The Cross-Domain Priming of Language and Motor Rate

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ABSTRACT Previous research has indicated that the language domain is involved in domain-general processing of temporal information. The current research investigates a connection between the motor and language domains in temporal processing. Participants were primed with a specific rate (fast/slow) in the tactile domain only, or the tactile and motor domains, and were asked to produce speech; rate of speech was recorded and measured. It was expected that participants would adjust their speech rate to match the rate of the prime. A significant interaction of Gender and Rate was found, such that females were influenced by the rate of the prime in the expected direction (e.g., fast prime led to faster speech), while males were influenced by the motor prime in the opposite direction (e.g., fast prime led to slower speech). Previous research has found gender differences in the human mirror system. This may account for the gender differences in the current study, such that females may have been more likely to synchronize with the rate of prime, therefore rendering the expected effect on speech rate. These results may have implications on social and linguistic research on gender differences in communication, and the future directions of cross-domain processing.

Introduction

The modularization of language in the brain has been a topic of debate in the scientific community. This theory purports that brain areas that process language operate separately and independently from other domains. Fodor (1985) argues that the brain is modularized, and that each module is essentially an "encapsulated computation system" responsible only for its designated area of processing (p. 518). He likens these modules to a specialized computer system that performs a specific set of actions and has no access to information outside of its own module's database. According to this theory, language mechanisms in the brain belong to a module and cannot communicate with other domains. Some researchers continue to support the idea of a modularized system in the brain, particularly concerning the language domain (Grodzinsky, 1999). However, a substantial amount of empirical evidence has been found which contradicts Fodor's theory of modularization. For example, behavioral evidence of common temporal processing between the language and visual domains, as well as between the language and musical domains, indicates shared processing mechanisms (Hupp & Jungers, 2013; Jungers, Hupp, & Dickerson, 2015). Common temporal processing refers to the idea that two domains may share mechanisms in the brain that allow for sharing of timing processes. In addition, brain imaging studies have contributed to the understanding of a motor-language connection (Van Dam, Rueschemeyer, & Bekkering, 2010); however, there is not yet behavioral evidence of a common motor and language temporal processor.

The current research contributes behavioral evidence of a shared temporal processing mechanism between the language and motor domains. The findings in the current study expand upon existing research contradicting the theory of modularization of language. Research in this area is necessary to understand how temporal information is processed in and across domains. It is thought that a cross-domain processing mechanism is responsible for similarities in temporal processing across domains; the current research focuses on rate transfer from the tactile/motor domains to the language domain to investigate this hypothesis.

Background

Language Domain

Previous researchers have suggested shared temporal processers within and across a variety of domains. For example, perception of language rate subsequently affects the production rate of language. Jungers and Hupp (2009) examined this language rate persistence in adults. Participants viewed an image and heard a description of that image spoken in a fast or slow rate, repeated the sentence, and then they created their own picture description of another image. Participants who were primed with faster speech produced faster picture descriptions than those primed with slower speech. This experiment was repeated with preschool children resulting in the same patterns: faster primes led to faster sentence production (Hupp & Jungers, 2009). This pattern continues when adult participants hear, but do not repeat priming sentences, then produce picture de-

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scriptions (Jungers & Hupp, 2009). The rate of language perception affected the rate of language production. This research contributes to the understanding of rate persistence and the possibility of within-domain temporal processing mechanisms from perception to production of language.

Motor Domain

There is also evidence of a similar temporal processing mechanism within the motor domain. Capelli, Deborne, and Israël (2007) had participants complete a timing task, asking participants to press a button once per second by their own estimation. Participants did this blindfolded and wore headphones emitting white noise to block out any external stimuli. Participants were seated in a robotic chair, and completed this task during two phases: no motion and self-motion (rotating the chair). It was found that participants pressed the button more slowly while decelerating in their rotations and pressed the button more quickly while accelerating in their rotations. This indicates a within-domain motor temporal mechanism, as the rate of one motor action affected the rate of another motor action.

The Language and Motor Domains

Research has connected processing in the motor and language domains in many ways. Glenberg and Kaschak (2002) studied the action-sentence compatibility effect (ACE), which involves a sentence task with a motor response. Participants were presented with sentences that were either nonsense sentences (e.g., boil the air) or were sensible sentences that involved an action that is performed toward the body (e.g., scratch your head) or away from the body (e.g., scratch your cat). Participants were asked whether or not the sentence was sensible. Participants responded using a box held in their lap that had three buttons arranged to be closer, in the middle, and farther away. There were two conditions of this study. In the yes-is-far condition, if the sentence was sensible, the participants were instructed to press the button farthest from them, and to press the button closest to them if the sentence was not sensible. In the yes-is-near condition, the button assignment was reversed. Researchers expected that the understanding of the sentences would interact with their responses in this task. For example, a sentence indicating a motion toward the body (e.g., scratch your head) paired with an action away from the body (e.g., yes-is-far condition), would result in longer response times because the understanding of the sentence contradicted the action they must perform.

Response time significantly differed according to when the response required (yes-is-near or yes-is-far) was congruent with the direction of the action in the sentence (toward the body – near, or away from the body – far). For example, response times were faster if the participant was in the yes-is-near condition and is presented with "scratch your head" versus the away verb sentence "scratch your cat". When the required action and the presented sentence were consistent with one another, response time was reduced. Glenberg and Kaschak (2005) attribute this to the idea that "the understanding of sentences is grounded in the actions which underlie them" (p. 24). This explains why it takes more time to react when the required action and the sentence do not align: a contradiction would require something of a cognitive override to occur. Their research suggests that language and action have a high level connection, and takes effort to disentangle, as the ACE task requires.

Researchers found similar results of common processing across the motor and language domains in a gesture priming task (Vainiger, Labruna, Ivry, & Lavidor, 2014). Participants viewed video clips of three types: depictions of either significant gestures (those conveying meaning; SG), meaningless gestures (hand movements and facial expressions not associated with any meaning; MG), or video clips of landscapes (e.g., a volcano; LS), which served as the control. In a series of experiments, participants completed tasks that required them to respond to linguistic primes that were either sensible and congruent with the presented video clips or sensible and unrelated to the video clips, or were non-words. In all three conditions, participants were the fastest for significant gestures with congruent meanings. Therefore, when significant gestures were paired with congruent meanings, participants were significantly faster at determining if a series of letters was a word or non-word, repeating presented word(s), and determining if the presented words were congruent with the video stimuli. This indicates interconnectedness of the language and motor domains, as gestural and linguistic pairings that made more sense (i.e., ones that were congruent) led to faster RTs than any other condition and pairing. This research supports the idea that non-verbal motor gestures and language are incorporated to construct meaning (Vainiger et al., 2014).

Neural Evidence of Shared Processing between the Language and Motor Domains

Brain-imaging techniques have allowed researchers to investigate the structures involved in cross-domain processing. Neural evidence of connections between the language and motor domains has been found, and continues to be an area of interest. Researchers found that motor areas of the brain were activated during a linguistic task involving action verbs (Van Dam, Rueschemeyer, & Bekkering, 2010). Participants underwent fMRI scanning while reading a series of verbs and being given a semantic task in which the participants would respond "Go" if the presented verb involved an action involving the mouth (e.g., to bite), and would give no response if it was a verb that did not (e.g., to clean). Furthermore, abstract verbs (e.g., to judge) were included, along with verbs denoting a concrete action (e.g., to pinch). Only 27 of 108 words used would have elicited a "Go" response; therefore, 81 trials were performed while the participant performed no motor response. This was done to ensure the participants were semantically processing the presented words giving an accurate depiction of verb-processing in the fMRI images. Results showed that comprehension of language containing action verbs elicited activation of motor areas of the brain, as motor areas of the brain were activated when processing action verbs even without performing motor actions. Furthermore, the verbs that denoted a specific action, as opposed to the abstract verbs, showed higher levels of activation in motor areas of the brain.

Similarly, Heiser, Iacoboni, Maeda, Marcus, and Mazziotta (2003) found that language areas of the brain are activated during a motor task. Participants completed a task involving imitation of a button pressing action. Participants watched videos either of a hand pressing a sequence of two of four keys or of a red light hitting a sequence of two of four keys. Participants were asked to imitate the button pressing sequence on an identical set of keys. During this task, participants received repetitive transcranial magnetic stimulation (rTMS) to Broca's area, which temporarily disrupts functioning to the targeted area of the brain. Researchers found that motor behavior was disrupted when participants attempted to imitate the videos in which the finger pressed the keys but not those where the red light "pressed" the keys. Researchers argue that this is because the finger-pressing task involves actual imitation of an action, while imitating the sequence of the light is not actual imitation but following spatial cues. Researchers believe this occurs because mirror neurons in Broca's area assist in imitation of an action and not simply due to an interruption of internal dialogue (i.e., internal repetition of steps to follow to complete the task; Heiser et al., 2003). For example, participants could arguably have an internal dialogue outlining instructions of how to do each task (i.e., imitation of finger-presses and imitation of the light). If this was the case, researchers would see disruptions in both tasks, not only the finger-pressing imitations.

The imitation factor led researchers to believe that Broca's area contains mirror neurons that assisted participants in the behavioral imitation task and therefore was disrupted when the rTMS was introduced. It is thought that Broca's area is primarily dedicated to language processing, which makes this research a point of interest as a motor task was disrupted due to rTMS of a language area of the brain (Freberg, 2010). Other researchers speculate that the mirror neurons in Broca's area may have contributed to the evolution of speech in humans (Rizzolatti & Arbib, 1998). They believe that the mirror neurons aided in imitation of communicative gestures and facial expressions and eventually aided in imitation of speech. Mirror neurons in the brain that activate when watching or performing some specific motor actions also activate when they are told that someone has performed this action, meaning that language can activate these mirror neurons involving motor processing (Cappa & Pulvermüller, 2012). Taken together, these research findings suggest that neural mechanisms for language and motor domains overlap in humans.

Cross-Domain Processing

While behavioral research on cross-domain processing between the language and motor domains is quite limited, many researchers have found evidence of cross-domain processing between other domains. Hadjikhani and Roland (1997) examined cross-domain transfer using a positron emission tomography (PET) scan while participants performed tactile and visual matching tasks. Each participant completed each task: tactile-tactile (TT), tactile-visual (TV), visual-visual (VV), and the motor control condition. A series of ellipsoid objects were used; for each task, the ellipsoids would either be identical or varying degrees of differ-

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ently shaped from one another, and participants would determine if they were identical or not by raising their right thumb if they determined them to be identical. In the TT condition, participants held two ellipsoids and felt them in their hands to determine if they were the same. In the VV condition, participants were shown one, then another, and then determined if they were the same. In the TV, participants were given one ellipsoid to feel in their hand, and then were visually presented with another. In the control condition, participants were told to move their hands as if they were holding and feeling the object. Researchers found that an area of the brain known as the insula-claustrum was active only during the TV task; this is a thin area of cortex that lies between the insula and putamen areas of the brain, and is thought to be involved in the cross-domain transfer of information (Crick & Koch, 2005; Hadjikhani & Roland, 1997). Researchers believe that brain areas dedicated to different domains may communicate, exchange information, and interact through the insula-claustrum. This area may be a relay station for information across domains.

Additional research has found evidence for common temporal processing across the language domain and other domains of processing. Hupp, Sloutsky, and Culicover (2009) found behavioral evidence for a domain-general temporal processor both within the language domain and across the language, music, and visual domains. This was examined through a multitude of experiments involving a series of novel syllable combinations and novel image sequences. These sequences were used to determine attentional preferences to a temporal sequence among participants (e.g., beginning or ending of sequence), train them to change their preference, and transfer this learned preference across domains. First, these researchers established that adults had an attentional preference to the beginning of linguistic sequences. This continued when melodies and visual image sequences were used in place of linguistic sequences. Researchers believe this to be evidence of shared preferential attention to the beginning of a temporal sequence in the linguistic, music, and visual domains.

Then, participants were trained in one domain to change their temporal preference (e.g., to attend more to the end of the temporal sequence), and then they successfully transferred this newly trained preference across domains. These experiments indicate similarity and flexibility of temporal processing across linguistic and non-linguistic domains. The training to attend to a different portion of a temporal sequence successfully transferred from the language domain to the music and visual domains indicating a cross-domain transfer of temporal processing. These researchers purport that this evidences a domain-general mechanism for temporal processing that influences linguistic processing.

Hupp and Jungers (2013) found further behavioral evidence of shared temporal processing mechanisms between the language and visual domains. In Experiment 1, participants viewed two videos of a star moving toward a target, one in which the star moves quickly, the other slowly. Participants then heard a sentence indicating that the star is headed toward the target, spoken in a fast or slow rate. They were asked to select which moving image the sentence was referring to (the only difference between the images being rate at which the star moved). Participants who heard the fast sentence chose the fast moving star, and those who heard the slow sentence chose the slow moving star. Participants included adults and preschool aged children; both age groups demonstrated that the processing occurring in the language domain was related to the processing of the visual domain.

In Experiment 2, participants viewed a video of a star moving quickly or slowly to one of two targets. The participants said aloud which target the star was moving towards (e.g., "The star is going to the dog"). Both children and adults spoke more quickly when describing fast-moving stars and spoke more slowly when describing slow-moving stars. The rate at which a visual image moved affected the rate of the participants' speech. This research indicates common temporal processing between the language and visual domains.

Jungers et al. (2015) found behavioral evidence that rate persistence occurs across the language and music domains as well, which further supports the theory of shared temporal processing across domains. Participants were primed with either a fast or slow sentence or melody, and then were asked to produce picture descriptions. Participants primed with fast sentences or melodies spoke faster, and participants produced slower descriptions after slow primes (sentences or melodies). This study provides evidence for a cross-domain mechanism for processing temporal information in the language and music domains.

Timing Mechanisms

Evidence of shared temporal processing within and across domains throughout the previously stated research indicates a possible underlying timing mechanism, as proposed by Buonomano and Laje (2010). A shared timing mechanism may account for the coordination of motor movements in addition to the timing of speech. A shared timing mechanism would allow one to successfully time a motor action in relation to the environment, such as catching a ball. It would allow one to successfully converse with another person, correctly timing responses by coordinating speech rate. Motor tasks and speech production depend on carefully timed movements specific as short as a tenth of a millisecond. It is possible that the motor domain and other domains of processing may share a timing mechanism. Buonomano and Laje (2010) discuss different models of proposed timing mechanisms, including dedicated models of timing and intrinsic models of timing. Dedicated models suggest that there are specific mechanisms that are responsible for timing, while the intrinsic models suggest that the neurons of the brain are capable of managing timing on their own; there is still no conclusive evidence indicating which model is correct (Buonomano & Laje, 2010).

Current Study

Previous behavioral and neurological research has found much evidence of shared processing between the language and motor domains, indicating that the two domains seem to be strongly interconnected. Furthermore, evidence for a cross-domain temporal processing mechanism has been found between the language domain and other domains of processing (e.g., visual, music). However, none of these studies have provided behavioral evidence for a shared temporal processing mechanism between the language and motor domains. Doing so may shed light on how the brain processes temporal information and contribute evidence to the understanding of shared processing between all domains. The current research aimed to find behavioral evidence of a shared temporal processor between the language and motor domains consistent with evidence of other cross-domain temporal processing. The expected results would contradict the theory of the modularization of language and support a domain general temporal processor.

This research investigated motor to language temporal processing by priming participants with a tactile and motor prime, or just a tactile prime, at a fast or slow rate and asking them to produce picture descriptions. As cross-domain rate transfer and evidence of connected neural activity has been demonstrated in previous research across other domains, it was expected that there would be a rate transfer from the tactile/motor primes to language production, such that the faster tactile/motor prime would elicit faster speech production, and the slower tactile/motor prime would elicit slower speech production.

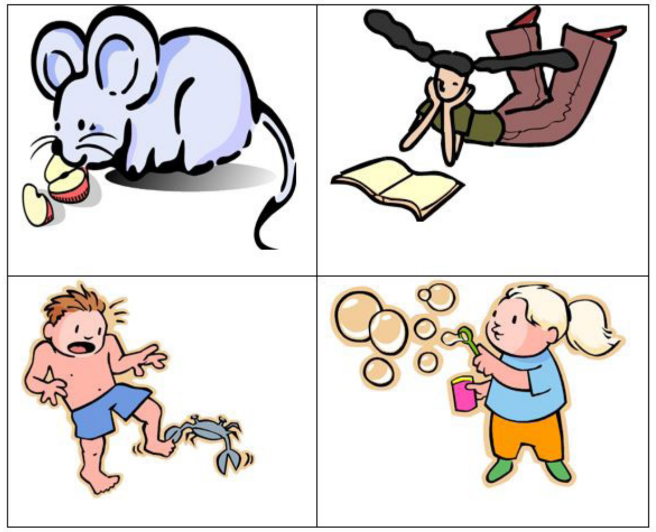
Method

Participants

Participants were 81 undergraduates from a regional campus of a large university in Ohio. All participants were adults (30 males, 51 females; M = 18.79 years, SD = 2.32). Participants were predominantly white (n = 65). They received class credit for their participation. An additional 10 participants were excluded from the final data for not being native English-speakers (n = 7), or if they spoke inaudibly, skipped, or made other errors on 50% or more of the trials (n = 2). A participant was excluded due to a technical error with the equipment (n = 1).

Materials

Figure 1. Examples images used in the current study.



Thirty-two novel cartoon images were presented to the participants via PowerPoint on a desktop PC. For example images, see Figure 1. These images were included in two practice phases, one test phase, and a

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memory quiz. Six images were used in Practice Phase 1, four in Practice Phase 2, and sixteen in the Test Phase. There were twelve images used in the memory quiz; six were taken from the Test Phase, and six were previously unused images. The images were centered in the middle of the screen. The size of the images varied; the images were an average of 6.7 inches in height and 7.0 inches in width.

Participants wore a head-mounted microphone which was connected to a Tascam DR-03 recording device to record their speech. Participants held an iPhone 4 during the second practice phase and the test phase. An app called "Seconds" (Runloop Ltd, 2014) was used on this device to emit vibrations at either 2-second intervals (fast) or 4-second intervals (slow) to provide the tactile prime. A 13-second video clip was displayed on an instruction slide, demonstrating an arm movement which the participants in the Tactile/Motor condition were asked to perform. In the video clip, the arm movement was performed at 3-second intervals, which is equidistant from the two primed rates used in the current study. The video started automatically upon viewing the slide, and played continuously while remaining on the slide. As demonstrated in the video, participants were instructed to hold the iPhone in their non-dominant hand with their palm facing down. Whenever a vibration was felt, the participants rotated their hand so their palm is facing upwards and brought their hand close to their face, as if they were checking the phone, then returned their hand to the original position. Participants were instructed to look at the computer screen, not the iPhone, as they performed the motor action.

The order of the images that the participants were asked to describe was initially randomized when the PowerPoint was created. Two versions of the PowerPoint presentations were used. The first version used the original order of images after randomization, and the second version used the images in the original PowerPoint in reverse order. The same method of randomizing, selecting, and ordering the images was used for a memory quiz given at the end of the study. The same images were used in each phase. For example, the same four images were used in Practice Phase 2, but were presented in either the original or mirrored order. This was done to control for any effects of presentation order.

A 12-item memory test was given to assess memory of the novel images used in the study. The images were randomly ordered when creating the quiz. Participants were asked, "Did you see this image?" and responded by circling their answer (yes or no) on an answer sheet. See Appendix B for the memory test response form. Half of the images were images they had seen in the study, and half were foil images – images they had not seen in the study, but were similar. Therefore, half of the responses were "yes," and half were "no". Participants also completed a form including basic demographic information. This form included information such as age and gender, as well as their language background, and whether or not they know the purpose of the study. See Appendix C for the demographics form.

Design and Procedure

Figure 2. The eight conditions in the current study.

Tactile Only Slow: Order 1	Tactile Only Fast: Order 1	Tactile/Motor Slow: Order 1	Tactile/Motor Fast: Order 1
Tactile Only Slow: Order 2	Tactile Only Fast: Order 2	Tactile/Motor Slow: Order 2	Tactile/Motor Fast: Order 2

There were two main between-subjects independent variables for this study: Task (Tactile/Motor vs. Tactile Only) and Rate of Prime (Fast vs. Slow). The order in which the images were presented (Original, Mirrored) was a control variable. These manipulations resulted in eight conditions; see Figure 2. The dependent variable was speech rate (seconds/syllable).

Once the study began, all instructions were presented on the computer. Participants read the consent form on the PowerPoint slides. They were instructed to press a button to continue if they consented to participate. Then, they read the introduction to the study, which informed them that they would be describing pictures while being distracted by a cell phone and would later be tested on how this affected their memory of the pictures they were describing. The participants were told that the goal of the current study was to examine multitasking and memory when distracted by a cell phone. This description was used to distract participants from the true purpose of the study. At this point, they were given the head mounted microphone to wear, and participants read further instructions, directing them to create picture descriptions for novel images and say them aloud. Their utterances were recorded and later coded for speech rate. Once each phase of the study was started by the participant, the presented images advanced automatically after six seconds. The slides advanced automatically only between presentations of the images, stopping at the end of each phase.

There were six initial practice picture descriptions without the tactile/motor prime, referred to as Practice Phase 1; the first three images were captioned to provide examples of simple picture descriptions (e.g., "The boy climbed the tree"), followed by three uncaptioned images. If necessary, the experimenter provided corrective feedback after Practice Phase 1 (e.g., adjusting voice volume, clarifying that they should only use simple statements to describe pictures).

Next, participants were introduced to the tactile/motor prime. All participants were given an iPhone vibrating at fast or slow intervals. Participants in the Tactile/Motor condition were asked to perform the motor action whenever they felt the vibration emitted from the iPhone. Participants viewed a video demonstration of the motor action, which involved raising the hand towards the face, rotating it upwards, and then returning it to a resting position. The video provided only a visual demonstration, with no accompanying audio or instructions. The participants would then begin performing the motor movement until prompted to stop. Those in the Tactile Only condition were instructed to hold the cell phone in their non-dominant hand (i.e., with no motor action accompanying the vibrations). After viewing the instructions, those in the Tactile/Motor group were prompted to demonstrate the motor action for the experimenter; if needed, the participant was given corrective feedback. This was followed by a 20-second period to experience the prime (i.e., performing the motor action or holding the cell phone). Participants continued the priming task throughout practice phase 2 and the test phase. For data analyses, the test phase was divided into Block 1 (first 8 trials) and Block 2 (second 8 trials); there was no break between Blocks 1 and 2, and there were no methodological differences between the two blocks.

After this, participants practiced describing four images with the Tactile Only or Tactile/Motor prime, referred to as Practice Phase 2. They then completed Blocks 1 and 2 of the 16-trial Test Phase, continuing to describe each picture while receiving the fast or slow prime. The participants completed the 12-item memory quiz. Afterwards, they were instructed to complete the demographics form, and then they read the debriefing statement (presented on the computer). Copies of the consent form and debriefing statement were available for participants to keep.

Results

All speech rate data was coded by two research assistants who were both hypothesis and condition blind. One research assistant coded 77.78% of the speech data, and the second coded 22.20% of the speech data; 12.34% of the data was coded by both research assistants. Inter-rater reliability of the speech rate was $r = .96$. The coders were initially trained on coding speech data by an experienced speech analysis researcher. After coding some of the data, the coders discussed discrepancies, established reliability, and continued to code data independently. The coding involved determining when each utterance began and ended and counting the syllables in each utterance. Coders noted any additional, unrelated utterances, pauses, or other behavior that may have affected the data. No individual trials were removed from the final data. Speech rate was calculated by dividing the length of the utterance (in seconds) by the number of syllables spoken to calculate a seconds/syllable rate.

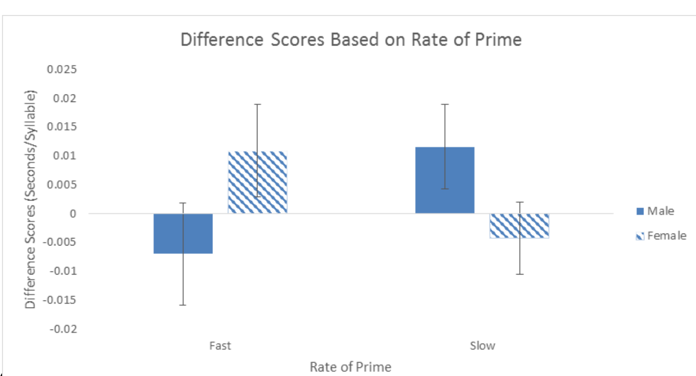
No participants reported that they knew the true purpose of the study, instead reporting the purpose given by the cover story (i.e., multitasking). The accuracy on the memory test ($M = 99.89\%$) was well above 50% chance performance, one-sample $t(80) = 485.19$, $p < .001$ indicating that participants were attending to the pictures in the study.

For initial analyses, a 2 x 2 (Rate of Prime x Condition) ANOVA on speech rate during the test phase was performed. It was found that there was no main effect of condition on speech rate, $F(1, 73) = 0.08$, $p = .79$. Participants who received only the Tactile prime had an average speech rate of $M = .248$ seconds/syllable ($SD = .035$), and those who received both the Tactile and Motor primes had an average speech rate of $M = .244$ seconds/syllable ($SD = .039$). It was also found that there was no main effect of Rate of Prime on speech rate, $F(1,73) = 0.16$, $p = .69$. Those who received the slow prime had an average speech rate of $M = .242$ seconds/syllable ($SD = .035$), while those who received the fast prime had an average speech rate of $M = .249$ seconds/syllable ($SD = .044$). Because there is such variation in individuals' speech rate, further analyses were performed to investigate changes in speech rate across the test trials.

To analyze the data further, a difference score was calculated comparing the change in speech rate from the first block of 8 test trials with the second block of 8 test trials. This change in speech rate between Blocks 1 and 2 was calculated by subtracting the average speech rate of Block 2 from Block 1. When calculating speech rate, a negative number would indicate that the participant decreased their speech rate from Block 1 to Block 2, while a positive number would indicate an increased speech rate from Block 1 to Block 2. Comparing Block 1 and Block 2 of the test trials could indicate if participants were changing their speech as a result of the primed rate after a period of exposure.

A 2 x 2 x 2 (Rate x Condition x Gender) ANOVA on this change in speech rate was performed. There was a significant Gender x Rate of Prime interaction, $F(1,73) = 4.63$, $p < .05$. See Figure 3 for mean difference scores and standard errors. To tease apart this interaction, the effect was analyzed for each gender separately. For females, there was a marginal effect of Rate, such that from Block 1 to Block 2, females increased their speech rate when primed with a fast tactile prime, and decreased their speech rate when primed with a slow tactile prime, $F(1,49) = 2.30$, $p = .14$. The male group also had a marginal effect of Rate, such that from Block 1 to Block 2, males increased their speech rate when primed with a slow tactile prime, and decreased their speech rate when primed with a slow prime, $F(1,28) = 2.84$, $p = .10$.

Figure 3. The mean difference scores of speech rate between Block 1 and Block 2 based on Rate of Prime (seconds per syllable). Error bars indicate standard error of the mean. Difference score was calculated by subtracting Block 2 from Block 1, such that a positive number indicates an increase in speed from Block 1 to Block 2, and a negative number indicates a decrease in speed from Block 1 to Block 2.



It was expected that those primed with a fast rate would speak faster, and those primed with a slow rate would speak slower. Interestingly, this research revealed that gender mediated this effect of priming rate. In the current study, the speech rate of female participants was affected by the rate of prime in the expected direction, while the male's speech rate was not, and in fact went in the opposite direction. The unanticipated gender differences in the current study may be an implication of gender differences in the mirror system.

The human mirror system is thought to be responsible for learning and imitation of motor movements. Cheng, Tzeng, Decety, Imada, and Hsieh (2006) found that females had more cortical activation in the primary motor cortex when observing a motor action than their male counterparts. These results led researchers to believe that the mirror system is more active in females than males, as the motor cortex was more strongly activated in females when viewing a motor action, indicative of mirror system activity. These results resonate with the findings of the current study, such that higher activation of the female mirror system may explain the gender differences found. A more active mirror system would allow an individual to better imitate and synchronize with environmental influences. Accurately performing the tactile/motor task may have allowed the female participants to better synchronize their speech rate with the rate of the prime. The current results could reinforce these findings, and contribute evidence to gender differences in the mirror system.

In the current study, it was also expected that there would be a significant difference between the Tactile Only and Tactile/Motor conditions, which was not found in this case. With the extensive amount of evidence indicating the interconnectedness of the language and motor domains, an anticipated effect of condition would have indicated a cross-domain transfer between the language and motor domains. However, the results of the current study indicate a cross-domain transfer between the tactile and language domains (mediated by gender), such that the rate of the tactile prime affected the rate of speech. While the mirror system is most well known for interactions with the motor and visual domains, it seems as though the tactile domain may be involved in the mirror system as well.

McKyton (2011) found activation in areas of the brain implicated as part of the mirror system during

a tactile task. Participants underwent fMRI scanning while touching four types of items: the experimenter's hand, a realistic rubber hand, an everyday object (cell phone, sunglasses), or a simple texture (rough paper, bubble nylon). It was found that three areas of the brain showed significantly higher activation when touching the experimenter's hand, than when touching any other object, even the rubber hand; these areas are the anterior medial prefrontal cortex (aMPFC), the left ventral premotor cortex (vPMC), and the right posterior superior temporal cortex (pSTC). The aMPFC has been found to be involved in processes such as theory of mind, or self-referential processes (Gallagher et al., 2000; Gusnard, Akbudak, Shulman, & Raichle, 2001). More relative to the current study, the vPMC and the pSTC have been implicated as part of the mirror system. Specifically, the pSTC has been known to be active when witnessing biological motion, particularly motion of the hand. This area has also been found to be cross-modal, with research focusing on audio-visual interaction (Pelphrey, Morris, Michelich, Allison, & McCarthy, 2005).

If the gender differences found by Cheng et al. (2006) in the mirror system persist in the tactile domain, this could indicate why gender differences were found in the current study. The mirror system is mostly known for involvement with the motor and visual domains; however, McKyton's (2011) findings indicate that this may include the tactile domain as well. If this is true, the gender differences in the mirror system involving motor tasks may continue to the tactile domain. Importantly, the current results seem to evidence cross-domain temporal processing between the tactile and language domains, which is further mediated by gender.

The implications of a gendered mirror system may translate to social synchrony as well. Researchers found gender differences in non-verbal symmetry in conversation partners (Rotondo & Boker, 2002). These researchers examined the head movements of males and females engaged in conversations with one another. It was found that females will lead and follow behaviors of their speaking partners. In other words, they tend to match the non-verbal movements of their speaking partner. When males are speaking to females, males adapt to their female conversation partners; however, males do not appear to attempt synchronization when in conversation with one another. Synchronization of non-verbal movements may occur more often in females due to higher levels of activation in the mirror system, contributing to more successful imitation of their speaking partner's behaviors. This further supports the gender differences obtained in the current study. If females are more likely to synchronize conversational behaviors with a speaking partner, it may follow that they are also more likely to follow speech rate patterns and motor behaviors more successfully than males.

The unexpected gender effects of the current study may have implications on social and communicative synchronicity. In further research on communication, speech, and social behaviors, it would be important to recognize gender as an important variable. Many components of speech and social interactions that have been focus of research have been found to have a differential effect based on gender.

Further research should continue to investigate the possibility of a cross-domain transfer between the language and motor domains. Furthermore, future research on the human mirror system should recognize gender as an important factor to examine. It seems clear that the mirror system has implications on our behavior and is mediated by gender. Importantly, the current study has found evidence of cross-domain processing between the language and tactile domains, mediated by gender. Future research should continue to expand on this, examining the extent to which gender affects tactile processing, and how this impacts the cross-domain transfer of information.

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