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Under-standing: How embodied states shape inference-making

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ABSTRACT

How do embodied states influence the inferences people make about the meaning that is intended by communicators? We propose that embodied states encourage mental representation of certain meanings while inhibiting others, thereby facilitating or hindering comprehension in social interactions and potentially causing miscommunication. Four experiments demonstrate that bodily postures incompatible with the intended meaning of a sentence attenuated inferences of those meanings, especially when the intended meaning was not articulated directly and required more extensive inference-making effort. Participants were faster at responding to sentences containing verbs inferring a sitting position when they were sitting than when they were standing, and vice versa. Participants were also more likely to interpret the intended meaning of sentences as relevant to sitting when participants were themselves sitting, and relevant to standing when participants were standing. These outcomes were especially evident when the sentences required higher-interpretive effort (e.g., used indirect language) than lower-interpretive effort (e.g., used literal language). These results suggest that embodied states shape inferencemaking and can thereby influence comprehension and affect communication success, especially when inferences are more effortful to make.

1. Introduction

What predicts success in communicative interactions has long been an area of research interest (e.g., Berger & DiBattista, 1993; Knowlton & Berger, 1997). Effective comprehension within conversations depends on the ease with which people make appropriate inferences about communicators' intended meaning (R.W. Gibbs Jr., 2003; Grice, 1975; Kasher, 1982). Inference-making about intended meaning helps people anticipate or understand others' intentions, actions, and emotions (A. Majid, Sanford, & Pickering, 2007), thereby facilitating responses to those others (Cook, Limber, & O'Brien, 2001). For instance, if someone says "hit me," inferring that the speaker means "give me another card in this blackjack game" would lead to less violent outcomes than would mistakenly inferring an interpersonal challenge. Consequently, researchers have sought to understand how inference-making works (Bach, 1999; Kintsch, 1993), and especially why it may succeed or fail (Cain, Oakhill, Barnes, & Bryant, 2001; Linell, 2015). The current work advances our understanding of inference-making by testing the role of embodied states in shaping inferences during comprehension. We suggest that embodied states, such as standing or sitting in the context of processing relevant concepts, enhance the perceived viability of certain

meanings, while inhibiting the perceived viability of other meanings, consequently affecting derivation of the intended meaning. A large body of literature has shown that embodied states are associated with communication comprehension (e.g., Fischer & Zwaan, 2008; R.W. Gibbs Jr., 2013; Vankov & Kokinov, 2013). However, such investigations do not provide evidence for the cognitive processes that underlie this link. The current work extends the embodiment-comprehension literature by investigating the influence of embodiment on one such process—inference-making. This research therefore contributes to a broader theoretical framework concerning the role that physical states play in communication.

2. Theoretical background

2.1. Inference-making as a process underlying comprehension in interactions

It has long been known that language comprehension involves inference-making (e.g., Graesser, Singer, & Trabasso, 1994; Ryskin, Kurumada, & Brown-Schmidt, 2019; Singer, 2013). In communication settings, inference-making is the process whereby the mind generates

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different optional intended meanings for a certain utterance and then selects the meaning that is most appropriate (that is, most probable to be the intended meaning) given the context in which the utterance was made. For instance, in the utterance "let's go to the bank", the word "bank" can refer to a financial institution or to a river bank. The mind invests effort in making the correct inference (and deciding whether to bring money or a swimsuit).

How are specific inferences formed? Context and prior knowledge have long been considered central influencers in determining how plausible inferences are created and evaluated (e.g., Giora, 1997; Graesser et al., 1994). A useful theory suggests that the concept of *affordance* (i.e., the potential to implement an action within environmental constraints) is crucial to comprehension and prediction of actions and meanings (e.g., González-Perilli & Ellis, 2015). An inference is made as a mental calculation of the feasibility of enacting a certain meaning, or at least simulating it in the recipient's mind (e.g., Gibson, 1977; Lu, Chen, & Shao, 2009). In other words, inferring a meaning involves a mental prediction of the feasibility that the meaning will or can occur in reality. For example, a small child who says "I'm going to kill you" affords less of a real threat than a large man saying the same thing, and recipients should more readily infer the adult's intended meaning as literal compared to that of the child's.

A major question within research on comprehension in interactions is what contributes to the formation of certain inferences, but not others. In some cases, no effortful inference-making is required, because there is a straightforward relation between what is said and what is meant. For example, when two people A and B are both looking at a flower and A says "what a beautiful flower," B infers without difficulty that A means that particular flower because the word refers directly to the object. However, when A and B are both looking at B's infant daughter and A says "what a beautiful flower," additional effort is necessary for B to infer that A means "I think your infant daughter is as beautiful as a flower." That is, the meaning of the word "flower" does not directly refer to its defined object ("daughter") and therefore requires mental effort to be inferred.

Much like other aspects of cognition and communication, inferencemaking is influenced by features of the people doing the information processing and the context in which the information appears. In the next section we explore the possibility that embodiment – the sensorimotor simulation of concepts – can be an important source of influence on this process.

2.2. The role of embodiment as an anticipatory mechanism in language comprehension

Embodiment refers to the roles that sensory and motor states, such as bodily postures and movements, play in cognitive processes, helping us make sense of the world and understand what is being said or done around us (P.M. Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). In contrast to theories of cognition proposing that processing in semantic memory systems is separate from systems involved in other aspects of the mind, such as perception and action, and theories asserting that knowledge is represented a-modally, embodied perspectives propose that processing systems are modality-specific, integrated (to a degree), and constrain each other (e.g., Barsalou, 2008, 2010; Glenberg, 1997; P.M. Niedenthal et al., 2005). As people attempt to understand situations, they may enact behaviors associated with those situations or mentally simulate associated motor and affective processes (Barsalou, 2010; Decety & Grèzes, 2006; Gallese, 2003). For example, thinking about a prior chance encounter with a bear is likely to reengage neurons involved in processing vision, fear, and fleeing during the course of this memory (P.M. Niedenthal, 2007). Evidence suggests such effects are bidirectional, with physical states also shaping aspects of mental processing. In prior studies, occupying the dominant hand with an object (e.g., a mug) inhibited evaluations of a different target object (e.g., a ring) and made it more difficult to envision holding the target,

because the hand was enacting a posture fit for a mug but unfit for a ring, making mental simulation of ring holding more difficult (Shen & Sengupta, 2012).

Within communication, embodied states may play a similar role in facilitating or inhibiting language comprehension (e.g., Casteel, 2011; Crossley, 2013; Fischer & Zwaan, 2008; A.M. Glenberg & Robertson, 2000; van Dam, van Dijk, Bekkering, & Rueschemeyer, 2012; Vankov & Kokinov, 2013). In a now classic demonstration, people more rapidly understand a sentence (e.g., "she rejected the idea") when simultaneously performing movements compatible with its meaning (e.g., pushing away one's hands) (A.M. Glenberg & Kaschak, 2002). As another example, R.W. Gibbs Jr. (2013) demonstrated that comprehension of metaphorical language (e.g. "your relationship is moving in the right direction") involves bodily simulation of the metaphorical images described in that language (e.g. walking longer and farther in one direction). Similarly, McGlone and Pfiester (2009) demonstrated the role of motor simulation during the processing of temporal metaphors (e.g., "we are approaching the weekend"). Although this literature shows that comprehension benefits from such embodied compatibility, it does not directly test the influence of embodiment on the mechanism that underlies this comprehension—inference-making. Can bodily states that are compatible with motor simulations of certain intended meanings enhance inferences about these intended meanings and inhibit the inference of other intended meanings that are not relevant to those motor simulations?

To address this question, we suggest that embodiment can serve as a meaning prediction mechanism during comprehension. We rely in part on research showing that bodily states can influence anticipation, like forecasting emotional responses to events. For example, participants who watched a horror movie experienced bodily states such as elevated heart rate. The elevated heart rate influenced inferences of a subsequent sound of a squeaky window as due to a possible burglar. In other words, the physical state of perceivers led them to anticipate a certain meaning for the auditory cue (Pezzulo, 2014). Further, the interoceptive sense of bodily physiology (e.g., increased heart rate) can enhance prediction of one's emotional response, facilitating preparedness to cope with those emotions (Seth, 2013). Taken together, these findings suggest that there is a link between automatic activation of neural or motor processes relevant to a certain meaning and the way certain intended meanings are inferred (cf., Gallese, Keysers, & Rizzolatti, 2004; P.M. Niedenthal, 2007). Generalizing this literature, we suggest that bodily states increase the viability of certain inferences and reduce the viability of other inferences by facilitating sensorimotor simulation and the resulting mental representation of certain inferences while inhibiting others. We discuss this in more detail next.

2.3. The role of embodied states in facilitating and inhibiting inferred meanings

Anticipating which meanings are viable and which are not can improve communication by facilitating understanding and eliminating the need for clarification (van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005). Importantly, the inferences people make about others' intentions in conversation may depend on one's own situation and context (N.A. Palomares, 2009, 2013; N.A. Palomares, Grasso, & Li, 2015). We suggest that one way in which specific inferences are made, while others are not, occurs when individuals who are engaged in conversation adopt bodily states that are *compatible* or *incompatible* with the meanings implied in those conversations. Research has shown that sensorimotor simulation elicits anticipation of certain events, such as intended actions, and that this simulation can in turn facilitate or inhibit affordance of these events, thereby facilitating or inhibiting comprehension of the events (Casteel, 2011; González-Perilli & Ellis, 2015; Guérard, Guerrette, & Rowe, 2015; F. Ianì, Foiadelli, & Bucciarelli, 2019; Vankov & Kokinov, 2013). For example, pantomiming an action, such as sweeping the floor with a broom, interfered with reading speed

for a different action, such as hitting a puck with a hockey stick, that required the same motor motion as the first action (Casteel, 2011), suggesting that the meaning evoked by embodying the first action inhibited the processing of the meaning associated with the second action. Similarly, observation of actions performed towards objects (such as extending a hand and grabbing a hammer) facilitated later processing of meanings compatible with these same actions (e.g., "hammer"), whereas observation of interrupted actions (such as extending a hand towards a hammer with the grabbing motion cut off) inhibited this processing (González-Perilli & Ellis, 2015). Finally, engaging in complex motor actions incompatible with simulation of simple actions, such as pouring liquid from a jar into a glass, inhibited memory for those objects (Guérard et al., 2015; See also F. Ian), 2019 for a review of research on the role of embodiment in memory).

Drawing on this collection of evidence, we suggest that bodily states compatible with certain interpretations of a word or phrase may afford the physical ability to enact those interpretations, and facilitate mental representations of those interpretations, whereas incompatible states constrain this ability. For example, the command "go" could be interpreted as either "walk" or as "drive," with these two actions requiring different bodily postures to physically perform. Because of this, someone in a standing posture may be more likely to infer "go" as"walk," whereas someone in a sitting posture may be more likely to infer "go" as "drive." The ability to enact behaviors through compatible bodily states should ease comprehension by making relevant mental representations and consequent inferences more accessible, whereas incompatible states should degrade understanding by making relevant inferences less accessible. This perspective suggests that the primary role of embodiment within comprehension is to help elicit appropriate (afforded) inferences. Thus, embodied states can interfere with comprehension when they are incompatible with speakers' intended meaning.

Further, if inference-making depends on bodily states, this dependency should be more influential in cases when inference-making is effortful. Some inferences require more cognitive elaboration than others. For example, research indicates that conventionalized phrases (those acquiring common meaning through repeated use), such as idioms (e.g., "They stood their ground") or direct request (e.g., "Close the door please"), are processed as single-meaning units and therefore require relatively little inference-making effort. Conversely, nonconventionalized phrases, such as natural phrases (e.g., "They stood apart") or indirect requests (e.g., "Not sure I like that chilly breeze in here," implying that the recipient should close the door) require processing of separate meanings for each constituent word and thus involve relatively higher inference-making effort (Hillert & Swinney, 1999; Mashal, Faust, Hendler, & Jung-Beeman, 2008). The greater effort involved in making such inferences may allow for factors that affect this inference-making, such as bodily states, to exert more influence than when processing relatively simpler inferences.¹ That is, if embodiment facilitates inference-making, this would be more beneficial in situations requiring higher processing effort (Hull, 1943; Kool, McGuire, Rosen, & Botvinick, 2010). We therefore suggest that bodily states will have a greater impact on inference-making while processing nonconventionalized phrases compared with conventionalized ones.

Building on the role of affordance in inference-making, and the power of embodied states in meaning derivation, we suggest that the degree to which a particular meaning is likely to be inferred should depend on a person's bodily state, making this state a critical element in inference formation. We therefore propose that embodiment contributes to the predictive power of inference-making, thus enhancing its efficiency. To sum, we predict that:

H1a. People will be faster to infer meanings that are compatible with their bodily states than meanings that are incompatible with their bodily states.

H1b. The influence of bodily states on the speed of inference-making will be stronger for non-conventionalized language, which requires relatively more processing effort, compared with conventionalized language.

H2. People will be more likely to infer meanings that are compatible with their bodily state at the time of comprehension than meanings that are not compatible with their bodily states at that time.

Note that H1a and H1b involve the speed of inference-making, whereas H2 involves the content of those inferences. We tested these predictions by manipulating bodily states through participant postures, an important mode of embodied action (cf., Harmon-Jones & Peterson, 2009). In Studies 1 and 2, we also manipulated processing effort via language requiring higher or lower inference-making effort. For language requiring less inference-making effort, we used conventionalized language: idiomatic phrases (e.g., "She couldn't stand it any longer") in Study 1 and direct request phrases ("Please close the door") in Study 2. For language requiring greater inference-making effort, we used nonconventionalized language: natural sentences (e.g., "She couldn't stand there any longer") in Study 1 and indirect request phrases ("There is a lot of noise coming from the corridor") in Study 2. The postures in our experiments were either compatible or incompatible with performance of the actions implied by the meanings of target phrases. We predicted that incompatible bodily states would impair inferences of the intended meaning. We expected this to result in slower processing times, especially for language requiring greater inference-making effort (Studies 1, 2), and in a lower likelihood to infer the posture-incompatible intended meaning (Studies 3, 4).

3. Method

Four experiments examined the contribution of bodily states to inference formation. Study 1, a pilot experiment, showed that people responded to sentences requiring greater inference-making effort (natural phrases) more slowly when their posture was incompatible with the intended meaning in the sentence, but this did not happen when sentences involved little inference-making effort (idiomatic expressions). Study 2 directly demonstrated quicker lexical decisions via inferencemaking in the comprehension of requests (beyond the response time evaluated in Study 1) when posture was compatible with the action intended in the request. Studies 3 and 4 examined the choice of inferences themselves rather than processing speed and showed that people are more likely to make inferences compatible with their posture in contexts that afford posture-relevant meanings. Thus, Studies 1 and 2 tested Hypotheses 1a and 1b, and Studies 3 and 4 tested Hypothesis 2.

3.1. Study 1 – a pilot

3.1.1. Participants and procedure

Twenty-two undergraduates (mean age 23; 9 females) sat or stood at a computer and judged the grammatical correctness of 20 phrases as quickly as possible using keys labeled "correct" and "flawed." This procedure was then repeated in the other posture with another set of 20 phrases. The phrases consisted of 5 idiomatic expressions containing the target word "stand" in various forms (e.g., *they stood for their rights*), 5 natural phrases containing the word "stand" (e.g., *they stood in the street*), 5 natural phrases not containing the word "stand" (e.g., *street they in*

¹ This should be true even if language processing involves automatic activation of mental processes relevant to understanding meaning, as evidence suggests that processing can be simultaneously automatic and effortful (e.g., Barrett, Frederick, Haselton, & Kurzban, 2006; Dan Sperber & Wilson, 1986, 2002; Pinker, 1997).

walked).² See full list of materials in the online appendix. Thus, this study used a 2 (Embodiment: compatible, incompatible) by 4 (Phrase Type: idiomatic with target word, natural with target word, natural without target word, nonsense fillers) fully within-subjects design, helping to mitigate the small number of participants. We conducted sensitivity analyses for each study using G*Power 3.1.9.2 (Faul, Erd-felder, Buchner, & Lang, 2009). The present sample size and repeated measures design afforded 80% power to detect at least Cohen's d = 0.255.

To reiterate, H1a predicted longer reaction times for postureincompatible natural phrases than posture-compatible ones, and H1b predicted attenuation of these differences for idiomatic expressions, because they are easier to process and do not require additional help to facilitate inference-making, compared to natural sentences which are not processed as single units. The natural phrases *not* containing the word "stand" were expected to yield similar results to the idiomatic expressions, as inferred meaning in these phrases is also not dependent on posture affordance.

3.1.2. Results and discussion

A 2 \times 4 repeated measures analysis on log-transformed response times (to correct for skew) revealed a significant interaction of embodiment and phrase type ($F(1,21) = 5.2, p < .001, \eta_p^2 = 0.197$). Though analyses were conducted on log-transformed values, we present untransformed scores here for interpretive ease. Supporting H1a, planned contrasts showed that participants responded more slowly to natural phrases containing the word "stand" when in a sitting posture (M =2397 ms, SD = 921.6) compared with a standing posture (M = 1946 ms, *SD* = 648.4; *F*(1,21) = 7.6, *p* = .012, Cohen's *d* = 0.566). In contrast, no significant differences emerged between these postures for the other phrase types: idiomatic expressions with the word "stand" (F(1,21) =0.39, p = .64) (supporting H1b), natural sentences not containing the word "stand" (F(1,21) = 0.65, p = .46), and the filler phrases (F(1,21) =0.54, p = .49). The filler phrases were processed more slowly (M =2159.42, SD = 708.9) than the other three phrase types (M = 2120, SD= 585.0), though not significantly (F(1,21) = 1.54, p = .19). See Fig. 1. Additionally, the difference in processing time between idiomatic and natural phrases in the incompatible (sitting) condition ($\Delta M = 315.3$, SD = 734.5) was significantly greater than the difference in the compatible (standing) condition ($\Delta M = 90.6$, SD = 526.9; F(1,21) = 5.27, p = .032, d = 0.325).

The results of this experiment suggest that incompatible postures can impede processing of language that requires more effortful inferencemaking, thus supporting Hypotheses 1a and 1b.

3.2. Study 2

Study 2 built upon Study 1 by improving two issues: First, in Study 1, differences in inference-making effort between phrase types were presumed based on evidence from existing literature, but we did not directly measure inference-making (rather, we measured response speed for the phrases). In the current study, we measure inference-making via reaction time to inferred meanings. Quicker reaction time to a word representing an inferred meaning would suggest that this word was already inferred and therefore was more accessible in the mind compared to a word that elicited slower reaction time. Second, in the current experiment, none of the stimuli phrases contained the word "stand", addressing the concern that the posture instructions (e.g., "please *stand* at the computer") in Study 1 semantically primed this word and thus speed up responses to that word.

This experiment tested the effect of embodiment compatibility on inference-making using direct and indirect requests. We used an implicit test of inference-making employing a lexical decision task (Förster & Liberman, 2007). We measured the speed with which participants judged different verbs (e.g., "close") to be words or non-words after reading direct requests which explicitly mentioned the verb (e.g., "Close the door please") or indirect requests which merely implied the action to be done (e.g., "It's chilly in here"). We manipulated compatibility of posture (sitting / standing) and intended meaning of the request: half of the requests referred to an action which is typically performed in a sitting position (e.g., sewing) and half of the requests referred to an action which is typically performed while standing (e.g., closing the door). Although we expected the verbs that were explicitly mentioned in the direct requests to facilitate lexical decisions through semantic priming, we also predicted that the compatibility of bodily state with intended action would play a greater role in comprehension of indirect requests (i.e., higher inference effort) than direct requests (i.e., lower inference effort).

3.2.1. Participants and procedure

Forty community members in a U.S. east coast city ($M_{age} = 35$, 22 women) participated in this 2 (Participant Posture: standing/sitting) by 2 (Request Type: direct, indirect) by 2 (Request Posture: standing/sitting) fully within-subjects design study. Using this sample size and repeated measures design afforded 80% power to detect at least Cohen's d = 0.152. Participants were randomly assigned to begin in a sitting or a standing posture.

We prepared 80 request phrases, 40 of them were for actions typically performed while standing, such as "Close the door please," and the other 40 were for actions performed while sitting, as in "I would like you to sew my sock." Within these two types of requests, half (20) were phrased directly, as exemplified in the previous sentence, while the other half were phrased indirectly, as in "There is a lot of noise coming from the corridor, how about that door?" or "Can you handle a needle and a thread? I have a hole in my sock." Target verbs denoting the implied action were paired with each request (*close* and *sew* for the examples here). Thus, four types of requests were used: 20 direct-sitting, 20 direct-standing, 20 indirect-sitting and 20 indirect-standing. See full materials in the online appendix.

Participants first adopted either a standing or a sitting posture (in counterbalanced order) and read the request phrases in random order. When finished reading a request phrase, participants pressed any key on the keyboard to move to the next screen. On that screen a target word was displayed. The target word was the intended verb or a nonsense word. Following standard lexical decision methods, participants pressed one of two keys (right shift for "word" or left shift for "non-word") to identify this target as quickly as they could. Afterwards, participants repeated the procedure in the alternate posture for the remaining half of the requests and verbs.

Importantly, while the direct requests included the target verbs in the statements (e.g., "close" or "sew"), the indirect requests did not. Therefore, we expected no effect of embodiment on the speed of reaction to the target verbs after reading direct requests, as no inferences were needed to identify the intended verb. However, because the action verb was not mentioned in the indirect requests, it had to be inferred. Thus, we expected that the restricted embodiment resulting from an incompatible posture would inhibit this inference-making and consequently slow response times to the target verbs for indirect requests.

3.2.2. Results and discussion

Response times for target verbs were log-transformed to correct for skew (actual response times are presented for interpretive ease). The accuracy rate was 88% and only accurate results were included in the analysis. Repeated measures analysis revealed no 3-way interaction on response time (p = .263). To simplify the analyses, we therefore collapsed the Participant Posture and Request Posture conditions into a

² The study was conducted in Israel with a native-speaker sample, employing idiomatic expressions and natural phrases in Hebrew. The examples given in the paper are comparable translations. Phrases were equated on number of syllables across phrase type.



Fig. 1. Judgment times (in milliseconds, with standard errors) for grammatical correctness of phrases containing the word "stand" in standing and sitting position. Inference-making effort is relatively greater for natural phrases.

single Posture Compatibility variable representing the match (sit/sit or stand/stand), or lack thereof (sit/stand or stand/sit), between participant and request postures. We ran a 2-way Repeated Measures analysis using Posture Compatibility (compatible/incompatible) by Request Type (direct/indirect). We found a main effect for Request Type indicating that response times following indirect requests (M = 740.5 ms, SD = 174.53) were significantly slower than those following direct requests (M = 682.6 ms, SD = 182.99; F(1,40) = 11.2, p = .002, $\eta_p^2 = 0.22$). This result replicates literature indicating that comprehension of indirect language requires higher processing effort (Hillert & Swinney, 1999; Mashal et al., 2008; van Ackeren, Casasanto, Bekkering, Hagoort, & Rueschemeyer, 2012), thus supporting our use of direct and indirect requests as a manipulation of inference-making effort.

The analysis also revealed a significant interaction of Posture Compatibility and Request Type (see Fig. 2; F(1,40) = 4.9, p = .032, $\eta_p^2 =$

0.11). Consistent with Hypotheses 1a and 1b, lexical decisions following indirect requests were significantly slower for posture-incompatible verbs (M = 772.5, SD = 185.3) compared with posture-compatible verbs (M = 708.4, SD = 163.7; F(1,40) = 18.4, p < .001, d = 0.366). In contrast, the effect of posture on response times to verbs following direct requests did not reach significance (F(1,40) = 1.0, p = .3). Further, planned contrasts indicated that, for posture-incompatible verbs, participants were slower to respond to verbs following indirect requests (M = 772.5, SD = 185.3) than direct requests (M = 690.0, SD = 195.9; F(1,40) = 12.33, p < .001, d = 0.432), whereas this difference was smaller for the posture-compatible verbs (M = 708.4, SD = 163.7; and M = 675.2, SD = 169.9, respectively; F(1,40) = 11.02, p = .002, d = 0.199).

In this experiment, inference-making for indirect requests was slower when participants' bodily states were incompatible with the intended



Fig. 2. Lexical Decision times (in ms, with standard errors) for intended verbs following direct and indirect requests in verb-compatible and incompatible bodily postures.

meaning of the indirect request than when their states were compatible with the intended meaning. This result supports H1a. Next, supporting H1b, we found that this was not as strongly the case for the more easilyprocessed direct requests, which mentioned the intended verb. Finally, the difference between posture conditions for indirect requests rules out an alternative, semantic priming explanation because the target verbs were not mentioned in the indirect requests and therefore were unlikely to be semantically primed. One limitation of this experiment is that reading time for the initial sentences may have influenced subsequent response times to the target verbs (this initial reading time was not measured), though it is not clear that slower or faster reading times would necessarily result in more or less efficient inference-making.

3.3. Study 3

Departing from the approach of testing the speed of reaction to inferred meanings, Studies 3 and 4 examined the tendency to actually infer meaning as an effect of bodily states (as hypothesized in H2). In this study, participants in sitting or standing postures saw sentence fragments (e.g., "Margaret's mom reminded her to...") and chose between two possible endings for those fragments, one implying a standing posture ("walk the dog") and the other implying a sitting posture ("write to her grandma"). Choosing a meaning that corresponds with the participant's posture would serve as evidence that the posture makes certain inferences more mentally accessible, potentially by increasing the affordance of those inferences.

3.3.1. Participants and procedure

Two hundred twenty-four undergraduate students at an East Coast US university took part in this 2-cell, between-subjects study ($M_{age} = 20$, 120 females). Participants either sat or stood in front of a computer monitor. For standing participants, the monitors were raised and the mouse was placed on an elevated surface. The experimenter told standing participants that the researchers were examining different furniture settings in the lab. Participants completed the study in sessions of up to 16 participants, with all participants in a session either sitting or standing. Using this sample size and design afforded 80% power to detect at least Cohen's d = 0.376.

Participants first read an introduction that explained: "Imagine you are having a conversation with someone, and this person begins saying a sentence. The sentence could have many endings, you will see two possibilities. Please choose which of the two endings you think that your conversation partner is most likely going to say. Let's start with a few practice examples. To begin press the next button." Next, participants completed 3 training sentences that were not included in the analyses. After that, participants read 25 sentence beginnings (20 relevant to the experiment and 5 filler beginnings) and chose the most likely ending for each sentence, out of a pair of endings, one implying a sitting posture and the other implying a standing posture. All 20 experimental sentence beginnings were found to equally imply a sitting or a standing posture in a pretest (see online appendix). For example, the sentence beginning "At the park, the sisters ... " had two endings: "... had a picnic in the shade", which assumes a seated position, or "...played fetch with their dog" which assumes a standing position. The five filler sentences included endings that did not involve sitting or standing postures, in order to reduce possible suspicion about this factor (e.g., beginning: "The geese and the ducks in the yard"... ending: "made a lot of noise"). All 25 sentences were presented in random order and the ending choice order was randomized within each sentence. See the online appendix for the preparation of experimental sentences, pretests, and full experiment materials. Finally, participants were debriefed, thanked, and dismissed.

3.3.2. Results and discussion

We coded the choice of standing-posture endings as 0 and sittingposture endings as 1. We then calculated the sum of the 20 posturerelevant sentence choices, so that numbers over 10 represented greater choice of sitting-posture endings and numbers lower than 10 represented greater choice of standing-posture endings. A *t*-test comparing the calculated sum between participants who were standing and those who were sitting revealed significant differences between the two conditions (t(222) = 4.24, p < .001, d = 0.602). Participants were significantly more inclined to choose the posture-compatible ending of the phrase (M = 11.17, SD = 2.00), than the posture incompatible ending (M = 9.95, SD = 2.05). Fig. 3 portrays these results.

These results suggest that even when two optional endings are equally sensible, inference-making is influenced by the compatibility of specific meanings with bodily states of the recipient. To investigate this effect even further, we conducted the next study, where we not only manipulated posture but also manipulated the relevance of the posture for the inferences to be made. We predicted that when bodily states are irrelevant to inference-making, people's inferences would not be influenced by their posture.

3.4. Study 4

Study 4 replicated the procedure and materials in Study 3 but introduced posture-irrelevant sentences. In addition to the 20 sentences that had relevant standing or sitting continuations, participants also made choices about endings for 20 other sentences that implied no posture-relevant inference. For example, for the beginning "Many people..." a specific posture-relevant inference is not implied. Given the endings paired with this sentence: "...are allergic to peanuts" and "...are allergic to pollen," we were expecting no posture influence on ending choice for posture-irrelevant sentences and endings. These irrelevant sentences were chosen from a larger set based on findings from a pretest in which participants indicated no significant preference for sittingrelevant or standing-relevant endings (see online appendix). We predicted that the effect found in Study 3 would replicate for the 20 posturerelevant beginning and endings, but would be attenuated for beginnings and endings where posture is irrelevant to the implied inference.

3.4.1. Participants and procedure

Two hundred fifty undergraduate students at an East Coast university took part in this study ($M_{age} = 20, 138$ females). All procedures were the same as in Study 3, except that participants chose between two endings not only for the 20 posture-relevant sentences but also for an



Fig. 3. Choices (raw counts) for phrase endings that conveyed inferred meanings compatible or incompatible with the participant's posture. Compatible endings represent sitting choices while being seated and standing choices while actually standing.

additional set of 20 posture-irrelevant sentences. Thus, this study was a 2 (posture relevant/irrelevant sentence, within subject) X 2 (participant posture: sitting/standing, between subject) mixed design. All 40 sentences were presented in random order and the ending choice order was randomized as in Study 3. Using this sample size and mixed design afforded 80% power to detect at least Cohen's d = 0.094.

3.4.2. Results and discussion

As in Study 3, we coded the choice of standing-posture endings as 0 and sitting posture endings as 1. We then calculated the sum of the 20 posture-relevant ending choices and the sum of the 20 posture-irrelevant ending choices. As before, numbers over 10 represented greater choice of sitting-posture endings and numbers lower than 10 represented greater choice of standing-posture endings. We then ran a 2-way mixed analysis with type of phrase (posture relevant or irrelevant) as a withinsubjects factor, and participant posture (sitting/standing) as a betweensubjects factor. The test revealed a significant interaction of phrase type and posture ($F(1,248) = 8.09, p = .007, \eta_p^2 = 0.186$). Planned contrasts showed that sitting participants chose sitting endings more often (M =10.4, SD = 1.95) than did standing participants (M = 9.6, SD = 2.02) when sentences were posture-relevant (F(1,248) = 5.09, p = .025, d =0.403), whereas no significant choice difference was present for the posture-irrelevant phrases ($M_{\text{sitting}} = 9.89 \text{ SD} = 2.01$, $M_{\text{standing}} = 10.11$ SD = 2.00, F(1,248) = 0.243, p = .623). Fig. 4 presents these results.

These results provide additional support for the proposal that bodily states influence the inferences people make within conversation: participants in this experiment chose those inferences that were compatible with their bodily posture, but this was true only when posture was relevant to the target inference. When the inference was not dependent on bodily state, participants showed no influence of the posture on their inference-making.

4. General discussion

Effective interaction and successful communication lie at the foundation of positive relationships and general goal attenuation (Linell, 2015). The present experiments revealed two complementary findings regarding the role of embodied states on inference-making. First, intended meaning was inferred more slowly when participants adopted postures incompatible with that meaning. This effect emerged most dramatically when greater effort was required to infer the intended meaning. We interpret this to indicate that embodied states promote construction of meaning, but from a more mechanistic level of explanation, the effort effects found here may reflect different time courses associated with processing linguistic and action-related simulation content. The linguistic system's activation has been shown to peak prior to the peak of the simulation system (Barsalou, 2008), making embodied simulation sensitive to inputs from language processing (A.M. Glenberg et al., 2008; F. Ianì et al., 2019). Here, the effort involved in inferencemaking may have served as an input to subsequent action simulations, with posture compatibility acting on this input.

Second, in Studies 3 and 4, participants were more likely to choose sentence endings (reflecting action-based inferences) consistent with their bodily states. These studies depart from much of the traditional work on embodiment, which focuses on implications of bodily states for specific cognitive processes (e.g., processing speed, memory), but not necessarily the content of those cognitions. The fact that posture influenced the sentence constructions in Studies 3 and 4 shows that posture can influence not only the speed of processing meanings, but the anticipation of a specific intended meaning. This finding may suggest that embodiment plays a role in the activation and use of mental representations that guide anticipation of intended meanings. A broader conclusion is that posture influences the inferences people make about others' goals in interactions, which in turn shapes comprehension of what others say and mean (N.A. Palomares, 2009).

Inference-making is a fundamental element of interaction and can be responsible for the interaction's success or failure. Slower response times are indicative of delayed cognitive processing, which may result in communication problems such as less fluent conversation or the generation of wrong inferences (Markovits & Doyon, 2004). Integration of the body's role in the inference-making process may contribute to a more complete theoretical understanding of how inference-making actually works and may help to provide tangible solutions to many instances of failure within communicative interaction.

Beyond its theoretical contribution to conceptualizations of inference-making, this work also investigated contexts with real-world relevance, such as understanding requests or commands. Our manipulation of bodily state compatibility simulated relatively realistic conditions of comprehension. For example, oftentimes personal circumstances (e.g., when driving, lying on the sofa) or feasibility of actions (e.g., flying, swimming) may prevent the embodiment, and hence the inference, of intended meanings. In daily life, the



Fig. 4. Choices (in raw counts) for phrase endings that conveyed inferred meanings compatible or incompatible with participant's posture. Compatible endings represent sitting choices while being seated and standing choices while actually standing. Choices within each set of columns sum to 20.

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incompatibilities arising from such factors may interfere with effective interaction. To explore the breadth of this phenomenon, future research might test the influence of compatible and incompatible postures on comprehension of communication in contexts with immediate consequences of inference-making such as military training, emergency forces actions, or sporting events.

Another important question is whether the effects of embodied compatibility and incompatibility are exclusive to action-related meanings. A number of studies suggest otherwise: motions and postures compatible with experiences may enhance the accessibility of emotions (Riskind & Gotay, 1982; Stepper & Strack, 1993), internal states such as pain, smell and taste (Gough, Campione, & Buccino, 2013; A. Majid, 2013), and memories (Casasanto & Dijkstra, 2010; Dijkstra, Kaschak, & Zwaan, 2007). Whether incompatibility also impairs inference-making for such action-free constructs remains to be investigated.

Moving forward, research might focus on some of the most common instances of potential posture incompatibility. Consider that online interaction, especially computer-mediated communication, is often conducted in a sitting posture. The current work suggests that this relatively universal posture may have strong implications for how people process meaning in online settings. A better understanding of how inference-making proceeds in online versus face-to-face interaction could be quite important for facilitating the accuracy or speed of transferring information that is compatible or incompatible with the sitting posture required by computer-mediated communication.

Communication involves very different types of language, such as different genres, different linguistic complexity levels, or using more and less frequent/familiar words. Our experiments demonstrate posture effects for the same language/sentences, suggesting effects beyond word familiarity/frequency. Relatedly, in Study 2 we measured responses to a verb that appeared in a preceding sentence. We could measure an alternate, perhaps improved design comparing phrases that vary in inference-making effort (e.g., using more/less familiar synonyms of the same verb) but that do not include the same verb as the target verb in the reaction time task. Further, our use of conventional and nonconventional expressions, which are naturally more and less frequent in language, respectively, invites future investigation of whether embodied states influence comprehension of less frequent/familiar language as much as more frequent/familiar language. By the same token, future research may focus on the question of whether embodied states influence inference-making in more/less familiar or frequent situations. If embodied states serve as anticipatory mechanisms, they may be especially useful in facilitating comprehension and inference-making in unfamiliar/infrequent situations.

Is the role of embodied states similarly influential in all instances of conversation? The current work suggested that the language used by the communicator can influence the extent to which embodied states contribute to inference-making. We showed that conventional language does not benefit from embodied states as much as non-conventional language, the latter of which requires more effortful inference-making. Future work on this topic could consider situations where the intended meaning is easier or more difficult to infer due to non-linguistic aspects of the situation, such as when conversing with close acquaintances versus strangers, or in more or less conventional situations such as home versus formal events. It is plausible that in these situations utterances are more expected, such as a groom saying "I do" to his bride on a wedding ceremony. If so, then embodied states in these cases do not influence inference-making as much as in situations that involve strangers or non-conventionalized situations.

Finally, while the current research focused on sitting versus standing posture as a manipulation of embodied states, future work may extend our findings to other bodily states that are compatible or incompatible with intended meanings, such as the inferences made from descriptions of food palatability while eating/swallowing versus other activities.

To sum, this work serves as initial evidence for the influence of

posture on inference-making, thereby moving research on embodiment beyond general examination of comprehension to investigating the processes underlying comprehension. Thus, our findings contribute to knowledge about the role of bodily posture in language processing and the success and failure of communicative conversation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2021.103276.

References

- Bach, K. (1999). The myth of conventional implicature. *Linguistics and Philosophy*, 22(4), 327–366.
- Barrett, H. C., Frederick, D. A., Haselton, M. G., & Kurzban, R. (2006). Can manipulations of cognitive load be used to test evolutionary hypotheses? *Journal of Personality and Social Psychology*, 91(3), 513–518.
- Barsalou, L. W. (2008). Cognitive and neural contributions to understanding the
- conceptual system. Current Directions in Psychological Science, 17(2), 91–96.
 Barsalou, L. W. (2010). Grounded cognition: Past, present, and future. Topics in Cognitive Science, 2(4), 716–724.
- Berger, C. R., & DiBattista, P. (1993). Communication failure and plan adaptation: If at first you don't succeed, say it louder and slower. *Communication Monographs*, 60(3), 220–238.
- Cain, K., Oakhill, J. V., Barnes, M. A., & Bryant, P. E. (2001). Comprehension skill, inference-making ability, and their relation to knowledge. *Memory & Cognition*, 29 (6), 850–859.
- Casasanto, D., & Dijkstra, K. (2010). Motor action and emotional memory. Cognition, 115 (1), 179–185.
- Casteel, M. A. (2011). The influence of motor simulations on language comprehension. Acta Psychologica, 138, 211–218.
- Cook, A. E., Limber, J. E., & O'Brien, E. J. (2001). Situation-based context and the availability of predictive inferences. *Journal of Memory and Language*, 44(2), 220–234.
- Crossley, N. (2013). Mead, Merleau-Ponty and embodied communication. Journal of Pragmatics, 58, 46–48.
- Decety, J., & Grèzes, J. (2006). The power of simulation: Imagining one's own and other's behavior. *Brain Research*, 1079(1), 4–14.
- Dijkstra, K., Kaschak, M. P., & Zwaan, R. A. (2007). Body posture facilitates retrieval of autobiographical memories. *Cognition*, 102(1), 139–149.
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149–1160.
- Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: A review of the role of the motor system in language comprehension. *The Quarterly Journal of Experimental Psychology*, 61(6), 825–850.
- Förster, J., & Liberman, N. (2007). Knowledge activation. In A. W. Kruglanski, & E. T. Higgins (Eds.), Social psychology: Handbook of basic principles (2nd ed., pp. 201–231). New York: Guilford Press.
- Gallese, V. (2003). The roots of empathy: The shared manifold hypothesis and the neural basis of intersubjectivity. *Psychopathology*, 36(4), 171–180.
- Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. Trends in Cognitive Sciences, 8(9), 396–403.
- Gibbs, R. W., Jr. (2003). Embodied experience and linguistic meaning. Brain and Language, 84(1), 1–15.
- Gibbs, R. W., Jr. (2013). Walking the walk while thinking about the talk: Embodied interpretation of metaphorical narratives. *Journal of Psycholinguistic Research*, 42, 363–378.
- Gibson, J. J. (1977). The theory of affordances. In R. Shaw, & J. Bransford (Eds.),
- Perceiving, acting, and knowing. Mahwah, New Jersey: Lawrence Erlbaum. Giora, R. (1997). Understanding figurative and literal language: The graded salience hypothesis. Cognitive Linguistics, 8, 183–206.
- Glenberg, A. M. (1997). Mental models, space, and embodied cognition. In Creative thought: An investigation of conceptual structures and processes (pp. 495–522). Washington, DC: American Psychological Association.
- Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. Psychonomic Bulletin & Review, 9(3), 558–565.
- Glenberg, A. M., & Robertson, D. A. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory and Language*, 43(3), 379–401.
- Glenberg, A. M., Sato, M., Cattaneo, L., Riggio, L., Palumbo, D., & Buccino, G. (2008). Processing abstract language modulates motor system activity. *Quarterly Journal of Experimental Psychology*, 61(6), 905–919.
- González-Perilli, F., & Ellis, R. (2015). I don't get you. Action observation effects inverted by kinematic variation. Acta Psychologica, 157, 114–121.
- Gough, P. M., Campione, G. C., & Buccino, G. (2013). Fine tuned modulation of the motor system by adjectives expressing positive and negative properties. *Brain and Language*, 125(1), 54–59.
- Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review*, 101(3), 371.

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- Grice, H. P. (1975). Logic and conversation. In Syntax and Semantics (Vol. 3, pp.41-58). New York, NY: Academic Press.
- Guérard, K., Guerrette, M., & Rowe, V. P. (2015). The role of motor affordances in immediate and long-term retention of objects. Acta Psychologica. November 2015 162:69–75.
- Harmon-Jones, E., & Peterson, C. K. (2009). Supine body position reduces neural response to anger evocation. *Psychological Science*, 20(10), 1209–1210.
- Hillert, D., & Swinney, D. (1999). The processing of fixed expressions during sentence comprehension. In A. Cienki (Ed.), *Conceptual structure, discourse, and language*. Stanford, CA: CSLI Publishers.
- Hull, C. L. (1943). Principles of behavior. New York, NY: Appleton-Century.
- Ianì, F. (2019). Embodied memories: Reviewing the role of the body in memory processes. Psychonomic Bulletin & Review, 26(6), 1747–1766.
- Iani, F., Foiadelli, A., & Bucciarelli, M. (2019). Mnemonic effects of action simulation from pictures and phrases. *Acta Psychologica*, 194, 37–50.
- Kasher, A. (1982). Gricean inference reconsidered. *Philosophica (Gent)*, 29, 25–44.
- Kintsch, W. (1993). Information accretion and reduction in text processing: Inferences. Discourse Processes, 16(1–2), 193–202.
- Knowlton, S. W., & Berger, C. R. (1997). Message planning, communication failure, and cognitive load: Further explorations of the hierarchy principle. *Human Communication Research*, 24(1), 4–30.
- Kool, W., McGuire, J. T., Rosen, Z. B., & Botvinick, M. M. (2010). Decision making and the avoidance of cognitive demand. *Journal of Experimental Psychology: General*, 139 (4), 665–682.
- Linell, P. (2015). Mishearings are occasioned by contextual assumptions and situational affordances. Language & Communication, 40, 24–37.
- Lu, Z. Y., Chen, J. Q., & Shao, Y. J. (2009). Affordance information retrieval in text comprehension. Acta Psychologica Sinica, 41(9), 793–801.
- Majid, A. (2013). Making semantics and pragmatics "sensory". Journal of Pragmatics, 58, 48–51.
- Majid, A., Sanford, A. J., & Pickering, M. J. (2007). The linguistic description of minimal social scenarios affects the extent of causal inference-making. *Journal of Experimental Social Psychology*, 43(6), 918–932.
- Markovits, H., & Doyon, C. (2004). Information processing and reasoning with premises that are empirically false: Interference, working memory, and processing speed. *Memory & Cognition*, 32(4),592-601.
- Mashal, N., Faust, M., Hendler, T., & Jung-Beeman, M. (2008). Hemispheric differences in processing the literal interpretation of idioms: Converging evidence from behavioral and fMRI studies. *Cortex*, 44(7), 848–860.
- McGlone, M. S., & Pfiester, R. A. (2009). Does time fly when you're having fun, or do you?: Affect, agency, and embodiment in temporal communication. *Journal of Language and Social Psychology*, 28(1), 3–31.
- Niedenthal, P. M. (2007). Embodying emotion. Science, 316(5827), 1002-1005.

- Niedenthal, P. M., Barsalou, L. W., Winkielman, P., Krauth-Gruber, S., & Ric, F. (2005). Embodiment in attitudes, social perception, and emotion. *Personality and Social Psychology Review*, 9(3), 184–211.
- Palomares, N. A. (2009). It's not just your goal, but also who you know: How the cognitive associations among goals and relationships influence goal detection in social interaction. *Human Communication Research*, 35, 534–560.
- Palomares, N. A. (2013). When and how goals are contagious in social interaction. Human Communication Research, 39, 74–100.
- Palomares, N. A., Grasso, K. L., & Li, S. (2015). Understanding others' goals depends on the efficiency and timing of goal pursuit. *Journal of Language and Social Psychology*, 34, 564–576.
- Pezzulo, G. (2014). Why do you fear the bogeyman? An embodied predictive coding model of perceptual inference. *Cognitive, Affective, & Behavioral Neuroscience, 14*(3), 902–911.
- Pinker, S. (1997). How the mind works. New York: W.W. Norton.
- Riskind, J. H., & Gotay, C. C. (1982). Physical posture: Could it have regulatory or feedback effects on motivation and emotion? *Motivation and Emotion*, 6(3), 273–298.
- Ryskin, R., Kurumada, C., & Brown-Schmidt, S. (2019). Information integration in modulation of pragmatic inferences during online language comprehension. *Cognitive Science*, 43(8), Article e12769.
- Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. Trends in Cognitive Sciences, 17(11), 565–573.
- Shen, H., & Sengupta, J. (2012). If you can't grab it, it won't grab you: The effect of restricting the dominant hand on target evaluations. *Journal of Experimental Social Psychology*, 48, 525–529.

Singer, M. (2013). Inferences in language comprehension. Inc: Sage Publications.

Sperber, Dan and Wilson, Diedre (1986). Relevance: Communication and Cognition. Oxford: Basil Blackwell. (1995 – 2nd edition).

- Sperber, D., & Wilson, D. (2002). Pragmatics, modularity and mind-reading. Mind and Language, 17, 3–23.
- Stepper, S., & Strack, F. (1993). Proprioceptive determinants of emotional and nonemotional feelings. Journal of Personality and Social Psychology, 64(2), 211–220.
- van Ackeren, M. J., Casasanto, D., Bekkering, H., Hagoort, P., & Rueschemeyer, S. A. (2012). Pragmatics in action: Indirect requests engage theory of mind areas and the cortical motor network. *Journal of Cognitive Neuroscience*, 24(11), 2237–2247.
- Van Berkum, J. J., Brown, C. M., Zwitserlood, P., Kooijman, V., & Hagoort, P. (2005). Anticipating upcoming words in discourse: Evidence from ERPs and reading times. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(3), 443–467.
- van Dam, W. O., van Dijk, M., Bekkering, H., & Rueschemeyer, S. A. (2012). Flexibility in embodied lexical-semantic representations. *Human Brain Mapping*, 33(10), 2322–2333.
- Vankov, I., & Kokinov, B. (2013). The role of the motor system in conceptual processing: Effects of object affordances beyond response interference. Acta Psychologica. May 2013, 143(1), 52–57.