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Cosmetic Use of Botulinum Toxin-A Affects Processing of Emotional Language

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Abstract

How does language reliably evoke emotion, as it does when people read a favorite novel or listen to a skilled orator? Recent evidence suggests that comprehension involves a mental simulation of sentence content that calls on the same neural systems used in literal action, perception, and emotion. In this study, we demonstrated that involuntary facial expression plays a causal role in the processing of emotional language. Subcutaneous injections of botulinum toxin-A (BTX) were used to temporarily paralyze the facial muscle used in frowning. We found that BTX selectively slowed the reading of sentences that described situations that normally require the paralyzed muscle for expressing the emotions evoked by the sentences. This finding demonstrates that peripheral feedback plays a role in language processing, supports facial-feedback theories of emotional cognition, and raises questions about the effects of BTX on cognition and emotional reactivity. We account for the role of facial feedback in language processing by considering neurophysiological mechanisms and reinforcement-learning theory.

Keywords

language comprehension, emotion, facial expressions, facial feedback, botulinum toxin, denervation, embodied cognition, emotion simulation

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Is language comprehension the manipulation of abstract symbols by rules of syntax (e.g., as suggested by Chomsky, 1959)? Recent behavioral and neuroscientific evidence suggests that language comprehension involves a mental simulation of sentence content (Barsalou, 1999) that calls on the same neural systems used in literal action, perception, and emotion (Glenberg & Kaschak, 2002; Havas, Glenberg, & Rinck, 2007; Niedenthal, 2007; Pulvermüller, 2005). In this study, we demonstrated that involuntary facial expression plays a causal role in the processing of emotional language.

In a previous study, we (Havas et al., 2007) provided evidence for emotion simulation in language. Participants read and judged the valence of sentences describing pleasant situations (e.g., "You execute the difficult dive flawlessly") and unpleasant situations (e.g., "The police car pulls up behind you, siren blaring") while reading times were measured. Participants were instructed to hold a pen either in their teeth (to produce a smile) or in their lips (to prevent a smile) while reading. This procedure reliably induces emotional states in participants without making them aware that these states have been induced (Strack, Martin, & Stepper, 1988). As predicted, reading times for sentences describing pleasant situations were faster while participants were smiling than while they were prevented from smiling, and the reverse was found for reading times for sentences describing unpleasant situations. These results indicate that facial expressions influence simulation, but processes related to participants' voluntary control of facial posture could also provide a basis for the observed interactions.

Previous work (e.g., Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009) has demonstrated that reading words that describe emotions selectively activates facial muscles: Negative-emotion words activate the corrugator supercilii and positive-emotion words activate the zygomaticus. In addition, in an unreported experiment using the same sentences we used in this study, we verified that sentences describing happy situations (*happy sentences*) caused greater activity in the zygomaticus than did sentences describing sad situations (*sad sentences*) and describing angry situations (*angry sentences*),

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whereas sad and angry sentences caused greater activity in the corrugator supercilii than did happy sentences (see the Supplemental Material available online).

The question we tested in the research reported here is whether this peripheral activation plays a causal role in sentence processing when voluntary muscle control has been eliminated. Specifically, does paralysis of the facial muscle used in expressing negative emotions (corrugator supercilii) selectively hinder processing of sentences describing angry and sad situations, relative to happy situations? We recruited participants who were patients receiving cosmetic treatment of glabellar (frown) lines with subcutaneous injections of botulinum toxin-A (BTX). Participants were first-time BTX patients, receiving injections only in the frown muscle (corrugator supercilii). BTX is a neurotoxin that causes temporary muscular denervation by preventing the release of acetylcholine from presynaptic vesicles at the neuromuscular junction, which in turn decreases extrafusal muscle-fiber activity and muscle strength (Simpson, 1981). Toxicity is associated with a reduction in compound muscle action potential within 48 hr of intramuscular injection, which produces local muscle weakening within 1 to 3 days and peak weakening of compound muscle action potential around Day 21 (Pestronk, Drachman, & Griffin, 1976).

In two sessions (one before BTX treatment and one 2 weeks after BTX treatment), participants read sentences describing angry, happy, and sad situations and pressed a keyboard button when they understood the sentence. The dependent variable was sentence reading time. We made no reference to emotion during the task. By measuring the change in reading times before and after BTX treatment, we tested the prediction that paralysis of the corrugator supercilii selectively hinders processing of angry and sad sentences, relative to happy sentences.

Method

Participants

Forty-one female participants were recruited from among first-time patients receiving injections of BTX in their corrugator supercilii for treatment of glabellar (frown) lines. Patients were informed of the experiment through area cosmetic-surgery clinics, and interested patients were scheduled for treatment during available experiment times. Participants in the study were given a $50 credit toward the cost of their treatment. On arrival at the clinic for the first session, all participants provided written informed consent for the reading experiment. One participant did not receive BTX injections and was excused from the study. The Education and Social and Behavioral Sciences Institutional Review Board at the University of Wisconsin–Madison approved the study protocol, and participants were treated in accordance with the principles expressed in the Declaration of Helsinki.

Stimulus sentences

In the first session, each participant read 20 happy, 20 sad, and 20 angry sentences chosen at random from among 40 sentences of each type (see Table 1). The remaining 60 sentences were used in the second session. We verified the emotionality of the sentences in a prior norming study, and for each sentence, we constructed one yes/no comprehension question for which the correct answer was "yes," and one yes/no comprehension question for which the correct answer was "no" (see the Supplemental Material available online).

Procedure

Sentences were presented on a laptop computer using E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA) in five blocks of 12 sentences each, with consecutive blocks separated by a brief pause for participant questions. Participants were instructed to press "1" on the keyboard number pad with their right index finger when they finished reading a sentence. Reading time, the dependent variable of interest, was recorded for each sentence.

Following a sentence in a random third of the trials in each block, a yes/no comprehension question was presented (after a 1-s delay) to encourage comprehension. Participants answered "yes" by pressing the "x" key with their left index finger, or "no" with the "z" key using their left middle finger. For the remaining trials, the sentence was replaced with a fixation cross for 3 s until the next sentence appeared.

After arriving at the clinic, participants entered a private room and received reading-task instructions. We then administered five practice trials followed by the 60 sentences of the experimental trials. After they completed the first session, participants were scheduled for the second session and were

Table 1. Examples of Sentences Used in the Experiment

Sentence type	Example sentences
Angry	Reeling from the fight with that stubborn bigot, you slam the car door.
	The pushy telemarketer won't let you return to your dinner.
	The workload from your pompous professor is unreasonable.
Happy	The water park is refreshing on the hot summer day.
	Finally, you reach the summit of the tall mountain.
	You spring up the stairs to your lover's apartment.
Sad	You hold back your tears as you enter the funeral home.
	You open your email in-box on your birthday to find no new emails.
	Your closest friend has just been hospitalized for a mental illness.

immediately led to see the physician for the BTX injection (see the Supplemental Material available online). Two weeks later, participants read the 60 remaining sentences in the second session and then saw the physician for a checkup. The last 16 participants completed the 20-item Positive and Negative Affect Schedule (PANAS) self-report measure (Watson & Clark, 1988) immediately after the reading task in each session.

Results

Data were excluded from analysis if the sentence reading times were longer than 20 s. In addition, data for 1 participant with an average sentence reading time greater than 9,000 ms were excluded. The overall accuracy rate for comprehension questions was 89%. Each participant's reading times were subjected to a regression analysis using sentence length as a predictor. Trials with reading times more than 2.5 standard deviations from the mean residual reading time for the respective condition were eliminated (removing 2.6% of trials).

A series of 3 (sentence emotion: angry, sad, happy) × 2 (session: preinjection, postinjection) repeated measures analyses of variance (ANOVAs) was conducted on reading times, residual reading times, and comprehension-accuracy rates. There were no significant effects in comprehension accuracy (all *F*s < 3.1; see the Supplemental Material). In reading times, there was a main effect of sentence emotion: Reading times were longer for angry sentences (M = 4,809 ms, SE = 187) than for sad sentences (M = 4,181 ms, SE = 170) or happy sentences (M = 4,020 ms, SE = 157), $F(2, 74) = 128.798$, $p < .001$, $\eta^2 = .392$. In addition, there was a significant interaction of sentence emotion and session, as depicted in Figure 1, $F(2, 74) = 3.253$, $p = .044$, $\eta^2 = .010$. Reading times were significantly longer in the second session than in the first session for both angry sentences, $t(37) = 2.332$, $p = .025$, $d = 0.22$, and sad sentences, $t(37) = 2.348$, $p = .024$, $d = 0.23$. Reading times for happy sentences did not differ between the first session and the second session, $t(37) = 0.223$, $p = .825$. No other effects were significant. Exactly the same pattern of significant effects was found in analyses of residual reading times, as depicted in Figure 2 (see the Supplemental Material). Analysis of mood measures during both sessions ruled out an explanation of the results based on mood congruency (e.g., greater anxiety in the first session might facilitate processing of negative sentences; see the Supplemental Material).

Discussion

The results demonstrate that blocking facial expression by peripheral denervation of facial musculature selectively hinders emotional-language processing. This finding is consistent with embodied-simulation accounts of cognition (Gallese, 2003, 2008; Havas et al., 2007), according to which neural systems used in experiencing emotions are also used to understand emotions in language. The finding also offers evidence of a functional role for peripheral activation in processing emotional language, and it suggests a bidirectional link between emotion and language that is mediated in part by moving the face. Finally, the finding provides novel evidence supporting facial-feedback theories of emotion-related processing (Darwin, 1872/1998; Oberman, Winkielman, & Ramachandran, 2007; Soussignan, 2002).

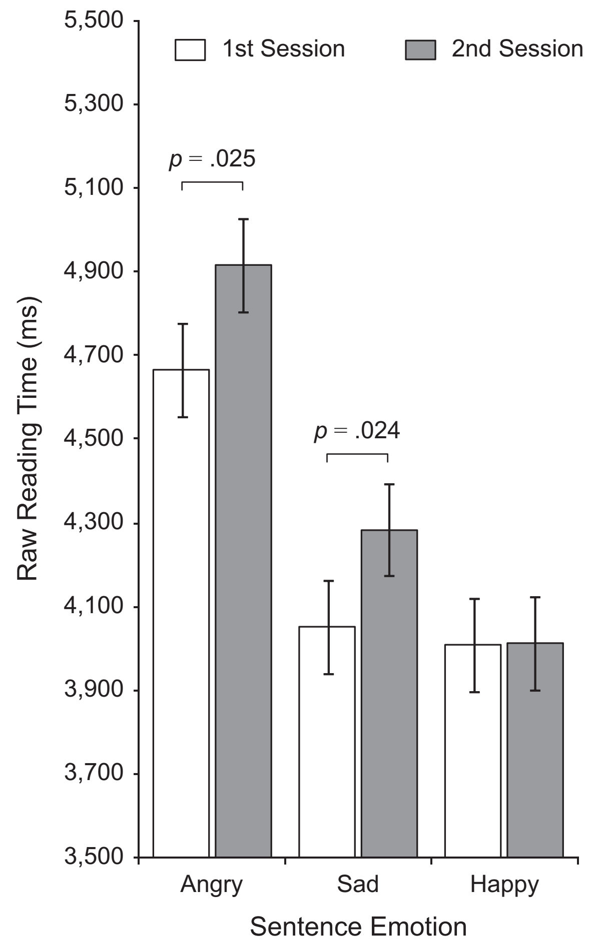

Fig. 1. Mean reading times for sentences describing angry, sad, and happy situations before (first session) and after (second session) botulinum toxin-A injection in the corrugator supercilii. Error bars indicate ±1 *SEM*. Brackets indicate significant differences between sessions.

Although temporal-order effects are a possibility in this study, a general-order effect is unlikely given the selectivity of the slowdown in reading times: The effect occurred only for angry and sad sentences, but not for happy sentences. Also, the observed pattern is inconsistent with a regression to the mean, in which angry and sad sentence reading times should be less extreme in the second session than in the first session. Next, we consider neurophysiological-level accounts of our data and then psychological-level accounts.

Given its known neurophysiological mechanisms of action, BTX may induce paralysis of facial muscles in two principal

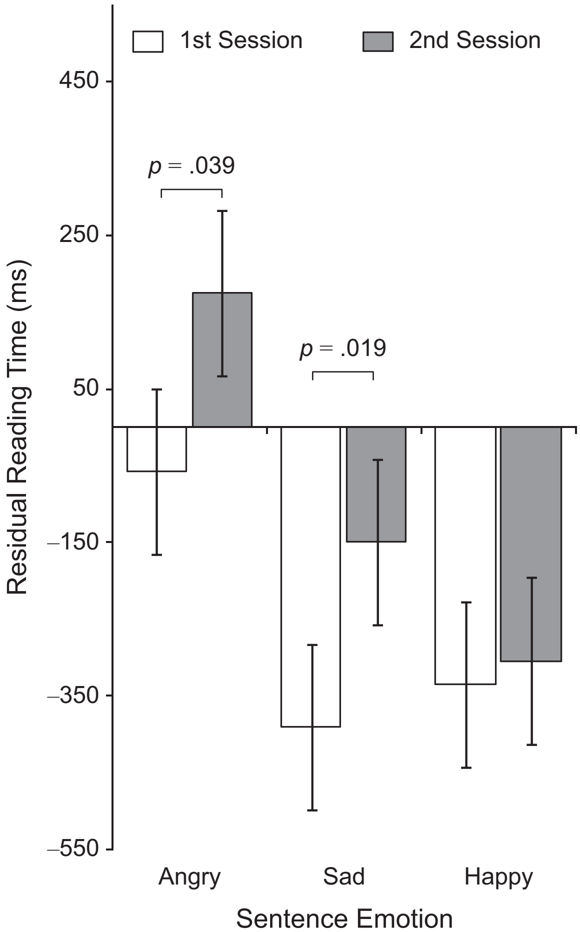

Fig. 2. Mean residual reading times (controlling for sentence length) for sentences describing angry, sad, and happy situations before (first session) and after (second session) botulinum toxin-A injection in the corrugator supercilii. Error bars indicate ±1 *SEM*. Brackets indicate significant differences between sessions.

ways that might affect processing of emotional language. We assume that the affected neural systems in both cases are recruited during a simulation of language content. First, BTX may impair language processing through its peripheral muscle-relaxant effects. By blocking cholinergic exocytosis at extrafusal neuromuscular junctions, BTX attenuates postsynaptic responses to voluntary and spontaneous efferent motor processes (Simpson, 1981). Neuromuscular blockade is established within 3 to 6 hr of treatment in rats (Pestronk et al., 1976), although in humans, local muscle weakness is not observed until more than 24 hr after injection for cosmetic treatment (Hamjian & Walker, 1994).

Given its initial peripheral effects, BTX could disrupt emotional processes that depend on stereotyped patterns of facial feedback (Soussignan, 2002). Alternatively, motor executive systems for controlling the affected muscles might respond to peripheral blockade with increased output but a loss of specificity, as is seen in the cortical response to muscle fatigue (Gandevia, 2001). In either case, a loss of specificity in the mechanism for simulating angry and sad emotions, but not happy emotions, would impair meaning resolution in processing of angry and sad sentences, but not happy sentences. A rapid mechanism is consistent with observations of immediate effects of facial-posture manipulation (Havas et al., 2007; Oberman et al., 2007; Strack et al., 1988).

A related consideration is that BTX may have direct effects on the central nervous system via retrograde transport in afferent motoneurons. Evidence for such effects is weak, but a recent finding showed that active BTX can be transported across afferent synapses in rats and can cause neurological changes remote from the injection site (Antonucci, Rossi, Gianfranceschi, Rossetto, & Caleo, 2008). Here again, if successful execution of an efferent motor pattern (frowning) is necessary for simulation of angry and sad content, but not happy content, then retrograde denervation could conceivably interfere with processing angry and sad language, but not happy language.

The second way that BTX injections may affect language processing is through central changes secondary to peripheral effects (Abbruzzese & Berardelli, 2006). Studies using rats suggest that BTX affects cholinergic processing at intrafusal junctions, blocking gamma motor nerve endings and reducing tonic afferent discharge of muscle spindles (Rosales, Arimura, Takenaga, & Osame, 1996). In motor control, tonic afferent feedback is thought to contribute to the formation of internal models of the state of the body; such models are useful for specifying motor commands before a movement has begun. Patients with severe sensory neuropathy (a loss of afferent feedback) show systematic movement errors consistent with an inaccurate internal model of the state of the body (Ghez, Gordon, Gilardi, Christakos, & Cooper, 1995).

Facial feedback may be a context-sensitive source of information for maintaining an internal model of the emotional state of the body, and it may be important for specifying adaptive actions through its influence on central networks. Paralysis of the corrugator supercilii over a period of weeks might gradually induce plastic changes in neural circuitry underlying the representation of negative emotional states, and these changes could lead to disrupted processing of angry and sad language, but not happy language. Consistent with this possibility is the finding that paralysis of the corrugator supercilii 2 weeks prior to an imitation task involving emotion expression reduced activation in neural centers involved in emotion processing (namely, amygdala, orbitofrontal cortex, and brainstem centers involved in autonomic regulation), relative to activation in the same subjects before injection (Hennenlotter et al., 2009).[1] Whether these changes are due to early peripheral effects or secondary central changes from BTX injection should be tested. In addition, our results suggest the need for further research on cognitive and emotional effects of cosmetic BTX injection.

At the psychological level, our account of how feedback from emotional states guides simulation in language was suggested by a recent theory of reinforcement learning (Doya, 2007, 2008). Because the most rewarding action in a situation depends on both the current state of the body and the current state of the environment, choosing the most effective action in a situation is difficult. However, predicting the optimal action is possible if an agent can simulate the reward of a potential action given the current context. In reinforcement learning, the action-value function is initially learned through feedback from the emotional state produced by a given action. Once this function has been learned, simulation of future actions will produce emotional-state feedback useful for guiding subsequent action (Doya, 2008).

Consider the following sentence: "Reeling from the fight with that stubborn bigot, you slam the car door." Comprehending words or phrases describing actions early in the sentence generates activity in the neural systems and periphery, including facial muscles, used in real actions or experiences (e.g., a fight with a stubborn person). Facial feedback would then contribute to autonomic and central changes (e.g., arousal) for preparing subsequent actions (e.g., slamming a car door). Because it is easier to simulate slamming a car door while the body is in an aroused state (Glenberg, Webster, Mouilso, Havas, & Lindeman, 2009), the sentence is readily understood. Thus, to borrow the words of Darwin (1872/1998), "the free expression by outward signs of an emotion intensifies" the processing of emotional language, whereas "the repression . . . of all outward signs softens" such processing (p. 366).

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Note

1. To the extent that these networks are involved in emotional experience, this mechanism might also play a role in the link between facial feedback and mood (Adelman & Zajonc, 1989).

Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

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