emotion review

*Emotion Review*
Vol. 1, No. 2 (Apr. 2009) 151–161

ISSN 1754-0739
DOI: 10.1177/1754073908100440
http://emr.sagepub.com

# Gender, Emotion, and the Embodiment of Language Comprehension

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## Abstract

Language comprehension requires a simulation that uses neural systems involved in perception, action, and emotion. A review of recent literature as well as new experiments support five predictions derived from this framework. 1. Being in an emotional state congruent with sentence content facilitates sentence comprehension. 2. Because women are more reactive to sad events and men are more reactive to angry events, women understand sentences about sad events with greater facility than men, and men understand sentences about angry events with greater facility than women. 3. Because it takes time to shift from one emotion to another, reading a sad sentence slows the reading of a happy sentence more for women than men, whereas reading an angry sentence slows the reading of a happy sentence more for men than for women. 4. Because sad states motivate affiliative actions and angry states motivate aggressive action, gender and emotional content of sentences interact with the response mode. 5. Because emotion simulation requires particular action systems, adapting those action systems will affect comprehension of sentences with emotional content congruent with the adapted action system. These results have implications for the study of language, emotion, and gender differences.

**Keywords**
embodiment, emotion, gender, language comprehension

There is no question that language and emotion affect one another. When we read a novel, the words may thrill, petrify, or titillate, and when listening to a bigot the words may invoke anger. Embodied approaches to language and cognition have a ready explanation for these effects: Language is understood through a simulation process that calls upon neural systems used in perception, action, and emotion. Thus, simulating the language produces much the same effect as being in the situation.

We begin by briefly reviewing data demonstrating the embodiment of language; that is, how perception, action, and emotion systems are used in language comprehension. Next, we review work showing gender differences in emotional reactivity. Given these gender differences, we are led to the following prediction: Men and women will differ in the processing of language about emotional situations. The results from several projects document those differences. There is an important caveat to keep in mind, however. Although men and women differ in their emotional reactivity, in fact the similarities are much greater than the differences (e.g., Bradley, Codispoti, Sabatinelli, & Lang, 2001). Similarly, whereas we document theoretically significant gender differences in the processing of emotional language, the effect sizes are small. Thus it would be incorrect to assume that these differences characterize everyone to the same extent.

*Author note*: This work was supported by a NSF grant BCS-0315434 to Arthur Glenberg. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Requests for reprints may be directed to Arthur Glenberg at glenberg@asu.edu. We express our thanks to many people who worked on these experiments, and in particular, Jerry Federspiel.
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## The Embodiment of Language and Emotion[1]

Although it has been proposed that language is an encapsulated system unaffected by other neural and cognitive processes (e.g., Fodor, 1983), recent investigations have provided overwhelming evidence that systems used in perception, action, and emotion affect language processes such as lexical access (Borghi, Glenberg, & Kaschak, 2004), syntactic analysis (Chambers, Tanenhaus, & Magnuson, 2004), and sentence comprehension (Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006). For example, Kaschak et al. (2005) demonstrated the influence of perceptual systems on comprehension. In one condition, participants watched a moving spiral simulating motion either toward or away from the participant. Simultaneously, the participants listened to sentences describing motion toward (e.g., "The car approached you") or away. Kaschak et al. found that the time to judge the sentence as sensible was affected by the interaction of spiral motion direction and direction of motion implied by the sentence.

Glenberg and Kaschak (2002) demonstrated the influence of action systems on sentence understanding. Participants judged the sensibility of sentences implying action toward (e.g., "Open the drawer") or away from (e.g., "Close the drawer") the participant. Participants were faster to judge "away" sentences when the sensible response was made by moving to a response button far away from the body, whereas readers were faster to judge "toward" sentences by moving to a button close to the body. Similar results were found for abstract sentences implying movement of information from one person to another. Apparently, people use neural systems related to action when determining the meaning of a sentence (see also, Hauk, Johnsrude, & Pulvermüller, 2004, and Zwaan & Taylor, 2006).

The Indexical Hypothesis (IH; Glenberg & Robertson, 1999, 2000) offers an explanation for these bodily effects on language comprehension. According to the IH, three processes contribute to language comprehension. First, words and phrases (e.g., "your lover") are indexed or mapped to physical situations or analogical perceptual symbols (Barsalou, 1999). Perceptual symbols are modality-specific representations selected from experience by attentional processes. Furthermore, these symbols can be used by a simulation process to anticipate future states. Thus, the perceptual symbol to which one might index "your lover" is likely to have modality specific components for the look (visual system), sound (auditory system), smell (olfactory system), and movement patterns (motor system) attended when interacting with a particular person (see Heberlein & Atkinson, 2009, for a review of the neural systems involved in emotion recognition based on several types of visual and auditory cues).

The second process specified by the IH is the derivation of affordances. Affordances (Gibson, 1979) are potentials for interaction between a biological system and a physical system. Thus, a chair affords sitting for a human, but not an elephant; similarly a chair affords hiding under for a toddler, but not for an adult. That is, affordances depend on body morphology and abilities. The affordances of "your lover" may well include social interaction such as talking and joking, hand-holding, hugging, and so on. Because affordances are derived using perceptual systems, operations on perceptual systems (e.g., watching a spinning spiral) will affect language comprehension.

The third process in the IH is the combination of affordances as specified by syntax (Chambers et al., 2004; de Vega, Robertson, Glenberg, Kaschak, & Rinck, 2004; Kaschak & Glenberg, 2000). Because the combination of affordances makes use of action systems (e.g., motor planning), operations on action systems will affect language comprehension. In a sentence such as "Your supervisor frowns as he hands you the sealed envelope" the syntax specifies that the envelope is transferred from the supervisor to you, rather than vice versa. Similarly, the syntax specifies that the simulation needs to include a frowning supervisor. Simulation of these events may well lead to a simulated (or real) frown upon your own face (see Niedenthal, Barsalou, Winkielman, Krauth-Bruber, & Ric, 2005 for a review of facial mimicry).

Within the framework of the IH, there are several pathways for emotional system processing and language to interact. By emotional system processing, we mean changes in both neural systems that contribute to emotion (frontal cortex, insula, amygdala, thalamus, and components of the ANS) as well as associated changes in physiological states (hormonal systems, heart rate, orienting, etc.). Consider first the notion of indexing words with emotional content to perceptual symbols. The perceptual symbol may have components that reflect previous attention to components of emotion. Thus, hearing "your lover" may well invoke feelings of happiness and arousal (and associated physiological states) because those are component parts of the perceptual symbol. In such a case, the language helps to induce an emotional state.

In addition, existing emotional states may match or mismatch emotions conveyed in language. Thus, to the extent that experiencing or simulating the emotion is a necessary component of deep comprehension, then being in the appropriate state should help to understand the language. We will refer to this statement as Prediction 1.

Emotion may also affect language comprehension by changing the affordances that are derived from situations or perceptual symbols. Affordances are possibilities for action that depend on bodily state and the physical situation. Because emotions can have profound effects on bodily states (e.g., Bradley, Codispoti, Cuthbert, & Lang, 2001; Levenson, 1992), such as preparing it for flight or fight, an emotional state can change the available affordances. For example, in reading about a canoe paddle during a camping trip, one might reasonably derive from the perceptual symbol of the paddle that it can be grasped in a manner to afford paddling (e.g., handle up and paddle down). However, if the text were to describe a frightening encounter with a bear, then one might derive from the perceptual symbol of the paddle that it could be grasped in a manner to afford swinging in defense (e.g., like a baseball bat).

Prediction 1 (being in a congruent emotional state will facilitate language comprehension) was tested by Havas, Glenberg, and Rinck (2007). They used the Strack, Martin, and Stepper (1988) pen procedure to induce facial configurations typical of

**Table 1.** Examples of the happy, sad, and angry sentences used in the experiments

| |
|---|
| Happy |
| Your lover chases you playfully around your bedroom. |
| You stand proudly on stage as the audience rises after your recital. |
| Sad |
| You open your email-inbox on your birthday to find no new emails. |
| You see a cat running across the street too late to avoid hitting it with your car. |
| Angry |
| You shout at the pushy telemarketer who had the nerve to call during dinner. |
| Reeling from the fight with that stubborn bigot, you slam the car door as hard as you can. |

emotion states. Manipulating facial configurations reliably induces the state (or at least makes it easier to enter the state) typical of the configuration. Thus, participants were asked to hold a pen using only their teeth, which induces smiling and brightens the mood, or they held the pen using only the lips, which induces a frown or pout. The participants were told that the experiment investigated how blocking the speech articulators might affect language processing. While holding the pen, participants read and judged happy, sad, and angry sentences (as pleasant or unpleasant in Experiment 1 or as easy or hard to comprehend in Experiment 2). Examples of the sentences are reproduced in Table 1.

In both experiments, there was an interaction between the pen position and the valence of the sentences on the time to make the judgment. That is, participants were faster to read and judge sentences describing a pleasant state of affairs (e.g., "Your lover chases you playfully around your bedroom") when holding the pen in the teeth (smiling) than when holding the pen in the lips (frowning). The opposite was found for sentences describing an unpleasant situation.

Havas et al. (2007) conducted a third experiment to test a simple priming interpretation of the interaction. That is, perhaps the effects have little to do with changes in the body and the derivation of affordances. Instead, when people are smiling, an abstract representation of words such as "lover" and "playfully" are activated. If this is the case, then holding the pen in the lips should facilitate a lexical decision that the stimulus "lover" is a word. In fact, however, the pen manipulation had no effect on lexical decision times. Thus, manipulating the emotional state affects language processing, and the effect seems to be in a manner predicted by the IH. That is, the induced emotion and the content of the sentence are congruent, readers can more easily derive the affordances needed to understand the sentences. Thus the data strongly confirm Prediction 1.

In an unpublished study, we further examined the role of facial muscles in language comprehension. We used electromyographic (EMG) recording from the facial muscles involved in producing expressions of happiness (zygomaticus major, and orbicularis oculi), and anger and sadness (corrugator supercillii) while participants read sentences describing angry, sad, and happy situations.

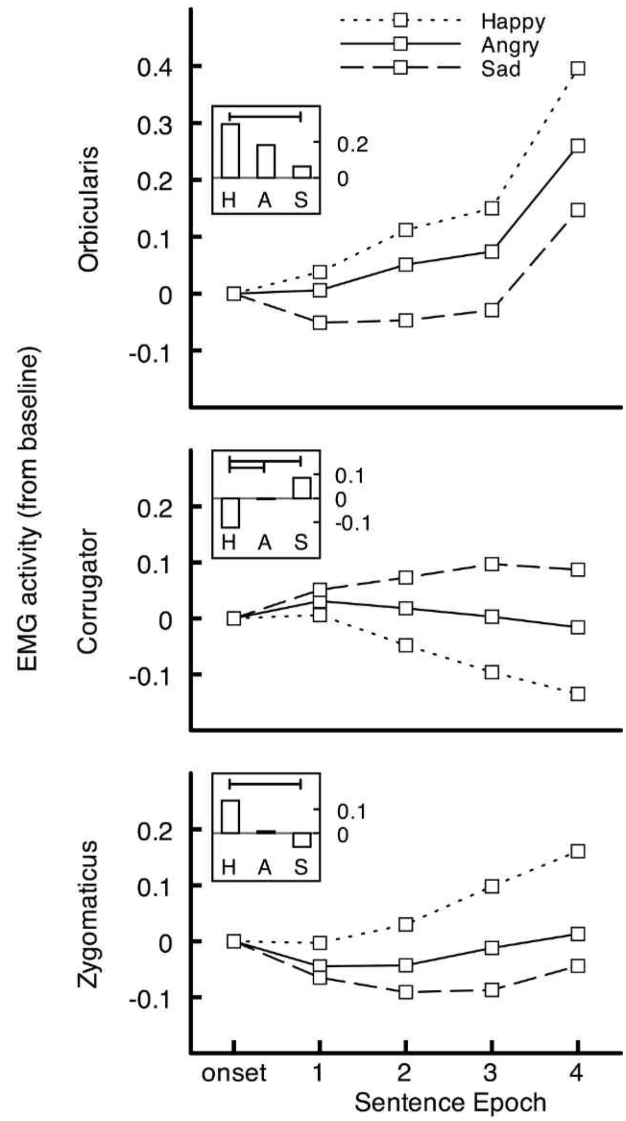


**Figure 1.** EMG change from baseline across sentence quarters (epochs) and overall (inset; horizontal bars indicate significant comparisons).

The sentences were shown individually on a computer screen separated by three-second pauses, and a comprehension question followed a random third of the sentences to encourage understanding. Participants used their right hands to press a key after reading the sentence, and the left hands to answer the comprehension question. Participants were initially told the purpose of the study was to measure skin conductance during reading.

We compared facial muscle activity during reading of angry, sad, and happy sentences. Figure 1 depicts the time course of activity from baseline (1000 ms before sentence onset) across four quarters of sentence reading time. Insets depict change from baseline for mean activity during reading of angry, sad, and happy sentences. The major findings were that muscles used in smiling (zygomaticus and orbicularis) are more active during reading of happy sentences than sad sentences, whereas the frowning muscle (corrugator) is more active during reading of sad and angry sentences compared to happy sentences. Thus, the evidence points to a bidirectional link between language and emotion (or at least the facial configuration typical of emotions). Namely, language understanding induces emotion-specific changes in the facial muscles (Figure 1), and changes in the facial muscles affect language understanding (Havas et al., 2007).

Again, a simple priming explanation might account for these effects on the basis of reactivity to individual words with strong emotional associations, in which case facial muscle activity would be unrelated to comprehension of emotional sentences. However, a similar study using words casts doubt on this kind of account. Niedenthal (2007) discusses an experiment which used EMG to measure facial responses to emotional and neutral words under two task conditions: in the "shallow" processing condition, participants judged whether the word was printed in capital or small letters, and in the "deep" processing condition, participants judged whether or not the word related to an emotion. Emotion words generated emotion-specific facial activation in the "deep" processing task, whereas the same words evoked no such response in the "shallow" task. Moreover, a similar pattern was found when using either concrete (Experiment 1) or abstract words (Experiment 2). As in our study, the emotion-specificity was weakest for anger-related processing. Thus, these results suggest that any effects of individual words depend on a consideration of the word's meaning.

In general, the EMG results are congruent with "facial feedback" theories (Adelman & Zajonc, 1987; Ekman, Levenson, & Friesen, 1983). That is, facial afference generated by emotional language might directly impact emotion and autonomic states through key neural structures of emotion such as the amygdala and thalamus.

## Gender, Emotion, and Language: Emotional Reactivity

There is evidence suggesting that men and women differ in their emotional reactivity. For example, Bradley, Codispoti, Sabatinelli, and Lang (2001) report gender differences in reactivity to pictures with varied emotional content, although it should be noted that the similarities were at least as impressive as gender differences. Women responded with greater defensive reactions (e.g., heart deceleration, startle response, stronger negative facial displays) to a wider array of negative stimuli (e.g., pollution, loss, illness) than did men. In regard to pictures depicting pleasurable events (e.g., erotica, sports, food, family), there were gender differences only in regard to erotica, with men responding more strongly (e.g., greater inhibition of startle).

Verona and Curtin (2006) examined gender differences in reactivity (as measured by startle response and ratings) to stress and frustration, as well as the effects of stress and frustration on aggression (increasing levels of shock supposedly administered to an employee). There were no significant gender differences in startle, although women reported more fear in the stressful context whereas men reported more hostility. Furthermore, men administered higher levels of shock than did women, particularly under stressful conditions.

Finally, Wallbot (1988) presented close-up clips of actors to participants and asked the participants to guess the emotion being portrayed. Participants were more accurate in identifying the emotions of sadness, fear, and depression in female actors than in male actors. In contrast, participants were more accurate in identifying the emotion of anger in male actors. One interpretation of these findings is that they reflect cultural stereotypes (Parmley & Brandeis, 2005; Plant, Kling, & Smith, 2004). An alternative interpretation is that there is a difference between the genders in the degree to which there are bodily changes in response to emotional stimuli (Madden, Feldman Barrett, & Pietromonaco, 2000). Indeed, some research has demonstrated differences between the genders in facial expressivity and physiology related to emotion. For example, Kring and Gordon (1998) report that skin conductance changes more for women than for men when viewing films depicting disgust and sadness, whereas the opposite is found for viewing films depicting anger and fear.

Consistent with the previous research (and cultural stereotypes), suppose that women enter sad states more easily than men, and men enter angry states more easily than women. Furthermore, consistent with Havas et al. (2007), suppose that being in a sad (or angry) emotional state makes it easier to understand language about sad (or angry) situations because of the congruence between the described emotional situation (and required simulation) and bodily state. This leads us to Prediction 2: women should understand sentences about sad events with greater facility than men, whereas men should understand sentences about angry events with greater facility than do women. We tested this prediction in a series of three gender and language experiments.

In the experiments, men and women read sentences written to reflect angry, sad, and happy situations (see Table 1 for examples).[2] The task was to read the sentence (sentence reading time was the primary dependent variable) and then answer a Yes/No question designed to encourage reading for meaning.

The sentences were written in the second person and gender cues were minimized. Also, the sentences described situations that were likely to be emotion-producing, but the sentences did not directly name a basic emotion. Normative data on the sentences were obtained in an independent experiment in which 29 women and 16 men used a 3-point Likert scale (0 = not at all, 1 = somewhat, 2 = very much) to rate the sentences on comprehensibility as well as implied amounts of aggression/anger, sadness/depression, fear, and happiness. The means were weighted so that each gender had an equal influence. We designated sentences as critical for the experiments when the mean rating on the target emotion (e.g., anger) was at least 1.5, all other emotion ratings were lower than .5, and the comprehensibility rating was higher than 1.5. These criteria produced 28 happy sentences, 14 sad sentences, and 14 anger/aggression sentences. Critical sentences were tested for main effects of gender on emotion ratings and comprehensibility ratings. The only significant effect was that women rated angry sentences as angrier (M = 1.88) than men (M = 1.76), $t(14) = 3.15$, $p < .01$. Importantly, there were no significant differences between the genders in the comprehensibility ratings.

In the first of the gender experiments, 96 women and 94 men participated. They read a total of 136 sentences (including the 56 critical sentences). Approximately half of the participants interacted with a male experimenter and the other half with a female experimenter. In an analysis of the reading times for the critical sentences, the interaction of gender and sentence content fell just short of statistical significance (see below). Consequently, we decided to replicate the experiment using only the 56 critical sentences. A total of 98 women and 74 men participated in the second gender experiment.

Across the two gender experiments, 12 women and nine men were eliminated for answering fewer than 75% of the questions correctly. Any observation of a sad sentence reading time greater than 8,000 ms was eliminated, as well as any observation of an angry sentence reading time greater than 10,000 ms (angry sentences were longer and more complex). Additionally, three women and five men were eliminated for having average reading times greater than 8,000 ms in any condition. For the remaining participants (88 women, 84 men in the first experiment; 91 women, 70 men in the second), analyses focused on the critical angry and sad sentences for which questions were answered correctly.

Because the sentences differed in length, a regression equation was created for each participant relating reading time to sentence length. A residual score was calculated for each sentence. A positive residual means that the participant took longer to read the sentence than predicted by sentence length, and a negative residual means that the participant took a shorter time to read the sentence than predicted by length. Then, for each participant we calculated the difference between the mean residual for the angry sentences and the mean residual for the sad sentences. Thus, the slower the reading of angry sentences (compared to sad sentences) the larger the difference score.

The mean residuals and the difference scores are presented in Table 2. Even controlling for sentence length, it is clear that the angry sentences took much longer to read than the sad sentences for both genders. This may reflect more complex syntax, use of low frequency words, or an effect of emotion. More importantly, note that women tend to read the angry sentences more slowly than the sad sentences, and that this difference is reduced for men. For the first gender experiment, the effect of gender on the size of the difference score was just shy of statistical significance, $t(170) = 1.84$, $p = .067$, $d = .28$. The effect was significant for the second gender experiment alone, $t(159) = 2.08$, $p = .039$, $d = .33$, and for the two experiments combined, $t(331) = 2.77$, $p < .01$, $d = .31$. Thus, the data confirm Prediction 2: women read sentences about angry situations slowly relative to sentences about sad situations, whereas men show the opposite effect, or at least a reduced effect.

Although the results are consistent with Prediction 2, several alternative hypotheses need to be eliminated. For example, perhaps women are more familiar with sad situations (or at least the words describing them), and men are more familiar with angry situations. Thus, the gender effect may reduce to a word frequency effect. Or, perhaps women find sad situations more interesting than angry situations, and the reverse for men. Or, given that the results are consistent with gender stereotypes, perhaps the results reflect compliance or conformation to a stereotype. None of these alternatives require that emotional systems have a direct effect on language comprehension (e.g., gender may affect word frequency, and it is word frequency that affects language processing, not the concurrent emotional body state). The third gender experiment was designed to help secure the interpretation that the differential effects of gender reflect direct contributions of emotional systems to language comprehension.

**Table 2.** Residual sentence reading times (ms) for gender Experiments 1, 2, and 3

| | *Angry sentences* | *Sad sentences* | *Difference* |
|---|---|---|---|
| | | Experiment 1 | |
| Women | 269 | −385 | 654 (SD = 589) |
| Men | 202 | −288 | 490 (SD = 581) |
| | | Experiment 2 | |
| Women | 277 | −410 | 687 (SD = 424) |
| Men | 192 | −346 | 538 (SD = 484) |
| | | Experiment 3 (Prime sentences) | |
| Women | 211 | −289 | 500 (SD = 455) |
| Men | 148 | −228 | 376 (SD = 415) |

Consider three assumptions about the operation of emotional systems. First, it takes time to move from one emotional state to another. Second, the stronger the first emotion, the longer the time needed to switch emotional states. For example, given introduction of a pleasant situation, it will take longer for a furious person to become happy than one who is slightly annoyed. Third, and consistent with the results of the first two gender experiments, suppose that women enter sad states relatively more easily than men, and men enter angry states relatively more easily than women.

These assumptions lead us to an old and a new prediction. As in the previous two gender experiments, women should read sad sentences relatively more quickly than men, and the opposite is predicted for angry sentences (Prediction 2, again). The new prediction, Prediction 3, is that following the reading of a sad sentence, women should read happy sentences more slowly than men (because while reading the happy sentences women are in a sadder state than the men), whereas following an angry sentence, men should read happy sentences more slowly than women (because while reading the happy sentences men are in an angrier state than the women).

The third gender experiment tested these predictions by presenting sentences one at a time, but successive sentences formed pairs. The first member of the pair, the prime, was a sad, angry, or happy sentence. Prediction 2 should hold for the prime sentences. The second member of the pair, the target, was always a happy sentence. Prediction 3 should hold for the target sentences.

Pairs of sentences were randomly created for each participant. Critical sentences from the first two experiments formed the angry and sad primes and the happy targets following these primes. Comprehension questions were never presented after prime sentences to reduce the time between prime and target sentences. Comprehension questions were presented after all target sentences and all filler sentences (so participants could not infer that angry and sad primes were never followed by questions).

The data from the prime trials were treated the same as in gender experiments 1 and 2. In addition, 11 participants (6 female, 5 male) were eliminated for average reading times of target sentences greater than 6000 ms (the happy target sentences were much shorter than the sad or angry sentences, hence a lower cutoff was used). The residual difference scores for the prime sentences are in Table 2.

In regard to Prediction 2, the effect of gender was not significant ($t(100) = 1.42$, $p = .16$, $d = .28$), although the effect is in the same direction and of comparable magnitude to gender experiments 1 and 2. A probable reason for the failure to reach standard levels of statistical significance is the smaller sample size compared to gender experiments 1 and 2.

Next, consider Prediction 3. Because the target sentences were all happy sentences of approximately the same length and randomly assigned to condition for each participant, there was no need to compute residual reading times. The target reading times are in Table 3, and they confirm Prediction 3: for women, reading a happy target was slowed by a sad prime (relative to an angry prime), whereas for men, reading a happy target was slowed by an angry prime (relative to a sad prime). Statistically, the mean difference score for women was reliably smaller than the mean difference score for men, $t(100) = -2.32$, $p = .022$, $d = -.46$.

The data are consistent with the claim that emotional state has a direct effect on language comprehension (perhaps through the derivation of affordances), and the data are difficult for several alternative hypotheses to explain. There is, however, at least one alternative, which we will call the associative hypothesis, that is consistent with most of the data.[3] Suppose that women have more experiences with sad situations than angry situations, and that the reverse is true for men. When understanding a sentence, these experiences are recalled through associative mechanisms, and they are used to form a coherent associative network (e.g., Kintsch, 1988). With a greater number of relevant experiences, it is easier to form a network, and that results in faster sentence understanding and a greater depth of comprehension. This reasoning explains the results of the first two gender experiments. Furthermore, once a large network is formed, it may fill the capacity of working memory so that it is difficult to understand a successive, but unrelated (e.g., happy) sentence. This reasoning provides an explanation for the results of the third experiment.

We have two reasons for preferring an explanation postulating a direct effect of emotion on language comprehension to this associative account. First, Havas et al. (2007) disconfirmed a related associative account. In their study, the Strack et al. (1988) pen manipulation affected sentence comprehension (presumably because the pen induced an emotional state that affected derivation and combination of affordances), however, the pen manipulation had no effect on a measure of associations, namely priming in the lexical decision task. Second, the associative account is based on the premise that there is a positive correlation between the number of relevant emotional experiences and the ease and depth of comprehension of a sentence (e.g., women have more sad experiences and hence understand sad sentences more quickly and more completely than men).

**Table 3.** Target sentence (happy) reading times for gender Experiment 3

| | *Angry primed* | *Sad primed* | *Difference* |
|---|---|---|---|
| Female | 2422 | 2523 | −101 (SD = 275) |
| Male | 2518 | 2480 | 38 (SD = 330) |

However, we found no differences between the genders in the ratings of sentence comprehensibility.

## Gender, Emotion, and Language: Action Systems

Emotions are not just for fun; it is almost a certainty that they have survived dramatic evolutionary changes because they are functional and adaptive. That is, emotions prepare and motivate animals to take action in the world (Bradley, Codispoti, Cuthbert, & Lang, 2001; Frijda, 1987, 2005; Levenson, 1992; see Heberlein & Atkinson, 2009, for a review of the neuroscientific evidence connecting emotion and action systems, and see Ping, Dhillon, & Beilock, 2009, for behavioral data relating ease of action and liking). If understanding language about emotions uses simulation of those emotions, then the mere understanding of emotional language should produce differential preparation for action. Furthermore, to the extent that the simulation is different in men and women, then the preparation for action should also be different. Prediction 4 is based on the following reasoning: because women are more responsive to sad states than are men, women should be more ready to take affiliative-types of actions than men; because men are more responsive to angry states than are women, men should be more ready to take aggressive actions than are women.

Mouilso, Glenberg, Havas, and Lindeman (2007) tested Prediction 4 using the lever apparatus illustrated in Figure 2 (note that the lever has a piston acting against it so that a small, but not negligible, force is needed to move it). Participants read sad and angry sentences such as those in Table 1, as well as neutral sentences such as "You talk with your cousin the telemarketer while passing the salt during dinner," and nonsense sentences such as, "While in a rush to make your meeting on the 24th floor, the empty box elevators to a sudden stop." The task was to decide as quickly as possible if a sentence was sensible or nonsense. The trick that allowed us to test Prediction 4 was how that decision was indicated. For half of the participants, they indicated "sensible" by pushing the lever as quickly as possible in the forward direction, away from their bodies. When making this response quickly, it generates a movement corresponding to an aggressive or striking-out movement (see Heberlien & Atkinson, 2009, for a review of data relating bodily actions and their speed to emotions). For the other participants, the lever apparatus was rotated 180 degrees from that illustrated in Figure 2. Thus for these participants, the "sensible" response resulted in pulling the lever toward their bodies generating an affiliative (bringing closer to the body)

**Figure 2.** The lever apparatus oriented for making the "aggressive" away response.

**Table 4.** Time to make the affiliative or aggressive response after reading angry or sad sentences (adjusted for neutral sentences)

| | *Angry–Neutral* | *Sad–Neutral* | *Difference* |
|---|---|---|---|
| *Men* | | | |
| Affiliative (toward) | −25 | −23 | −2 |
| Aggressive (away) | −30 | 24 | −54 |
| *Women* | | | |
| Affiliative (toward) | 2 | −18 | 20 |
| Aggressive (away) | 5 | 18 | −13 |

movement. For all participants, the "nonsense" response was made by using the thumb to press a button on the top of the lever.

The data used to test Prediction 4 are presented in Table 4. Note that these are not reading times. Instead, we measured the time needed to move the lever from its starting position to the final position, that is, the amount of time between when lever motion is first detected and when the lever contacts a switch near the bottom of the apparatus. After reading neutral sentences, women responded a bit faster when making the affiliative response (pulling the lever toward the body; M = 763 ms) than when making the aggressive response (pushing the lever away; M = 771 ms), whereas men responded a bit slower when making the affiliative response (M = 866 ms) than when making the aggressive response (M = 851 ms). Consequently, we subtracted these times from the times needed to move the lever after reading the sad and angry sentences, and it is those differences that are displayed in Table 4.

The first part of Prediction 4 is that for the aggressive response of pushing the lever away from the body, responding will be faster following Angry sentences compared to the Sad sentences, and this difference should be particularly strong for men. In fact, the 54 ms difference for men was statistically significant, whereas the 13 ms difference for women was not. The second part of Prediction 4 is that for the affiliative response of pulling the lever toward the body, responding will be faster following sad sentences compared to angry sentences, and this difference should be particularly strong for women. In fact, the −2 ms difference for men was not statistically significant, whereas the 20 ms difference for women was.

The results from this experiment quite strikingly demonstrate several facts. First, understanding emotional language produces a simulation of the emotion. Second, because that simulation is based in the neural systems used for emotion, the simulation produces components of the emotional state, namely preparation to take action congruent with that state. Third, there are gender differences in reactivity to emotions of sadness and anger that are reflected in differential preparation for action.

Nonetheless, the results leave open an important question regarding the comprehension of language. Is the simulation that produces the emotional state and action preparation a necessary component of language comprehension or simply an optional process that is executed after the sentence is understood? That is, is there a causal relation between the emotion simulation and comprehension? Prediction 5 is that increasing the difficulty of completing a simulation that prepares for action will increase the difficulty of comprehending language requiring that simulation.

There are at least two precedents for Prediction 5. First, Glenberg, Sato, and Cattaneo (2008) demonstrated that exercise of a toward or away movement in the first part of an experiment selectively slowed comprehension of sentences describing toward or away actions in the second part of the experiment. Second, Vermeulen, Corneille, Budke, and Niedenthal (in press) noted that making a perceptual judgment about an auditory stimulus (high or low in pitch) or a visual stimulus (light or dark gray) selectively interfered with subsequent conceptual judgments requiring a simulation in that modality (e.g, the auditory judgment interfered with judging if a blender is loud). That is, previous use of an action system (Glenberg et al., 2008) or perceptual system (Vermeulen et al., in press) affected a conceptual task supposedly requiring the system for simulation.

In making Prediction 5, a similar logic is used. That is, suppose that part of experiencing an emotion (e.g., anger) is preparation for a particular action (e.g., striking out). Thus, part of simulating the emotion consists of preparation of a particular action. Then, adaptation of the action system will affect the ability to simulate the emotion, and that will affect the ability to understand the sentence.

In some ways, Predictions 1, 3, and 5 are the same: manipulating the ease of using the emotion system to simulate language will affect speed of comprehension. To test Prediction 1, Havas et al. used the pen manipulation to increase the difficulty of entering a particular emotional state. To test Prediction 3, we used a sad or angry priming sentence to affect the difficulty of a simulation needed to understand a happy sentence. In the following experiments, we test Prediction 5 by adapting the action component required to simulate the emotion.

Before beginning the reading comprehension task, participants engaged in approximately 300 of the aggressive or the affiliative responses. The point of this manipulation was to adapt[4] or fatigue the action systems needed to make the aggressive or the affiliative responses. Consequently, it should be more difficult to complete the simulations putatively needed to understand the sentences. As in the Mouilso et al. (2007) experiment, participants judged if the sentences were sensible or not. Importantly, however, in this experiment the "sensible" and "nonsense" responses were made by pushing keys on a computer keyboard, not with the lever. Thus, we are asking whether adapting particular action systems (using the lever) will differentially affect comprehension of sentences requiring a simulation using those action systems when those actions systems are logically irrelevant to making the responses. And for good measure, will these effects depend on gender? That is, if men are more likely than women to engage in a simulation of anger that involves preparation for striking out, then fatiguing the actions involved in striking out should slow their understanding of anger-related sentences. Similarly, if women are more likely than men to engage in a simulation of sadness that involves preparation for affiliative response, then fatiguing those actions should slow their understanding of sadness-related sentences.

The data are in Table 5. Note that these are residual reading times (time between presentation of the sentence and the button push indicating a "sensible" response), rather than the time to move the lever as in Mouilso et al. (2007). We adjusted the data from the sad and angry sentences by subtracting time to read the neutral sentences because the fatiguing manipulation had slightly different effects on the neutral sentences for men and for women. For men, fatiguing the affliative response speeded reading of the neutral sentences (M = –57 ms) compared to fatiguing the aggressive response (M = –24 ms). In contrast, for women, fatiguing the affiliative response slowed reading of the Neutral sentences (M = 21 ms) compared to fatiguing the aggressive response (M = –27 ms).

The interaction of sentence content, gender, and previous lever movement direction is significant, although open to several interpretations. Focusing first on the data for the men, fatiguing the aggressive response slows the comprehension of angry sentences (positive numbers indicate slower reading than for the neutral sentences) compared to sad sentences. This slowing (difference score of 344 ms) is greater than after fatiguing the affiliative response (difference score of 73 ms). The form of this interaction is consistent with the assumption that men's understanding of angry sentences requires a simulation of that anger, and it is more difficult to simulate anger when the aggressive response is fatigued. Note that the interaction can also be read the other way: men find it easier to understand sad sentences when the aggressive response is fatigued compared to when the affiliative response is fatigued.

The data for women are quite different, and not completely consistent with our expectations. Note first that fatiguing the aggressive response has little differential effect on sentence comprehension time. Second, fatiguing the affiliative response does differentially affect comprehension time, but the effect is to speed comprehension of sad sentences relative to neutral sentences. One, admittedly ad hoc, explanation is based on the major muscles used in making the aggressive (triceps) and affiliative (biceps) responses. Given the difference in sizes of the triceps and biceps, our manipulation may have been more successful in fatiguing the smaller triceps (and the aggressive response) than the larger biceps (and the affiliative response). Thus, the affiliative response was more likely to be primed than fatigued, and the affiliative response plays a more central role in simulation for women than for men. A second ad hoc explanation is based on the notion of adaptation (see note 4). Namely, the affiliative response used by women in simulating the sad sentences is similar to the response used in the initial adaptation. Hence, this response is facilitated by the adaptation. In contrast, the aggressive response used by men in simulating the angry sentences is sufficiently different from the response that was adapted that there is interference.

**Table 5.** Residual sentence reading times (adjusted for neutral sentences) after fatiguing the affiliative or aggressive response

| | *Angry–Neutral* | *Sad–Neutral* | *Difference* |
|---|---|---|---|
| *Men* | | | |
| Affiliative fatigued | 73 | 0 | 73 |
| Aggressive fatigued | 167 | –177 | 344 |
| *Women* | | | |
| Affiliative fatigured | 29 | –229 | 258 |
| Aggressive fatigued | 6 | –14 | 20 |

## Discussion

We have been able to connect language processes and emotion by relating them both to action. On the language side, the connection to action is provided by the Indexical Hypothesis: language comprehension is tantamount to using linguistic stimuli to guide the derivation and combination of affordances to produce a simulation of the language. On the emotion side, the connection to action arises from a functional approach to emotions: emotions motivate actions (Bradley, Codispoti, Cuthbert, & Lang, 2001; Frijda, 1987, 2005; Levenson, 1992). From these perspectives, the mutual influences of language and emotion are to be expected. Also, to the extent that people differ in emotional responsivity, then those mutual influences will be modulated, as demonstrated by the experiments investigating gender effects.

Our data have implications for three usually disparate areas of psychology: language, emotion, and gender; we will consider these in turn, focusing on language. According to the IH, emotions and language interact through two routes. First, comprehension of emotional language should require simulations using emotion systems. Second, emotions produce literal changes in the body, thus changing the derivation and combination of affordances needed for perception, action, and language comprehension. For example, when one is angry ANS-produced changes in the body are consistent with aggressive, energetic, large muscle actions (Frijda, 1987; Levenson, 1992), particularly for men (Verona & Curtin, 2006). Consider how this bodily state might affect derivation of affordances upon reading a sentence such as, "Reeling from the fight with that stubborn bigot, you slam the car door as hard as you can." Car doors potentially afford many actions. Our claim is that when the body is in an angry, energetic state, the door affords slamming (or at least energetic slamming) more than when one is in a sad and less energetic state. Consequently, the angry body is prepared (in contrast to the sad body) to derive from the perceptual symbol of the car door the affordance that the door can be slammed, and the angry body is more ready to integrate that affordance with other aspects of the sentence.

This second process can be elaborated by considering how coordinated actions are accomplished through motor control. We use the formal motor control framework of Wolpert and colleagues (Haruno, Wolpert, & Kawato, 2001; Wolpert, Doya, & Kawato, 2003; Wolpert & Flanagan, 2001; see also Glenberg & Gallese, in preparation, for how the Wolpert model can be integrated with language). In this framework, the central nervous system learns to mimic the input–output functions of the motor apparatus using two kinds of internal models. Forward models (predictors) predict the sensory consequences of actions, while inverse models (controllers) do the opposite: they learn to derive actions on the basis of desired sensory states (Wolpert & Flanagan, 2001). Predictors and controllers fulfill complementary functions during motor learning and execution such that across experience, a predictor–controller pair (a module) is acquired for each effector or tool characterized by unique kinematics or dynamics (Haruno et al., 2001). Thus, the motor capabilities of the body are dynamically represented as internal models in the CNS.

Predictors are crucial for motor control because actual sensory feedback is noisy and delayed due to inherent limits in neural transmission (Harris & Wolpert, 1998). If a motor command is passed through a predictor (which is tantamount to simulation), then the resulting prediction can be used to guide forthcoming actions. Importantly, comparing predicted and actual sensory input yields an error signal useful for adjusting the motor program and for updating the predictor. A large error signal indicates that the current module is inappropriate for the context, and drives the CNS to switch to a module that produces smaller prediction error (Haruno et al., 2001). Thus, unanticipated sensory feedback directly modulates the motor system to optimize accuracy of future action.

Selection of the appropriate controller is also crucial, since controllers provide the basis for deriving goal-based actions (Wolpert & Flanagan, 2001). The problem of goal-based action is difficult because the number of actions that may possibly accomplish a given goal is many-to-one. In contrast to predictors, controllers are capable of learning the nonlinear dynamics of movement contexts. However, controllers are learned on the basis of the prediction error signal provided by the forward model (Flanagan, Vetter, Johansson, & Wolpert, 2003).

Under this motor control framework, we now offer some speculation on how emotions constrain the motor system, and thereby language comprehension. Suppose that one function of motor control is for regulating homeostasis of the body. Recent theory suggests that feedback regarding homeostasis may underlie emotions and emotional experience (Craig, 2003; Damasio et al., 2000). Because different states of the body (e.g., fatigue and arousal) have different dynamics, the motor system will form distinct modules for the control of action in those states. Consequently, the models used for simulating actions and for predicting the sensory consequences of actions (possibly in the insula, Critchley, 2005) will differ depending on the bodily state.

Thus, one function of the emotion system is to adjust perception and action simulation for the sake of maintaining homeostatic equilibrium. For example, simulation of actions while in a fatigued state might bias perception toward conservation of energy such that hills appear steeper (Proffitt, 2006). Similarly, a sad emotional state may make it difficult to integrate components of the sentence "You bound up the stairs to your lover's apartment," because it is difficult to simulate bounding in a low energy state.

How do particular motor patterns such as facial expressions or body movements of approach and avoidance come to influence simulation in this account? The emotion system is also responsive to changes in the environment. Consider again that across experience, the CNS acquires a predictor–controller module for each distinct homeostatic state of the body, and these modules are used for deriving goal-based actions within that state. When a module produces large prediction error, this initiates changes in the body and internal module for an effective motor response. For example, shortening of the limbs by clenching the fists may shift blood circulation from the periphery to the body's core for more powerful movements. In addition, the facial expression of surprise may alter the shape of the face to enhance sensory processing, while the facial posture of anger diminishes it (Susskind et al., 2008). Eventually, these motor patterns might be enough to trigger their associated homeostatic changes, or at least to shift the internal module and thereby affect the simulation process described above.

This speculative view suggests that emotion systems both coordinate changes in the environment with changes in homeostatic states of the body, and play a role in the selection of modules for sensory prediction and action. This view may also explain why emotions are associated with coordinated, even stereotyped, patterns of motor activity, despite the widely variable conditions under which they arise.

This account of the relation between emotion and language (through action) shares a family resemblance with accounts offered by Ping et al. (2009) and Heberlein and Atkinson (2009), but the account is quite different from the conceptual metaphor account developed by Lakoff and Johnson (1980, 1999) and reviewed by Crawford (2009). On the conceptual metaphor account, putatively abstract emotions are understood by using metaphorical processes to relate emotions to putatively concrete domains such as space. For example, many experiences lead to the development of the conceptual metaphor that "good is up." Then, the emotional state of happiness is understood in terms of this conceptual metaphor and leads to language such as, "I'm feeling up." However, as Crawford notes, given the sensorimotor experiences that accompany (and often define) emotions, it is not clear how emotions are abstract and hence in need of understanding through metaphor. Consequently, we endorse Crawford's proposal that domains such as space are recruited to support reasoning about emotions, rather than as the underlying representation of emotions.

Our results also have implications for the study of emotion. For example, the methodology used in our experiments may be useful for investigating the functions of emotions. If a sentence describes activity consistent with the function of an emotion, that sentence should be read with greater facility when experiencing the emotion than when not. The methodology of gender Experiment 3 might also be expanded to investigate questions related to how one exercises self control by switching from one emotion to another. Additionally, the gender Experiment 3 methodology suggests a behavioral measure of the depth to which an emotion is experienced. Namely, the more deeply an emotion is experienced, the longer it should take to comprehend a sentence describing a situation portraying an incongruent emotional state.

Finally, the results have implications for the investigation of gender differences in cognition and in communication. For example, do these results imply that there is some truth to the stereotype that men and women communicate about emotions differently? Even the subtle effects that we have documented might produce a cascade in real conversations. For example, pauses in conversations are meaningful (Clark, 1996). Thus, if one person takes 50 or 100 ms longer than expected to understand a communication about an emotional situation, that pause might be misinterpreted by a conversational partner. Or, our data might support observations about lack of empathy. When a woman communicates about a sad situation to a man, he may not appreciate the sadness to the same degree as another woman, and we suspect a similar lack of empathy when a man communicates about anger to a woman. It is important to note, however, that although our effects are theoretically and statistically significant, the effect sizes are small to modest. Thus, real-world effects are likely to be subtle and to apply to group averages, and not necessarily all individuals.

## Notes

1 We focus our review on research using linguistic units larger than the word, such as phrases, sentences, and discourse. See Niedenthal (2007) and Vermeulen, Niedenthal, and Luminet (2007) for examples of complementary research with words.

2 We thank Ira Fischler for the sentences that provided a core for the development of our stimuli.

3 We thank Leonard Berkowitz for suggesting this alternative.

4 Practice-induced adaptation can take on several forms. For example, the adaptation can be a type of learning that specializes the action system for a specific response using particular muscles, forces, and trajectories. Such an adaptation would facilitate making that specific response while interfering with making similar, but not identical, responses (e.g., responding with less force). Thus exact predictions are difficult to make. Having seen the data, we know that the practice-induced adaptation interfered with responding. Thus, for ease of exposition, we refer to this as a fatigue effect.

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