional vs. non-directional), on key release times, with separate analyses treating participants as random effects (F1) and sentences as random effects (F2). We use the variable label "sentence direction" to refer to the implied directionality of the event described by a sentence (as in Glenberg & Kaschak, 2002), and thus action compatibility effects should be observed as an interaction between sentence direction and response direction. We treated sentence direction as within-items because the pairs of directionally different sentences were constructed as very close parallels to each other.

The main effect of response direction was significant only by items ($F(1,15) < 1$; $F(1,26) = 9.57$, $p = .005$, $\eta^2_{\text{partial}} = 0.269$) thus presumably related to differences between participants in their relative speed of preparing responses toward or away from the body. There was a significant effect of verb type ($F(1,15) = 134.04$, $p < .001$, $\eta^2_{\text{partial}} = 0.899$; $F(1,26) = 5.83$, $p = .023$, $\eta^2_{\text{partial}} = 0.183$): sentences with directional verbs were overall slower than sentences with non-directional verbs (release time 2344 msec and 2093 msec respectively from sentence onset). The main effect of sentence direction and the interaction between sentence direction and verb type were reliable by participants only (sentence direction: $F(1,15) = 7.89$, $p = .013$, $\eta^2_{\text{partial}} = 0.345$; $F(1,26) = 1.92$, $p = .178$; sentence direction x verb type $F(1,15) = 6.69$, $p = .021$, $\eta^2_{\text{partial}} = 0.309$; $F(1,26) = 1.26$, $p = .272$). Crucially there was no interaction between response direction and sentence direction ($F(1,15) < 1$, $F(1,26) < 1$), nor did the other interactions reach significance (Response direction x verb type $F(1,15) = 6.67$, $p = .021$, $\eta^2_{\text{partial}} = .308$; $F(1,26) = 3.61$, $p = .069$; three-way interaction $F(1,15) = 1.18$, $p = .294$, $F(1,26) < 1$): see Figure 7.

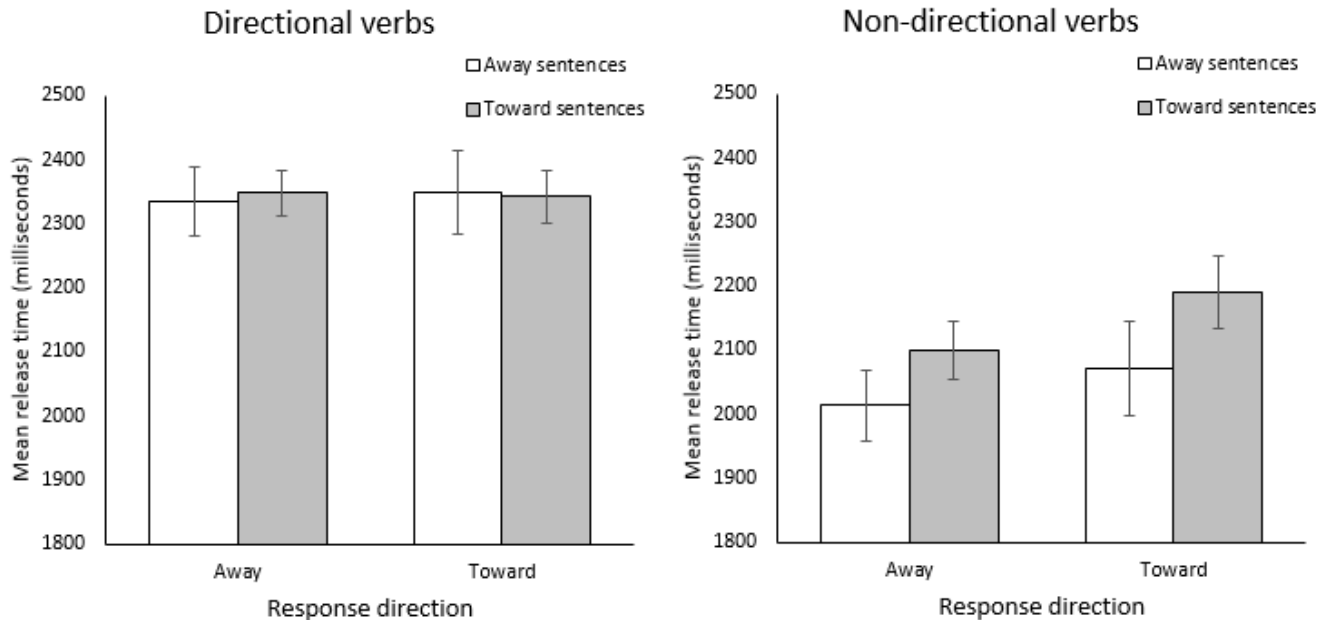


Figure 7: Results of Experiment 1, BSL 2nd/3rd person comparing directional/non-directional verbs. We report correct button release times to sensible sentences as a function of response direction and sentence direction (both away from or toward the body), separately for directional and non-directional verbs. Partly-directional verbs were grouped with non-directional verbs for this analysis (see main text). Error bars reflect standard error of the mean (by participants).

Finally, we carried out one additional set of ANOVA to assess whether native and non-native BSL signers performed differently in the task: including group (native/non) in 4-way ANOVA along with the three factors included in the main analysis. The pattern of results remained unchanged and there were no tests involving Group that reached significance both by subjects and items: The main effect of Group, and the interaction between Group and sentence direction were significant only by items (Group: $F(1,14)=2.51$, $p=.135$; $F(1,26)=42.1$, $p<.001$. Interaction: $F(1,14)=4.40$, $p=.055$; $F(1,26) = 4.71$, $p=.039$. All other $F<1.6$, $p>.2$).

Discussion

In Experiment 1 we did not find an action compatibility effect; responses were not faster when the

sentence implied an event moving in the same direction as the hand action required to make a sensibility decision. This was also not modulated by sentence type: patterns of release times were no different when the movement in the sign varied depending on the verbs' arguments (directional verbs) vs. when it did not (non-directional verb). Although there may have been some differences among specific items in the different conditions this should not have had consequences for the lack of action compatibility effects, as each sentence occurred both with movement toward and away from the body for each participant in the different sessions. This suggests that the lack of action simulation – and thus lack of motor system involvement – may be related to perceiving sign language, which is produced by means of motor movement of the same articulators involved in the actual action event; or alternatively, that iconicity of the BSL sentences may have provided enough information that motor activity was not needed during comprehension (in line with the proposal by Zwaan, 2014).

A first null result, while providing positive evidence in favour of the null hypothesis, is not yet sufficient to allow us to draw conclusions about motor simulation in sign language comprehension. Furthermore, it may be the case that action compatibility effects require the direction of the button press, and thus the motor planning required to prepare the response, to closely converge with the direction implied by the event. In the 2nd/3rd person transfer used in Experiment 1, the direction of the event being implied does not map exactly onto the direction of the button press (see Secora & Emmorey, 2014, p.5-6). As illustrated in Figure 3, the position of a 3rd person referent in signing space is such that the implied event would move somewhat diagonally, offset approximately 45° from the center of the producer's body and offset approximately 45° from the participant's direction of response. If sentence compatibility effects require close directional convergence between the sentence judgment response and the simulated event, this discrepancy could reduce or eliminate action-response compatibility effects compared to English for which the implied direction of actions is not constrained in this manner. In Experiment 2 we address this issue by using sentences for which the movement implied in described events corresponds more directly to the movement implied by the use of signing space.

Experiment 2

In this experiment, we converted the BSL sentences from Experiment 1 into sentences implying transfer between 1st/2nd person. Sentences with directional verbs like POST-TO that encode transfer between 1st/2nd person (e.g. *I posted the box to you*) involve phonological movement between the signer's body (1st person) and a location opposite the signer's body (2nd person). Thus, directional verbs move along the central axis, straight toward or straight away from the body. This modification of person reference in the verbs creates complete directional convergence between the direction of motion entailed by the event, the physical motion present in the sign, and the direction of button-press response (see Figure 8). The same is true of the partly directional verbs such as AWARD-TO: for sentences involving 1st and 2nd person they behave like other directional verbs. For sentences with non-directional verbs which include 1st and 2nd person pronouns, there is also identical implied direction between participants in the described events and the button-pressing response (although the physical movement in such signs is constant regardless of the direction implied by the sentence; see Figure 4).



Figure 8. Correspondence between directional movement and implied motion in 1st/2nd person sentences. Left: stills from BSL verb POST-TO in a 1st-2nd person sentence (English translation: *I posted [something] to you.*) Center: stills from BSL verb AWARD-TO in a 1st-2nd person sentence (English translation: *I awarded the degree to you.*) Both sentences include a verb that moves from 1st to 2nd person, and the angle of physical motion in the sentence, and the angle of motion implied in the sentence are both directly aligned with the direction of motion required for response, as indicated by the diagram on the right.

Method

Participants

16 deaf adult BSL signers who did not participate in Experiment 1 were recruited from the greater London area. Age of acquisition of BSL ranged from 0-11 years (mean 3.85; with 7 native signers who

acquired BSL from birth). Age of acquisition of English ranged from 0-5 years (mean 2.19): this is particularly relevant as the same individuals also participated in Experiment 4 which used English sentences. Participant age ranged between 18-59 years (mean age 30.75). All participants had normal or corrected to normal vision and were paid for their participation. One additional person participated in this study but was excluded due to low accuracy in Experiment 4 in which s/he also participated (including the data from this participant in Experiment 2 did not change the patterns of results we report here).

Materials

BSL materials for Experiment 2 were closely based on those we used in Experiment 1, but all sentences depicted transfer from 1st to 2nd or from 2nd to 1st person (see Appendix 2 in the Supplementary Material file for English glosses of the sentences). This had the consequence of making the sentences shorter (mainly because the 3rd person name JAMES and pronoun were replaced by a single 1st person pronoun in most cases). We also replaced the verb SPRINT (excluded in Experiment 1) with sentences containing BE-NEXT-TO. The non-directional verb TOAST was changed to DRINK, and there were a few other sentence-specific changes as shown in Appendix 2. Importantly, the verbs we termed "partly-directional" (like AWARD) were grouped with the directional verbs for analysis in this experiment, because for all of them the direction of physical movement in 1st-2nd person sentences corresponded to the direction of implied motion. List creation, task order etc. were the same as in Experiment 1.

Procedure

The procedure for Experiment 2 was the same as for Experiment 1, and it was similarly carried out in two separate sessions on different days, varying only in the direction of response for sensible sentences and the order of trials.

Results

As in Experiment 1 we first analyzed accuracy for sentences and for participants before proceeding further. All of the experimental sentences (i.e., the sensible ones) were above the criteria

for exclusion, while six pairs of nonsense sentences exhibited tendencies to be judged acceptable by some participants. Once these were excluded all participants were sufficiently accurate that none were excluded. We then excluded individual trials on which there were errors, or release times that were longer than 4000 msec (the latter including only three trials, 0.03% of the total).

We analyzed only the responses for sensible sentences, using button release latencies as our dependent measure. Again we used a 2x2x2 ANOVA (sentence direction x response direction x verb type). There was a main effect of Response direction by items only ($F(1,15)=1.06$, $p=.318$, $F(1,27)=32.89$, $p<.001$, $\eta^2_{\text{partial}}= 0.549$) possibly related to participant-specific differences in speed to respond toward vs. away from the body. Sentences referring to movement toward or away from the body did not differ in release times (Sentence direction $F_1<1$, $F_2<1$). Verb type was significant only by participants $F(1,15)=50.16$, $p<.001$, $\eta^2_{\text{partial}}= 0.770$, $F(1,27)=3.58$, $p=.069$, $\eta^2_{\text{partial}}= 0.117$ possibly reflecting tendencies for sentences with directional verbs to be shorter than sentences with non-directional verbs and thus elicit quicker responses. As in the previous experiment there was no interaction between response direction and sentence direction ($F_1<1$, $F_2<1$). None of the other interactions were reliable either (Response direction x verb type $F_1<1$, $F_2(1,27)=1.99$, $p=.170$; Sentence direction x verb type $F(1,15)=1.75$, $p=.206$, $F(1,27) = 1.09$, $p=.306$; three-way interaction $F(1,15)=1.41$, $p=.254$, $F_2<1$) (see Figure 9).

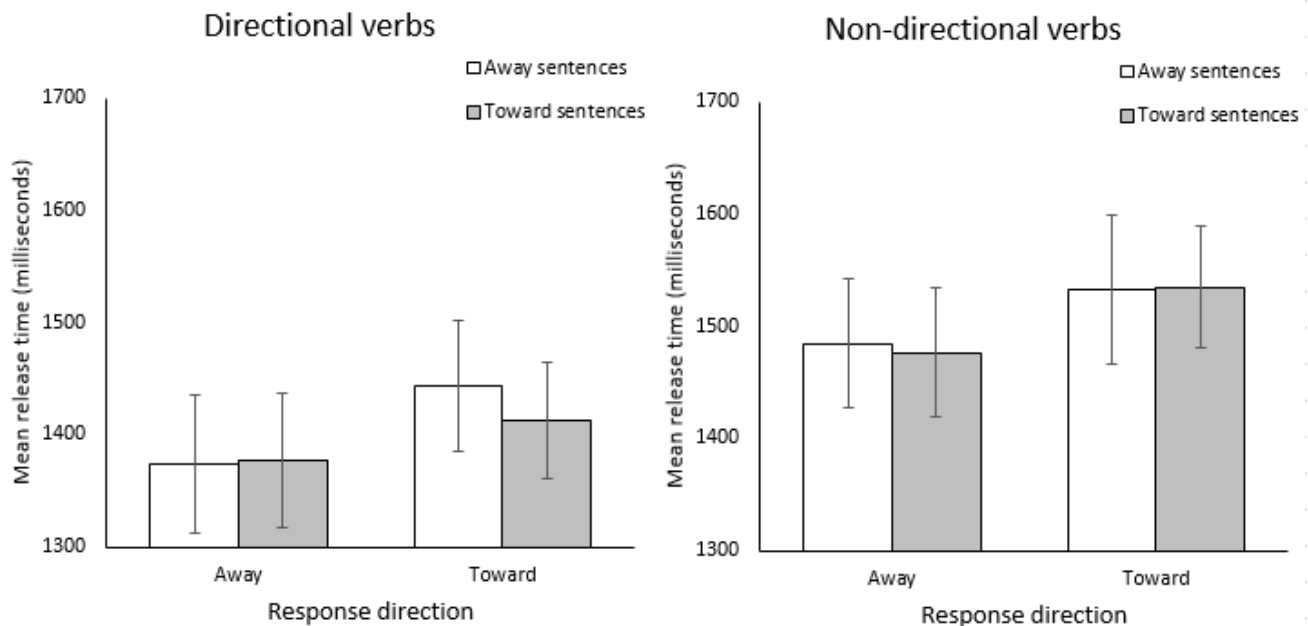


Figure 9: Results of Experiment 2 (BSL 1st/2nd person comparing directional/non-directional verbs). We report correct button release times to sensible sentences as a function of response direction and sentence direction (away from or toward the body), separately for sentences with directional and non-directional verbs. Partly-directional verbs were included with directional verbs in this analysis as their behaviour is the same for 1st/2nd person sentences. Error bars reflect standard error of the mean (by participants).⁵

Again we concluded by carrying out one additional analysis adding group (native/non-native) as a factor to the above. The pattern of results remained unchanged with no tests involving group reaching significance by subjects and items. The main effect of group and its interaction with response direction were significant only by items (Group: $F_1 < 1$, $F_2(1,27)=7.66$, $p=.010$. Interaction: $F_1(1,14)=2.71$, $p=.122$; $F_2(1,27)=47.9$, $p<.001$. All other $F < 2.2$, $p > .15$).

Discussion

As in Experiment 1, we found no action compatibility effect in Experiment 2: responses to BSL sentences were not faster when the direction of response is fully congruent with the event depicted by a sentence. Thus, evidence again favoured the null hypothesis of no action compatibility effect. There was also no tendency for sentence type to modulate response compatibility in this Experiment,⁶ overall suggesting that action events might not be simulated in BSL comprehension in the same way they are in reading English. One may wonder, however, whether our choices of materials for Experiments 1 and 2 may have contributed to our lack of response compatibility effects. In order to compare directional and non-directional verbs, we used events that may have differed in certain crucial respects from those events described in the original English study by Glenberg and Kaschak (2002). Other differences in methodology such as the repetition of verbs in multiple conditions may have also contributed to the lack

⁵ The faster response times here compared to Experiment 1 (Figure 6) reflect sentence length differences: the 1st/2nd person sentences were quicker to produce than the 2nd/3rd person sentences, as they did not contain the 3rd person name JAMES.

⁶ As the sentences in Experiments 1 and 2 were close modifications of each other, we also carried out an additional analysis involving all 32 participants, treating Experiment as a between-participants factor (2nd vs 1st person) factorially combined with Response Direction, Sentence Direction and Verb Type. We did not find evidence for direction simulation in this analysis either: null effects for Response Direction × Sentence Direction and all higher-order interactions involving these two terms.

of effects in Experiments 1 and 2 (although we found the same results in secondary analyses considering only the first appearance of a given verb). Therefore, in Experiment 3 we conducted a closer replication of Glenberg and Kaschak (2002) in BSL, using materials that were close translations of their English sentences and avoiding repetition of verbs in different conditions.

Experiment 3

Participants

The same participants from Experiment 1 also participated in this study, which was conducted along with Experiment 1 in two sessions conducted on different days. Order of the two studies within a session was manipulated between participants: if a participant performed Experiment 1 first in session 1, they also performed it first in session 2.

Materials

For Experiment 3, the original English sentences from Glenberg & Kaschak (2002) were translated into BSL by N.F., a native deaf BSL signer also highly proficient in English, in consultation with other highly proficient BSL-English bilinguals. BSL sentences were video-recorded and edited into single sentence clips. As in Glenberg and Kaschak (2002) and also our Experiment 1, all sentences depicted transfer from 2nd to 3rd or from 3rd to 2nd person, corresponding with direction of motion toward or away from the body, respectively (see Figure 3). Note that while the English sentences in Glenberg & Kaschak (2002) used different names (e.g. Adam, Andy) for the 3rd person agent/patient in each sentence, in the BSL sentences we opted to use just one name: “James” (initialized “J”) as in Experiment 1. 20 abstract and 20 concrete events were included, with two sentences depicting each event (one toward the body, one away from the body); nearly all involved directional predicates in BSL (see Appendix 3 in the Supplementary Material file for English glosses of the sentences). 40 nonsense sentences were also filmed, again closely resembling those used by Glenberg and Kaschak (2002). As in the previous experiments we treated these nonsense sentences as fillers, only analyzing the effects of implied directional motion in sentences depicting real events. Different test lists were created so that

each participant saw only one sentence referring to a given event, with equal numbers of abstract/concrete, toward/away sentences. Sentences were randomly ordered for each participant.

Procedure

The procedure was the same as in previous Experiments. As participants participated in both Experiment 1 and 3 in the same sessions, they were given a five-minute break between the two tasks, and response direction was kept the same within a session. Comparable practice trials were presented at the start of each task.

Results

As in the previous experiments we analyzed accuracy per item and per participant before proceeding. All of the experimental sentences met the criteria for inclusion and only eight of the filler (nonsense) sentences did not, and all of the participants were sufficiently accurate overall (mean accuracy 92.0%). Again we analyzed only the responses for sensible sentences, excluding errors and extremely long button releases: 4000 msec or longer (1.0% of trials). We used 2x2x2 ANOVA on button release latencies (sentence direction x response direction x concreteness).

None of the main effects or interactions reached significance both by participants and items. Response direction was not significant ($F_{1<1}$, $F_{2<1}$), nor was concreteness ($F_{1(1,15)} = 3.28$, $p = .090$, $F_{2<1}$). Similarly the effect of sentence direction was reliable only in the item analysis ($F_{1(1,15)} = 3.29$, $p = .090$, $F_{2(1,38)} = 7.21$, $p = .011$, $\eta^2_{\text{partial}} = .160$) possibly reflecting small differences in sentence duration in the two conditions. Crucially the interaction between response direction and sentence direction was not significant ($F_{1<1}$, $F_{2<1}$) nor were any of the other interactions (Response direction x concreteness $F_{1<1}$, $F_{2<1}$; Sentence direction x concreteness $F_{1(1,15)} = 1.56$, $p = .231$, $F_{2(1,38)} = 2.21$, $p = .145$; three-way interaction $F_{1<1}$, $F_{2<1}$); see Figure 10. The follow-up analysis adding group (native/non-native) again found no effects of group. Main effect of group and its interaction with response direction were significant by items only (Group: $F_{1<1}$, $F_{2(1,38)} = 10.55$, $p = .002$. Interaction: $F_{1<1}$, $F_{2(1,38)} = 6.48$, $p = .015$. All other $F < 1$).

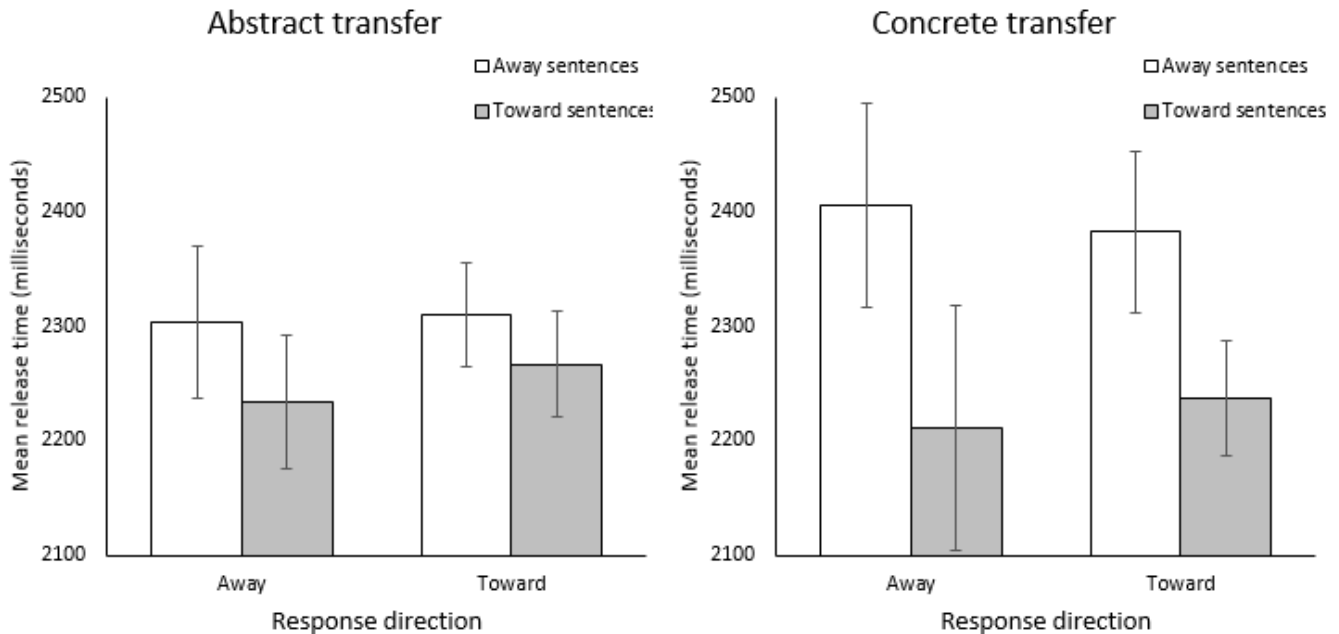


Figure 10: Results of Experiment 3, BSL replication of Glenberg & Kaschak, 2002). We report correct button release times to sensible sentences as a function of sentence direction and response direction (both away from or toward the body), separately for abstract and concrete sentences. Error bars reflect standard error of the mean (by participants).

Discussion

This accumulation of null effects begins to suggest that, indeed, BSL comprehension is not sensitive to motor planning processes, at least so far as directional motion of transfer events is concerned. One possibility is that some aspect of comprehending sign language may change the extent to which motor planning is involved in language comprehension. But it may simply be that the studies as presently conducted are insufficient to detect such effects if they are present, despite our attempts to maximize power by the use of within-participants and within-items design. It is also possible that the apparatus we used in the present study was sufficiently different to that used in previous studies to eliminate the effects of motor planning: in order to achieve greater precision in measurement of response latencies we used a response unit (Psychology Software Tools Serial Response Box) which

had a relatively small distance between the relevant keys (approximately 4cm), compared to previous studies which used more distant response keys on a computer keyboard (approximately 10cm). In order to address these issues, Experiment 4 assesses whether the lack of action compatibility effects in Experiments 1-3 is indeed specific to the use of sign language. We replicated the original experiment by Glenberg and Kaschak (2002) using visual presentation of written English sentences, but with sample size and other characteristics of the experimental design closely corresponding with Experiments 1-3. Part of Experiment 4 was conducted concurrently with Experiment 2, testing the same (BSL-English bilingual) participants who took part in that study.

Experiment 4

If the lack of an effect in Experiments 1, 2 and 3 is due to the use of sign language in the task, we should be able to observe action compatibility effects in the same participants when they are reading English sentences. Obtaining action compatibility effects using English is especially important in the face of the null effects we have reported so far, showing that our procedure is sound and our sample size sufficient to detect this effect, if it were there.

Participants

The same deaf participants who participated in Experiment 2 were also part of this study, plus one additional participant whose accuracy was low in the English task (see Results) and who was replaced; a total of 16 BSL signers were included in the final data set for both of these experiments. All of them were bilingual in BSL and English.⁷ Order of the two studies within a session was manipulated between participants: if a participant performed Experiment 2 first in session 1, they also performed it first in session 2.

Materials

⁷ Actually, all of the the signers recruited for the experiments reported here were BSL-English bilinguals. This status holds true of most users of sign language, as they must also be able to communicate in the spoken/written language of the surrounding hearing community.

We used the original set of concrete, abstract and corresponding nonsense sentences from Glenberg and Kaschak (2002). Preparation of lists, randomization etc. were carried out exactly as in Experiment 3.

Procedure

The procedure was the same as in Experiments 1-3 except that the English sentences were displayed as text, remaining on the screen until the response button was released to initiate a response. Sentences appeared as white text on a black background and were presented in Courier New 18 point bold typeface (1024x768 screen resolution). As participants participated in both Experiment 2 and 4 in the same sessions, they were given a five-minute break between the two tasks, and response direction was kept the same within a session.

Results

As in the previous experiments we first analyzed accuracy by items and participants. In the item analysis there were four sensible sentence pairs with low accuracy overall that were excluded. All of these use double object constructions ("You shot Shawn the rubber band"/"Shawn shot you the rubber band", "Mike rolled you the marble"/"You rolled Mike the marble", "Paul hit you the baseball"/"You hit Paul the baseball", "You kicked Joe the rugby ball"/"Joe kicked you the rugby ball"), although not all double-object sentences had such low accuracy. Eight of the nonsense sentences (treated as fillers) also had low accuracy. Having excluded these sentences, we examined participants' performance. As mentioned in the Participants section, one participant had low accuracy in the English task (60% correct overall) and was excluded from all analyses (including Experiment 2). The remaining participants were highly accurate (89.2% correct overall; and 92.7% correct for sensible sentences only). For analysis of release times, we excluded nonsense sentences, errors and especially slow release times (>4000 msec, 2.2% of trials).

We analyzed Experiment 4 using 2x2x2 ANOVA (response direction x sentence direction x concreteness) by participants and items. The main effect of response direction was significant only by items ($F(1,15)=2.40$, $p=.142$; $F(1,34)= 9.85$, $p=.004$) possibly reflecting subject-specific differences

in release times for responses away from the body vs. toward the body. The main effects of sentence direction and concreteness were not significant (sentence direction: $F(1,15)=3.78$, $p=.071$; $F_2<1$; concreteness: $F(1,15)=2.627$, $p=.126$, $F_2<1$). The crucial interaction between response direction and sentence direction was significant ($F(1,15)= 8.13$, $p=.012$, $\eta^2_{\text{partial}}= .352$, $F_2(1,34)=6.28$, $p=.017$, $\eta^2_{\text{partial}}= .156$) and did not significantly differ as a function of concreteness (three-way interaction $F(1,15)=2.99$, $p=.104$, $F_2<1$). None of the other interactions were significant (concreteness \times response direction $F_1<1$, $F_2<1$; concreteness \times sentence direction $F_1<1$, $F_2<1$); see Figure 11.

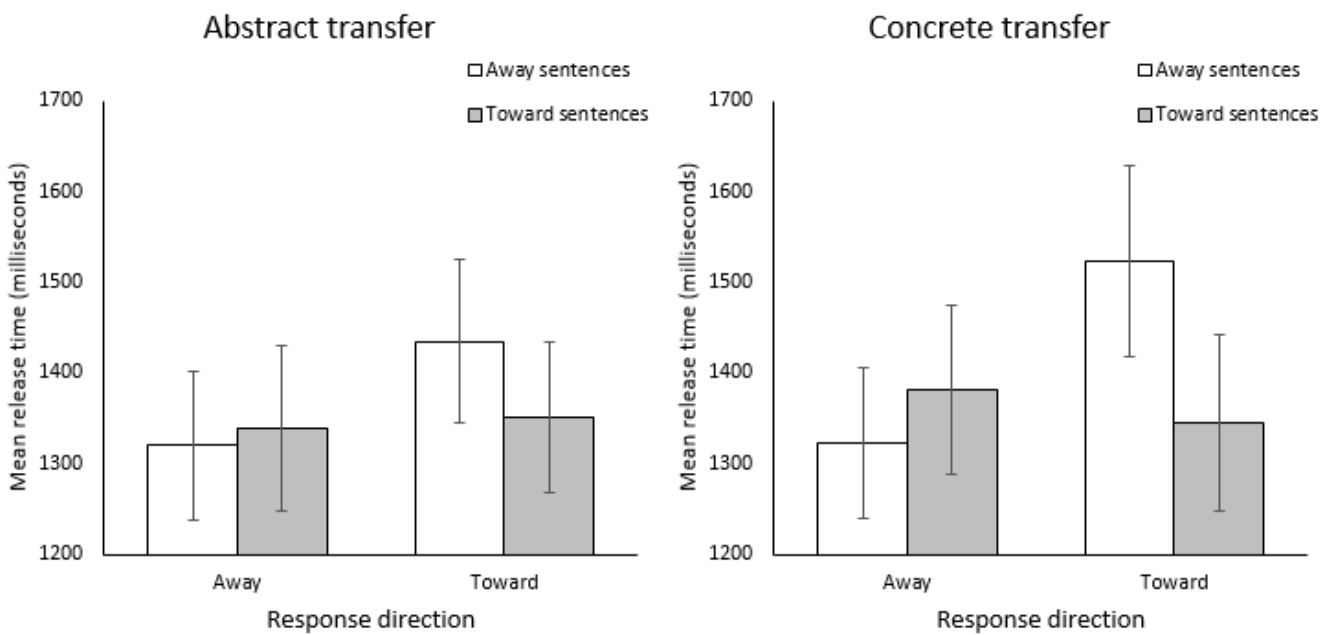


Figure 11: Results of Experiment 4 (English visually presented sentences). We report correct button release times to sensible sentences as a function of sentence direction (Away (from) or Toward the body) and whether the response direction is congruent or incongruent with the directional event being described, separately for concrete and abstract sentences. Overall, responses were faster when the response direction corresponded to the direction of the event described in the sentence. Error bars reflect standard error of the mean (by participants).

As in the previous three experiments we followed up by adding group (native/non-native) to the analysis above. Although the main effect of group approached significance ($F(1,14)=4.44$, $p=.054$; $F_2(1,44)=139$, $p<.001$) with native BSL signers tending to be faster than non-natives in this English reading task (native signers' mean release time = 1198ms (sd by subjects = 323), non-natives 1514

(282)) there were no interactions involving it (4-way interaction $F(1,14)=3.464$, $p=.084$, $F_2<1$. All other $F<1$).

Finally, we conducted statistical tests to test whether the crucial pattern of results in Experiment 4 is statistically different to the two most comparable BSL data sets we reported earlier: comparison to Experiment 2, in which the same participants responded to a different set of BSL sentences; and comparison to Experiment 3, in which a different set of participants responded to translation-equivalent BSL sentences. For each experiment we converted each participant's performance to a congruence score: the average release time for trials in which the response direction and sentence direction were the same, minus the average release time for trials in which the two were different. Negative values thus reflect faster release times for congruent pairings regardless of directionality. We then compared congruence scores for English sentences (Experiment 4) to those for BSL sentences (Experiment 2 or 3) using t-tests. For the comparison between Experiments 2 and 4 (same participants, different sentences): subjects paired sample $t(15)=-3.01$, $p=.009$, items independent sample $t(63)=-2.12$, $p=.038$. For the comparison between Experiments 3 and 4 (different participants, translation-equivalent sentences): subjects independent sample $t(30)=-2.84$, $p=.008$, items paired sample $t(35)=-2.69$, $p=.011$. This further supports the apparent pattern in the separate statistical tests: the action compatibility effect was observed only in English and not in BSL when the sets were directly compared on the relevant dimension.

Discussion

In contrast to Experiments 1-3 in which we repeatedly found no action compatibility effects in BSL, these effects were reliable in printed English, replicating the original Glenberg and Kaschak (2002) study with exactly the same deaf participants as in Experiment 2 (and translation-equivalent sentences to those in Experiment 3). Finding this effect in English vs. no such effect in BSL, in the same population, rules out possibilities that the null effects in BSL were related to lack of power, or to specific characteristics of the experimental apparatus or procedures, suggesting instead that action simulation is involved in language

comprehension when visually comprehending written language referring to transfer events, but not when comprehending the same kind of events in a signed language.

General Discussion

We assessed whether the same effects of action simulation observed during comprehension of English directional sentences can be observed in the comprehension of BSL directional sentences. Action compatibility effects have been argued to demonstrate that sentence comprehension relies on simulation of the actions encoded in the sentences. Specifically, responses are facilitated when the action implied by a sentence is directionally congruent with the action required to judge sentence sensibility, which suggests that motor simulation is involved in sentence comprehension. Operating in the visual-spatial modality, sign languages necessarily involve motor movement and utilize the high potential for action iconicity that the medium affords. These properties of sign languages make them an especially interesting test case for action simulation. In the introduction we spelled out several possible outcomes in BSL: action simulation for transfer events is the same as in written/spoken language; it is boosted by phonological movement encoding transfer in directional verbs; it is reduced or eliminated because iconic properties of sign languages provide additional contextual information not present in written English, or because the same articulators are used for language and action.

We found no evidence for action compatibility in BSL sentence comprehension across three experiments (1, 2, 3). The results thus suggest that viewing sign language sentences implying transfer events does not engage the motor system in comprehension in the way that has been found for written presentation of comparable English sentences. These results do not come about because of lack of power: we observed an action compatibility effect with the same participants when presented with English written sentences. This finding also indicates that it is not knowing a sign language *per se* that modulates the use of action simulation in sentence comprehension (i.e. in a second language), because signers showed the same pattern as non-signers for English sentences. The results further suggest that it is not phonologically-encoded transfer motion that blocks the involvement of action simulation in

comprehension, as there was no difference found between directional vs. non-directional verbs.

Why then do we fail to see action compatibility effects in BSL? A first possibility is that the involvement of our sensori-motor systems in language comprehension depends on the format in which language is presented. Apart from the recent study by Secora & Emmorey (2014) on ASL, to which we return below, action compatibility effects have been found previously, and replicated here, only for language presented in a unichannel format – written text (as in Glenberg & Kaschak 2002) or acoustically presented speech (Borreggine & Kaschak, 2006). These formats are not directly evocative of the events encoded in the sentences; they have no explicit visual/imagistic correspondence to the events being described. They are impoverished in this sense compared to the richer, depictive event representations provided by the visual modality of signed language. Thus, it may be that an “impoverished” written/spoken language representation relies on action simulation in comprehension, while a richer, multichannel language presentation – particularly involving depictive, iconic representation – does not. The action may not need to be “filled in” or simulated in the context of a rich, depictive representation of the event, consistent with Zwaan's (2014) proposal in which availability of referents and actions in the comprehender's environment may obviate the need to simulate them.

A related possibility is that the iconic properties of sign language action predicates play a role in affecting the involvement of the motor system. Even the non-directional verbs, which do not overtly encode the direction of motion of the action, were often highly iconic of the action (e.g. BSL DEAL-CARDS which resembles the act of dealing cards by a card dealer, but does not vary in its direction depending on who is doing the dealing). Such iconic properties may engage the same effectors in simulation, perhaps with other aspects of the event such as hand configuration and orientation being more salient than generic aspects of directional motion. Our creation of materials, in which sentences were kept as comparable as possible aside from their directionality, creates a contrast only along the dimension of directionality and not other aspects of bodily experience which may be simulated by comprehenders.

A role of other iconic properties in signed languages in reducing motor simulation effects,

however, does not seem consistent with the findings in ASL by Secora and Emmorey (2014): action compatibility effects were observed in that study, as reflected in their analysis of semantic congruence. As we mentioned in the introduction, their effect seems to be driven by single-person actions like PUT-ON-GLASSES and not by two-person actions like the transfer events we investigated in the present studies. One possibility for the difference is that simulation may be greater for simple sentences describing concrete actions with inanimate objects than for sentences describing transfer events and involving two participants. Sentences of the former kind may permit far more opportunities to simulate action using one's own body (such as putting on glasses). Such simulation may be weakened or eliminated when the actions are less focused on the body itself and involve actions of transfer between people.

Differences between sentence structures might also have played roles in the different patterns of effects observed in English, BSL and ASL, and may have more general consequences for the nature of simulation during language comprehension. In particular, word order differences may play a role. While the English sentences follow a rigid Subject-Verb-Object order, the BSL sentences had somewhat variable sentence structures (see Supplementary Materials), and the ASL sentences were all verb-final (a word order common to many sign languages; see Leeson & Saeed 2012 for an overview). These differences may have substantial effects upon the information that is available to simulate an event in order to aid comprehension. In the English sentences used by Glenberg and Kaschak (2002), in the majority of cases the first word already provides complete information about the directionality of the event within the context of the experiment. In sentences like "*Andy delivered the pizza to you*", upon reading the name "*Andy*" it is certain that the event would be toward the participant ("*you*"); and the opposite is true for sentences like "*You delivered the pizza to Andy*". Evidence compatible with such very early action simulation comes from a study of spoken English by Borreggine and Kaschak (2006), who found action compatibility effects only very early: when a response direction cue coincided with the start of a spoken sentence, but not at all when the cue occurred later (50 msec, 500 msec or 1000 msec after the end of the sentence). Borreggine and Kaschak suggest that only a few relevant action details

are available as the first few words unfold; in this case, arguably only the direction of motion (away from the body) until "pizza" provides additional constraints on the action such as the hand and arm configuration that would be needed to perform such an action. The absence of action-compatibility effects when response planning occurs at sentence offset (Borreggine & Kaschak, 2006) implies that motor activity is no longer involved as more fully specified interpretations are developed, supporting the notion that dynamic mental simulations of initially-underspecified events are developed in order to provide context as additional linguistic information is integrated (see also Glenberg et al., 2008 for evidence from TMS motor evoked potentials that motor simulation for transfer sentences, whether concrete or abstract, can occur very early in sentence comprehension). Specific characteristics of motor simulation may be short-lived as well: Zwaan and Taylor (2006) found action compatibility effects for sentences referring to rotary motion of the hand when words were displayed by rotating a dial in one direction or the other, but compatibility effects were only observed for the verb (where direction of rotation was specified). Similar evidence comes from studies by Bub and Masson (2010) investigating different hand configurations associated with holding or using objects. They found that motor activation varies dynamically during sentence comprehension, with early general activation related to possible affordances of objects being described (e.g. the difference between picking up a pencil and writing with it), becoming more specific later as additional contextual information becomes available (see also Heard, Masson & Bub, 2015).

One may thus wonder whether the single-person ASL sentences used by Secora and Emmorey (2014) were structured in a way that maximized the possibility of observing direction-related motor simulation, not only because they describe bodily activities of a single individual, but also because as all of these sentences were verb-final. Although more information is provided by the time the verb is produced compared to the English sentences used by Glenberg and Kaschak (2002) and other such studies, the very last piece of information available to the comprehender of these ASL sentences is the direction of movement. Consider the example "You put on glasses" (GLASSES YOU PUT-ON-GLASSES). The object and subject of the sentence are produced before the verb. Moreover, hand

configuration and location are available before movement (e.g. Emmorey & Corina, 1990), so the very last piece of information a comprehender gets is directional motion. As opposed to the situation we described in English above, the event has been otherwise fully specified by the time the motion occurs, which might suggest that "impoverished" situations are not necessary for simulation to occur. This seems especially true given the highly predictable contexts in the English and ASL experiments: verb always appeared second in English, and was always final in ASL.⁸ Taken together, these findings suggest tight constraints upon the nature of action simulation in sentence comprehension; future research on action compatibility effects in spoken languages with verb-final word order, e.g. Japanese or Turkish, would be particularly illuminating in further characterising the nature of the information that is simulated while comprehending sentences of various types.

Thus, our research suggests that the involvement of action simulation in language comprehension, at least when it comes to motor simulation related to comprehending transfer events, is dependent on the format and modality of language presentation. This is important to our understanding of the conditions under which and the degree to which language comprehension involves simulation. The idea that the use of action simulation may be contextually dependent is in line with previous observations that contextual variables (e.g. abstract vs. concrete contexts) modulate effects of embodiment in terms of differential activation of sensori-motor representation in language processing

⁸ While the BSL experiments we reported here were not designed to address this issue, we conducted post-hoc analyses to test whether there was evidence for action compatibility effects in verb-final sentences compared to those with verbs in other positions. None of our experiments yielded such evidence. In Experiment 1, approximately half of the verbs appeared in final position only in one condition (mostly the "toward" sentences). Of the remaining 16 sentences, 7 were verb-final in both conditions and 9 in neither. We compared the degree of facilitation for congruent combinations using t-tests by items (negative value = classic action-compatibility effect). There was no difference between the two: $t(14)=-0.85$, $p=.43$. Verb-final sentences mean congruence effect = +13ms, other sentences = -9: any trend is in the opposite direction that would be predicted. In Experiment 2, there was no difference between the verb-final sentences and others: $t(27)=1.41$, $p=.17$ (verb-final sentences mean congruence effect = -16ms, other sentences = +15ms). In Experiment 3, no "toward" sentences were verb-final (all sentences involving a 3rd-person recipient ended with the name sign for JAMES or the object of transfer, while some sentences involving 2nd-person recipient ended with the verb). Therefore we only compared sentences implying movement toward the body. Again there was no difference in the magnitude of action compatibility effects: $t(38)=-1.40$, $p=.17$. Verb-final sentences mean = +57ms, other sentences = +6ms.

(Willems & Casasanto, 2011; Zwaan, 2014). Context dependency of the degree to which embodiment (i.e. the involvement of sensori-motor systems) is evident in language comprehension demonstrates a fundamental flexibility, rather than rigidity, of the architecture of language processing.

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