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Socially induced motor plasticity affects language comprehension

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Socially Induced Motor Plasticity Affects Language Comprehension

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Abstract

Language understanding is a socially coordinated activity, but the mechanisms of social coordination in language are poorly understood. Evidence from embodied cognition has shown that movement-induced fatigue of actions slows comprehension of language that refers to those actions. Research on the mirror neuron system suggests that action systems of the brain are also involved in social understanding of actions performed by another, empathy, and possibly language. Here, we show that simultaneous performance and observation of kinematically similar actions produced a fatigue-like effect in sentence judgment times relative to dissimilar control actions. The results suggest that the same action systems used in language processing are influenced by social actions.

Keywords: language comprehension, embodied cognition, social cognition, joint action, motor plasticity, mirror neuron system.

Introduction

Language is fundamentally a social activity in which individuals coordinate their actions (Clark, 1996; Grice, 1975). Conversation involves intricately timed verbal and non-verbal signals for clarifying, initiating, guiding, and ending dialog (Clark, & Wilkes-Gibbs, 1986; Garrod & Anderson, 1987). The mechanisms of language coordination are of current interest.

According to theories of dialog, conversation is successful to the extent that there is similarity of mental states between participants (Garrod & Anderson, 1987). For example, dialog requires that participants share a common ground, or similarity in mental states about referents (Clark, 1996; Clark & Wilkes-Gibbs, 1986). Interlocutors tend to show similarity across linguistic and non-linguistic levels, including word use (Garrod & Anderson, 1987), syntax (Branigan et al., 2000), semantics (Clark, & Wilkes-Gibbs, 1986) and movements (Chartrand & Bargh, 1999). It has been proposed that the same neural systems used for action imitation are also used in dialog (Garrod & Pickering, 2004; Pickering & Garrod, 2006b).

Recent evidence from embodied cognition has shown a close link between action and language. Glenberg and Kaschak (2002), for example, implicated the action system's influence on language comprehension. Participants in this study responded to a series of sentences depicting transfer, either away from (" Close the drawer") or toward the body (" Open the drawer"). After reading each sentence, participants deemed it sensible or nonsense by pushing "yes" or "no" buttons and in so doing, were required to move their hands either toward their bodies or away. The results demonstrated an action-sentence compatibility effect (ACE). Sentence judgment times were shorter when the sentence depicted movement compatible with the movement required to make a sensible response. The ACE effect has been demonstrated for sentences describing both concrete and abstract (or metaphorical) transfer (Glenberg, Sato, Cattaneo, Riggio, Palumbo, & Buccino, 2008).

More recent evidence has shown that language comprehension is influenced by prior fatugue of the motor system. Glenberg, Sato, & Cattaneo (2008) demonstrated that fatigue of specific actions influences comprehension of written language depicting those actions. To fatigue the neural motor systems involved in toward and away movement, participants were asked to engage in a repetitive action in a toward or away direction. Participants moved 600 beans individually from a container to a target. They were then asked to read a series of sentences describing transfer either toward ("Mark deals you the cards") or away from the body ("You deal Mark the cards"), and judge them as sensible or nonsense by pressing a button. Response times (the time to read the sentence and push the button) were longer when the sentence depicted motion congruous to the movement the participant had previously fatigued. When the sentence depicted an incongruous movement, response times were shorter. This finding was taken as evidence that repeated movement induced plasticity in motor areas recruited in language processing. In particular, the repetition of movement induced muscular fatigue, forcing action-controlling neurons in Broca's region to increase their output, but no longer target the specific action (Glenberg et al., 2008). Thus, participants' comprehension of written depictions of the compatible action (toward or away) was slowed, compromised by shared involvement in both action and language in Broca's region (Gallese, 2008).

Although these studies demonstrate a close link between action and language, they do not address language as a joint action. Research on the mirror neuron hypothesis (Rizzolatti, Craighero, & Fadiga, 2002) suggests that action systems of the brain, including Broca's region, are involved in social understanding of actions, emotions, and possibly language (Rizzolatti & Arbib, 1998).

Mirror neurons, first discovered in the premotor cortex of the macaque monkey, fire both during execution and observation of the same action (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). A comparable mirror neuron system (MNS) in humans may contribute to a wide range of behaviors, including action understanding (Iacoboni, 2005; Rizzolatti, Fogassi, & Gallese, 2001), empathy (Blakemore & Decety, 2001; Carr et al, 2003; Gallese, 2003; Gallese, Keysers, & Rizzolatti, 2004), and language understanding (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Rizzolatti & Arbib, 1998).

Evidence supports the existence of a mirror-neuron-like mechanism in humans in which the observed actions of another are processed using the motor system of the observer. In one study, Fadiga, Fogassi, Pavesi, & Rizzolatti, (1995) used transcranial magnetic stimulation (TMS) to increase activation of the motor cortex responsible for grasping an object, while participants observed the same action, or just the object. The dependent variable was the motor evoked potentials (MEPs) in the muscle affected by the stimulated motor cortex. Muscle activation increased during action observation relative to the control conditions, showing that observed actions potentiate the execution of similar actions in the observer.

Other evidence shows that this mirror-like mechanism is specific to kinematically similar actions. Using fMRI, Calvo-Merino, Glaser, Grezes, Passingham, & Haggard (2005) showed that action observation produces the greatest increase in premotor and other cortical area activation for actions that the observers had been trained to perform themselves. And Stefan et al. (2005) used TMS to demonstrate the formation of a kinematically specific motor memory through action observations.

The role of the putative MNS in language has begun to be examined. Using fMRI, Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni (2006) asked participants to read sentences and observe actions involving either the foot, hand or mouth. They first located brain regions in each subject that were most active during observation of foot, hand, and mouth actions. Next, they compared activations in each region during the reading of sentences involving foot, hand, and mouth actions. They found congruence between areas active during observed actions and the activation levels during reading of sentences describing those actions. Brain regions responded most to sentences that involved the body part for which it was most active during action observation.

If the putative MNS in humans shares neural mechanisms with the action-based language system, then observing another agent repeatedly performing an action should elicit a generalizing response from action controllers similar to that observed by Glenberg, Sato, and Cattaneo (2008).

To test the influence of social actions in language comprehension, the present study adds to the beans task of Glenberg et al. (2008) and manipulates activation of action controllers through two kinds of simultaneous observed movements. In the Mirrored condition, the movement of both participants is kinematically identical; that is, both participants move beans in the same direction relative to their own bodies. In the Control condition, particpants' movements differ in the direction of movement; one participant moves the beans away from their body, while the other participant moves beans toward their body.

By definition of the MNS, both observation and execution of an action activate the same neural systems, and therefore simultaneous observation and execution of action in the Mirrored condition should elicit greater net activation of action controllers than in the Control condition. Based on the results of the Glenberg, Sato, & Cattaneo (2008) study, it is expected that greater activation of action controllers in the Mirrored condition will enhance the fatigue effect in sentence comprehension, relative to the control condition. That is, fatiguing movements toward or away from the body will slow the comprehension of sentences describing transfer toward or away from the body (respectively), and this effect will be enhanced in the Mirrored condition.

Participants

Participants were 80 Introductory Psychology undergraduate students at the University of Wisconsin—Madison (53 females, 27 males). Participants were native English speakers recruited using the UW psychology department's appointment scheduler and were offered course credit for their participation. They were paired randomly, irrespective of gender or handedness. All participants were treated in a manner consistent with the APA's "Ethical Principles of Psychologists and Code of Conduct" (American Psychological Association, 2002).

Design

The experiment consisted of a 2 (practice movement Mirrored or Control) x 2 (practice movement toward or away) x 2 (sentence movement toward or away) mixed design with repeated measures on the third independent variable. The first independent variable consisted of two levels—Mirrored or Control movement. In the Mirrored condition, both participants in a pair transferred beans from one container to another in the same direction, either toward or away from their bodies, while seated across from one another at a small table. In the Control condition, participants transferred the beans in opposite directions (see Figure 1 for a schematic illustration of these conditions). The second independent variable consisted of two levels - practice movement toward or away from the body. The third independent variable consisted of sentences describing transfer either toward the body ("Tony gives you the cup"), or away from the body ("Sarah passes the tray to you").

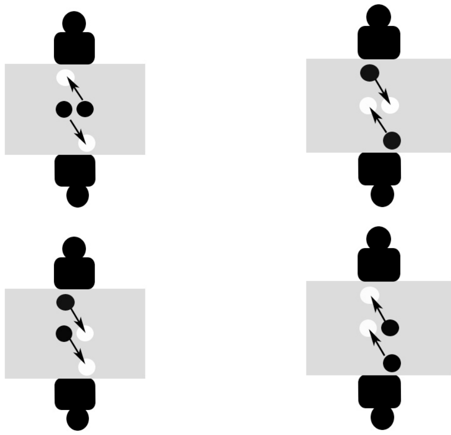

Figure 1: Schematic diagram of the Mirrored toward and away conditions (top row) and Control toward and away condition (bottom row).

In the reading task, the dependent variable was sentence judgment time; that is, the time between a sentence appearing on the screen and the participant pressing the "yes" button or "no" button to evaluate the sentence as nonsensical or sensible.

Materials

Experimenters used a protocol to guide the setup of materials, to assign participants to a condition, and to instruct participants in each phase of the experiment. For the first phase, the setup included four tupperware bowls on a card table, two for each participant. For each participant, one bowl contained three hundred beans, and the other bowl was empty but lidded with a hole in the top to serve as a target. All four containers were attached to the table by Velcro tabs.

For the second, reading comprehension phase of the experiment, short sentences were displayed one at a time on a computer monitor. Participants indicated that the sentence made sense or did not make sense using "yes" or "no" buttons located on the "3" and "8" keys on a keyboard.

For each participant, 280 sentences were shown in total. Half (140) of all sentences were sensible and half were nonsense ("You iron Linda the theory"). Of the 140 sensible sentences, 100 described transfer ("You give Angela a photo"), and the remaining 40 filler sentences did not ("Angela and you discuss the photo"). Following Glenberg, et al. (2008), half (50) the sensible sentences described transfer of a concrete object (" Tony gives you the cup"), and half described abstract transfer ("Liz tells you a story"). Also, half (50) the sensible sentences described transfer toward the body ("Meg hands you a paper" or "Liz tells you a story"), and half described transfer away from the body ("You hand Meg a paper" or "You give Chris advice"). Sentences were divided equally into two experiment halves. Example stimuli are provided in Table 1.

Table 1: Sample stimuli.

Sentence type	Example
Concrete transfer towards the body	Paul throws you the ball. Meg hands you a paper. Tony gives you a cup.
Abstract transfer towards the body	Chris gives you advice. Eric tells you a fact. Liz tells you a story.
Concrete transfer away from the body	You give Tony the cup. You throw Paul the ball. You hand Meg a paper.
Abstract transfer away from the body	You tell Liz a story. You give Chris advice. You tell Eric a fact.

Procedure

Participants were run in pairs. After participants signed consent forms, the experimenter read from a script, giving an overview of the experiment. First, the experimenter instructed each participant to go to one of two computer booths for practice in the language comprehension task. Practice consisted of instruction in the reading task, and six test trials. After finishing with practice, participants came out of the computer booths and were instructed to move 300 beans one at a time from the full container to the empty one using their right hands. Participants began the beans task at the same time. After both participants finished the bean transfer task, they returned to the reading booths to complete the first half of the sentence comprehension task. Participants typically finished the beans task within 1 minute of each other.

The experimenter then reversed the direction of movement for each participant by reversing the positions of the two containers. After both participants finished the first half of the reading task, they were instructed to return to the table and transfer the beans again, still using the right hand, to the empty container. When finished, the participants returned to the computer booths for the second half of the language task. When finished, participants were debriefed, thanked, and given course credit.

Results

Due to computer difficulties, experimenter error, or participant error, 7 participants were excluded from the analysis. We analyzed the data of the remaining 73 participants (48 females, 25 males; 70 right handed, 3 left handed). Because participants' accuracy in responding "yes" or "no" to the sensibility of each sentence reflects their reading comprehension, two participants with error rates higher than 10% were excluded from the analysis. Also excluded were trials containing erroneous responses or filler sentences. Only trials with raw sentence judgment times within two standard deviations of each participant's mean judgment time were used in the analysis.

We decided that the within subjects measure, away and toward movement, could produce carryover effects in the second half of the experiment. The analysis therefore includes only the first half of the experiment. A regression analysis adjusted judgment times to control for sentence length; these residual judgment times provide clearer data and the focus of our interpretation, but both raw and residual data were analyzed.

We predicted that participants in the congruent-toward practice direction condition would have higher (slower) judgment times on toward sentences than away and participants in the congruent-away practice direction condition would have higher judgment times on away sentences than toward sentences. Although we did not have specific predictions for participants in the incongruent condition, it was expected that less MNS stimulation and, by extension, less fatigue, would occur than in the congruent condition.

A three-way ANOVA was conducted separately for raw and residual judgment times. In the raw judgment times, there was a main effect of sentence direction on judgment times, $F\ (1, 69) = 10.33$, $p = .002$, showing longer judgment times for toward sentence (M=1718, SD=336) than for away sentences (M=1669, SD=305).

Contrary to the hypothesis, the difference between the Mirrored and Control conditions in raw judgment times only approached significance, $F\ (1,\ 69) = 3.48$, $p= .066$. An interaction between movement condition (Mirrored vs. Control) and practice direction (toward vs. away) also approached significance, $F\ (1, 69) = 3.89$, $p = .053$. None of these interactions were significant in residual judgment times.

Critically, the expected three-way interaction of sentence direction, practice direction, and movement condition was found in both raw [$F\ (1, 69) = 4.60$, $p = .035$] and residual judgment times [$F\ (1,69) = 6.01$, $p = .017$]. That is, the interaction of action and language depended on the movement condition. Mean residual judgment times for the three-way ANOVA are listed in Table 2.

Table 2: Mean residual judgment times.

	Practice toward	Practice away
Mirrored condition		
Toward sentences	41.0	10.3
Away sentences	-43.5	-8.0
Control condition		
Toward sentences	-19.8	31.6
Away sentences	18.7	-24.9

To decompose the three-way interaction, we ran a 2-way ANOVA for Mirrored and Control conditions separately. The 2-way interaction was not significant for the Mirrored condition in either raw or residual judgment times, but it was significant for the Control condition in both raw [F(1, 36)=7.86, p=.008] and residual judgment times [F(1,36)=6.88, p=.013].

To identify the source of the 2-way interaction in the Control condition, we conducted dependent-samples t-tests. There was a significant difference between raw judgment times for toward and away sentences after away practice [t(18)=3.420, p=.003], but not after toward practice [t(18)=.654, p=.522]. Similarly in residual judgment times, there was a significant difference between toward and away sentences after away practice [t(18)=2.575, p=.019], but not after toward practice [t(18)=1.235, p=.233].

We are aware that there are other ways to analyze the data that can take the nested design into consideration, and these alternatives are currently being explored.

Discussion

The aim of this study was to test one potential mechanism of social language coordination. Our results indicate an interaction between socially observed actions and language processing and support the hypothesis of Glenberg, Sato, and Cattaneo (2008) that action controllers in Broca's region are involved in comprehension of language describing concrete or abstract transfer. This study also adds to this hypothesis, suggesting that action controller output may increase during observation of others' similar actions. This finding implicates a mirror-neuron-like mechanism in mediating language comprehension and conversation.

As predicted, the pattern of results in the Mirrored condition indicates the fatigue of action controllers through simultaneous self-produced action and observation of action in the MNS. Participants in the Mirrored-toward practice direction, as expected, read toward sentences more slowly than away sentences. Participants in the Mirrored-away practice condition similarly demonstrated the expected pattern, judging away sentences more slowly than toward sentences.

In contrast, participants' judgment times in the control condition seem to reflect the opposite, or a facilitation effect. Participants in the Control-toward condition read toward sentences faster than away sentences and participants in the Control-away condition read away sentences faster than toward sentences. This finding is somewhat consistent with our prediction of a reduced fatigue effect in the control condition. We may attribute the discrepancy to an adjustment in procedure. Whereas participants in the Glenberg, et al. (2008) study transferred 600 beans in each condition, those in our study transferred only 300. Thus, the Control condition activates action controllers, although not to the point of fatigue. In this case, we would expect a pattern similar to an action-sentence compatibility effect (ACE) in which reading times are shorter when there is a match between the direction of motor response and the direction implied by the sentence. The fatigue effect found in the Mirrored condition would have resulted from the dual action and observation of movement, more closely approximating the experience of moving twice as many, or 600, beans.

The findings are generally consistent with several areas of research. The results support embodied theories of language comprehension in which action systems of the brain play a role in processing of language about actions (Glenberg & Kaschak, 2002). In particular, we replicate the findings of Glenberg et al. (2008) in which action induced motor plasticity affected language processing. Here however, we extend the source of neural plasticity from action-induced fatigue of action controllers to socially induced fatigue of action controllers, in which the MNS is the hypothesized mechanism.

Our findings differ from those of Glenberg et al. (2008) by revealing a U-shaped effect of motor practice on the output of action controllers, with smaller amounts of practice leading to facilitation, and larger amounts of practice leading to fatigue.

Second, the findings support the existence of a MNS in humans in which the observed actions of another are processed using the motor system of the observer (Rizzolatti, & Craighero, 2004). Studies of the human MNS have shown that action observation potentiates the execution of kinematically similar actions in an observer (Calvo et al., 2005; Stefan et al., 2005). Similarly, it was recently found that concurrent observation of a similar action not only produces a kinematically specific motor memory in the observer, but also enhances the effect of training, relative to physical training alone (Stefan, Classen, Celnik, & Cohen, 2008). We found that observation of a kinematically similar action contributes to a fatigue-like effect associated with neural plasticity. To our knowledge, this is the first demonstration that action observation elicits practice-like effects in language comprehension.

Third, the results are consistent with the view of language as fundamentally a joint action (Clark, 1996) in which successful communication of meaning is achieved through alignment of mental states (Garrod & Pickering, 2004; Pickering & Garrod, 2006).

The results can also be compared with the literature on S-R compatility (e.g., the "Simon Effect"). Whereas that literature has shown that motor responses can reflect the "fatigue" of a spatial features of an irrelevant stimulus (e.g. Proctor & Lu, 1999), we show that such a fatigue effect can be modified by observation of another person doing a related movement.

This study suggests a mechanism by which alignment takes place, namely by the matching of motor states via the mirror neuron system. Interlocutors converge in terms of linguistic features, including grammatical structure (Bock; Branigan, 2000), word use, sematics (Clark & Wilkes-Gibbs, 1986), speech characteristics (Giles, H., Coupland, N., & Coupland, J., 1992), and phonetics (Pardo, J. S., 2006). But motor behavior also converges in social interaction (Chartrand & Bargh, 1999), particularly when there is a desire to create rapport (Lakin & Chartrand, 2003). Our results may shed light on the recent finding that physiological concordance correlates with client-therapist bond (Marci, Ham, Moran, & Orr, 2007). An interesting question is whether dyads in our study would report a greater sense of rapport in the Mirrored versus Control condition.

Recent theory suggests that the function of the MNS is for interpersonal coordination, rather than imitation of actions (Newman-Norlund, van Schie, van Zuijlen, & Bekkering, 2007), although the evidence for this view is equivocal (Kokal, Gazzola, & Keysers, 2009). Because our movement conditions differed only in terms of the similarity of movement rather than the coordination required by the task, our results support the view that the MNS is involved in imitation.

Nevertheless, understanding how the MNS interacts with brain mechanisms for interpersonal motor coordination is likely to shed light on how conversational alignment supports joint actions in communication.

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References

Aziz-Zadeh, L., Wilson, S., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing actions. *Current Biology, 16*, 1818-1823.

Blakemore, S. J., & Decety, J. (2001). From the perception of action to the understanding of intention. *Nature Reviews Neuroscience, 2*, 561-567.

Branigan, H. P., Pickering, M. J., & Cleland, A. A. (2000). Syntactic co-ordination in dialogue. *Cognition, 75*, B13-25.

Calvo-Merino, B. Glaser, D. E., Grezes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: an fMRI study with expert dancers. *Cerebral Cortex, 15*, 1243-1249.

Carr, L., Iacoboni, M., Dubeau, M.-C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: A relay from neural systems for imitation to limbic areas. *Proceedings of the National Academy of Sciences, 100*, 5497-5502.

Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception-behavior link and social interaction. *Journal of Personality and Social Psychology, 76*, 893-910.

Clark, H. H. (1996). *Using Language*. Cambridge University Press.

Clark, H. H., & Wilkes-Gibbs, D. (1986). Referring as a collaborative process. *Cognition, 22*, 1-39.

Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: a neurophysiological study. *Experimental Brain Research, 91*, 176-180.

Fadiga L., Fogassi L., Pavesi G., & Rizzolatti G. (1995). Motor facilitation during action observation: a magnetic stimulation study. *Journal of Neurophysiology, 73*, 2608-2611.

Garrod, S., & Anderson, A. (1987). Saying what you mean in dialogue: A study in conceptual and semantic co-ordination. *Cognition, 27*, 181-218.

Garrod, S., & Pickering, M. J. (2004). Why is conversation so easy? *Trends in Cognitive Sciences, 8*, 8-11.

Gallese, V. (2003). The roots of empathy: The shared manifold hypothesis and the neural basis of intersubjectivity. *Psychopathology, 36*, 171-180.

Gallese, V. (2008). Mirror neurons and the social nature of language: The neural exploitation hypothesis. *Social Neuroscience, 3*, 317-333.

Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences, 8*, 396-403.

Giles, H., Coupland, N., Coupland, J. (1992). Accommodation theory: communication, context and consequences. In *Contexts of Accommodation* (Giles, H. et al., eds.), Cambridge University Press.

Glenberg, A., & Kaschak, M. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9*, 558-565.

Glenberg, A., Sato, M., Cattaneo, L. (2008). Use-induced motor plasticity affects the processing of abstract and concrete language. *Current Biology, 18,* R1-R2.

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*, 905-919.

Grice, H. P. (1975). Logic and conversation. In P. Cole and J. L. Morgan (Eds.), *Syntax and semantics, Vol. 3: Speech acts*. New York: Seminar Press.

Iacoboni, M. (2005). *Understanding Others: Imitation, language, and empathy. Perspectives on imitation: From neuroscience to social science: Vol. 1: Mechanisms of imitation and imitation in animals*. Cambridge, MA US: MIT Press.

Kokal, I., Gazzola, V., & Keysers, C. (2009). Acting together in and beyond the mirror neuron system. *NeuroImage, 47*, 2046-2056.

Lakin, J. L., & Chartrand, T. L. (2003). Using non-conscious behavioral mimicry to create affiliation and rapport. *Psychological Science, 14*, 334-339.

Marci, C., Ham, J., Moran, E., & Orr, S. (2007). Physiologic Correlates of Perceived Therapist Empathy and Social-Emotional Process During Psychotherapy. Journal of Nervous and Mental Disease, 195, 103-111.

Newman-Norlund, R. D., van Schie, H. T., van Zuijlen, A. M., & Bekkering, H. (2007). The mirror neuron system is more active during complementary compared with imitative action. *Nature Neuroscience, 10*, 817-818.

Pardo, J. S. (2006). On phonetic convergence during conversational interaction. Journal of the Acoustical Society of America, 119, 2382-2393.

Pickering, M. J., & Garrod, S. (2006). Alignment as the basis for successful communication. *Research on Language and Computation, 4*, 203-228.

Proctor, R. W., & Lu, C. H. (1999). Processing irrelevant location information: Practice and transfer effects in choice-reaction tasks. *Memory & Cognition, 27*, 63-77.

Rizzolatti, G., & Arbib, M. (1998). Language within our grasp. *Trends in Neurosciences, 21*, 188-194.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27*, 169-192.

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience, 2,* 661-670.

Stefan, K., Cohen, L. G., Duque, J. Mazzocchio, R., Celnik, P. Sawaki, L., Ungerleider, L., & Classen, J. (2005). Formation of a motor memory by action observation. *The Journal of Neuroscience, 25*, 9339-9346.

Stefan, K., Classen, J. Celnik, P., & Cohen, L. G. (2008). Concurrent action observation modulates practice-induced motor memory formation. *European Journal of Neuroscience, 27*, 730-738.