

# Gender influences the production and acquisition of complex skilled praxic movements

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The praxis system comprises a network of brain regions dedicated to complex skilled movements. Following suggestions of a female advantage on tasks that recruit the praxis system (Chipman & Hampson, 2006), we investigated how males and females *acquire* praxic movements. Subjects viewed and imitated sequences of hand movements, which were repeated ten times. Subjects' imitations were captured by a data glove, and the temporal and spatial characteristics of the imitation were compared to the model sequence. We propose a model that reflects the computations required for imitating hand movement sequences, and define the errors that arise from failures at these computations. Our results demonstrate a female advantage in both the production and acquisition of hand movement sequences, and show that this gender difference is accounted for by a female advantage in motor selection and preparation, rather than at the level of executing or sequencing the gestures. We outline the important implications of our findings for gender-sensitive instructional strategies, as well as for the understanding of the human praxis system.

Keywords: Imitation, Sequence learning, Apraxia, Sex differences, Gesture

## Introduction

Gesturing and imitation are critically important for learning new skills, and for communicating with and understanding others. For example, children's acquisition of new concepts is enhanced if they make appropriate gestures while learning (Goldin-Meadow, Cook, & Mitchell, 2009; Cook, Mitchell, & Goldin-Meadow, 2008), and learning is enhanced when children imitate their teacher's gestures (Cook & Goldin-Meadow, 2006). Furthermore, frequent gesturing by children at 14 months is associated with larger vocabulary at 54 months (Rowe & Goldin-Meadow, 2009).

Viewing and imitating gestures activates a fronto-parietal network of brain regions (Muhlau et al., 2005) that are associated with skilled movements; this left hemisphere dominant system is known as the praxis system. Damage to this system results in a neurological disorder known as ideomotor apraxia (see Heilman & Rothi, 2003; Wheaton & Hallett, 2007, for review). Patients with ideomotor apraxia lose the temporal and spatial fidelity of skilled movements, which can include gesturing to command, imitating seen movements, as well as pantomimed and actual tool use (Johnson-Frey, 2003).

Researchers have identified gender differences in the

praxis system's anatomical and functional organization. For example, apraxia more often results from anterior lesions than from posterior lesions in females (Kimura, 1983), and non-apraxic females show an advantage on tasks that depend upon this system (Chipman & Hampson, 2006). Chipman and Hampson (2006) required subjects to produce distinct movements in response to color cues. Judges viewed video records of subjects' performance, and noted that females made fewer perseverations, intrusions and substitutions, and executed their movements faster than males did. It was concluded that this female advantage in gesture production arises "somewhere between associative retrieval and executory stages of gesture production."

Although Chipman and Hampson (2006)'s study provided some insights into gender differences in gesture production, its experimental paradigm and analytic approach are limiting. First, the use of an associative retrieval task did not allow a distinction to be made between the retrieval and execution processes of the movements. In addition, all the movements were well-learned, so it is unclear if the female advantage extends to the acquisition of unfamiliar movements. Knowing this result's extensibility is important for optimizing rehabilitation strategies in apraxia, and for developing gender-sensitive instructional strategies. Moreover, reliance on video recordings, although useful, makes it difficult to produce a fine-grained, objective analysis of the temporal and spatial components of any movements that are recorded.

The present study utilizes a novel approach, developed by our group (Gold, Pomplun, Rice, & Sekuler, 2008), to

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clarify the gender differences in the functional organization of the praxis system. In the experimental paradigm subjects view, and then reproduce from memory, a stimulus model comprising a sequence of hand gestures. The subjects' movements are captured by a data glove and a multi-stage algorithm identifies spatial and temporal differences between the stimulus model's movement and the subject's imitation. The algorithm isolates errors not only for particular items in a sequence, but also for the order in which the items are reproduced; this distinction between the two types of errors is important as separate brain regions contribute to memory for item and order information (Histed & Miller, 2006).

Our experimental paradigm has the added advantage of allowing control over visual feedback. In particular, we are able to yoke a subject's movements in real-time to the movements of an animated hand displayed on a computer monitor. On a trial-by-trial basis we could present this feedback to subjects, or turn it off. This manipulation is important to our investigation as it has been demonstrated that males show greater reliance on visual feedback than females on praxis tasks (Chipman, Hampson, & Kimura, 2002). Also, some research has shown that apraxia is associated with an increased reliance on vision (Heilman, Rothi, Mack, Feinberg, & Watson, 1986; Ietswaart, Carey, & Della Sala, 2006).

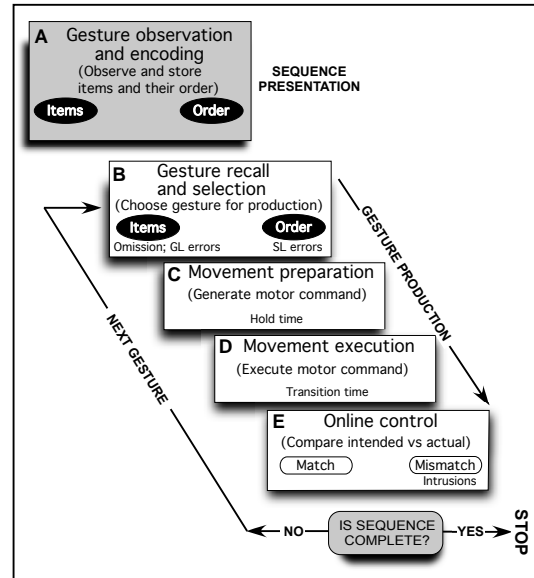
Our experimental task depends on a series of cognitive processes. Figure 1 summarizes those processes, and identifies the distinctive types of errors that likely arise from failures of each process. For simplicity's sake the diagram portrays the processes as being serially ordered, but it is possible that portions of some of the processes occur in parallel. The diagram is presented here in order to guide the reader through the rationale that motivates our analysis and interpretation of error types.

Our study attempts to refine the characterization of previously-reported gender differences on a task that draws heavily on the fronto-parietal praxis network (Muhlau et al., 2005). The study has several objectives: (1) to confirm the previously reported female advantage on gesture production; (2) to identify those praxis computations that females perform more efficiently than males do; (3) to determine whether the female advantage is restricted to well-learned skilled movements, or whether such an advantage is evident during the acquisition of such sequences; and (4) to examine gender differences in the exploitation of visual feedback during the course of learning.

## Method

### Subjects

Twenty-six subjects were recruited from the Brandeis University community, eight of these subjects were excluded from the analysis due to problems during testing. Of the eighteen subjects included in the analysis there were nine males (Mean = 23.89 years old, SD = 6.95), and nine females (Mean = 21 years old, SD = 4.15). Each subject gave



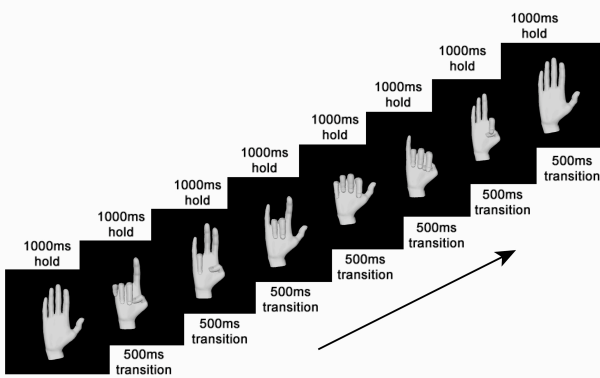
*Figure 1.* Key processes involved in reproducing a sequence of just-seen hand gestures. The dependent variables associated with each process are identified in italics. (A) The sequence of gestures is encoded during viewing. The information extracted includes the identity of each individual gesture (item information) and the place in the sequence that it occupied (order information). (B) Using both item and order information, the gesture to be reproduced is recalled and selected. An omission of a gesture reflects a failure to select that item, whereas gesture level (GL) errors reflect the selection of an incorrect item. Sequence level (SL) errors occur when items are selected in the wrong order. (C) A motor command must be generated to transition from the current gesture to the next one. Although an individual item could appear in more than one sequence, the gesture immediately preceding and following a particular gesture would not occur in another sequence. Thus the motor commands to transition from one gesture to the next were novel in each of the different sequences. The process of generating a motor command is reflected in the hold time, i.e., how long a gesture is maintained before the transition to the next one is initiated. (D) The gesture is produced by changing fingers' flexions and extensions from their current state to the state required for the new gesture. This process is reflected in transition time, i.e., the time required to change from the current gesture to the new one. (E) To ensure accuracy of reproduction, the movement must be monitored and corrected if necessary. This involves a comparison between the current state and the selected state. If a match is detected one will move on to the next item in the sequence, if a mismatch is detected subjects will correct the movement, which can be observed in intrusions. This series of computations will continue to be executed until the entire sequence is completed.

written informed consent in accordance with the principles of the Declaration of Helsinki, and the protocol had been approved by Brandeis University's Committee for the Protection of Human Subjects. All subjects had normal or corrected-to-normal vision, and were right-handed (Oldfield, 1971). All subjects reported no prior experience with American Sign Language (ASL); because some of our stim-

uli were similar to letters in ASL's finger spelling alphabet.

### Stimuli

The details of the method used to generate model gesture sequences has been described elsewhere (Gold et al., 2008). Model sequences were generated from 16 hand gestures, each defined by its combination of extensions and flexions of the five digits on the right hand. Experimental model sequences comprised eight different sequences of six gestures. Within any sequence, from one gesture to the next two digits changed flexion/extension (Figure 2). Each pair of successive gestures appeared just once across all sequences. Single, static gestures and two-gesture sequences served as practice stimuli.



**Figure 2.** Illustration of the events that define the stimulus-presentation phase of an experimental trial. Sequences of six different hand gestures are displayed on a screen, bookended by gestures in which all the digits of the hand are extended, signaling the start and end of the sequence. Each gesture is shown in static form for one second. Successive static gestures are separated by a 500 msec transition period during which subjects see a smooth transition that morphs one gesture into another. The total time to complete a model sequence is 11.5 sec. Note that the stimuli were presented in Caucasian flesh color during the experiment, rather than in the gray-scale depicted here.

### Apparatus

Subjects performed each imitation while wearing a right-handed 5DT™ DataGlove (Fifth Dimension Technologies), and hand and wrist sensors from a Polhemus' (Patriot™) motion tracking system (for further details see Gold et al., 2008).

A wooden frame with a curtain (positioned in line with the shoulder) occluded subjects' vision of their right hand and arm throughout the experiment. However, on some trials, subjects viewed a real-time animation of their hand movements using Vizard™ VR Toolkit (WorldViz). The hand animation looked identical to the hand viewed during the stimulus presentation, however, each of the digits as well as the position and orientation of the hand and wrist were electronically yoked to the subject's fingers,

hand and wrist, and moved (~30msec delay) with the subject's own movements.

### Procedure

Subjects viewed and imitated the stimuli seated at a table, with their right elbow supported on a foam rest, forearm and fingers extended, with the palm of the hand facing the shoulder. This orientation allowed subjects to imitate sequences without having to mentally rotate the stimulus. In the first set of trials, subjects viewed one static gesture at a time, and when a tone sounded they imitated the gesture. Each of the 16 gestures was displayed for one second, with a one-second retention delay before the tone. Next, subjects' practiced with sequences comprising two-gestures, with a one second retention delay before being cued to imitate the sequence. After viewing and reproducing eight different two-item practice sequences, subjects went on to the experimental phase of the experiment. In all practice trials, visual feedback of the subject's hand was provided.

In the experiment proper subjects were told that they would see six-item sequences of gestures, which they should imitate when the auditory "go" signal was given. They were told to produce as many of the gestures as they could remember, and to produce the gestures in the correct order, while refraining from guessing. They were informed that they would learn four different six-item sequences, and they would see each of the sequences repeated over ten successive trials. Further, subjects were informed that visual feedback of their hand movements would be visible on the display screen while they were learning two of the sequences, but that no visual feedback would be available while they learned the other two sequences. When a condition called for visual feedback, subjects saw on the computer monitor an animation of a hand whose movements were yoked to the movements of the subjects' hand. When a condition called for no visual feedback, subjects viewed a blank display as they reproduced each sequence. Subjects were allotted 14 seconds to complete the imitation, and used the left hand to initiate the next trial with a key press.

### Analysis

A multi-stage algorithm analyzed the flexion/extension captured from the data glove, and compared the subjects' imitation to that of the model (Gold et al., 2008). The algorithm begins by segmenting each imitation and its corresponding sequence into component gestures. Based on the velocity of each digit's movements, the algorithm segments the sequence into static or transitional components. A gesture qualifies as "static" if the velocity of each digit drops below 10% of its peak velocity for at least 100 ms; a "transitional" component is defined by the finger movements between two successive static gestures.

Once transitional and static components have been defined, our algorithm examines the flexion data for each digit in each time epoch. The flexion threshold was defined as a value of 0.5, with any digit whose flexion value

exceeded that threshold considered to be flexed, and any digit with a flexion value below the threshold considered to be extended. Each gesture can be characterized by its extended digits, starting with the thumb (1) and ending with the little finger (5). Thus, in this notation a completely open hand, all fingers flexed, would be represented as 12345.

Once the component gestures in a sequence have been identified, the algorithm compares the subject's imitation against the model gesture sequence; this comparison gauged the accuracy and timing of each imitation. The "bookend" gestures (i.e., the open-hand gestures at the start and end of each sequence) were discarded from both the model and its reproduction. After comparing each gesture in the imitation to gestures in the model, the algorithm reorders the gestures recovered from the imitation so as to minimize the number of incorrectly reproduced gestures across the entire gesture sequence.

After matching the reproduced gestures against the gestures in the model, the algorithm quantifies and categorizes the spatial and temporal components of the subject's movements; these include:

#### Spatial Errors:

**Omissions** - When one or more gestures in the imitation cannot be matched to any gesture in the model sequence. For example, if the model sequence 2-235-125-1-5-345 were reproduced as 2-235-125-1, the algorithm would assert that 5 and 345 had been omitted from the reproduced sequence, and would therefore attribute two omissions to that trial. Omissions are observed when fewer than six gestures are produced in the subjects reproduction, and as such reflect a failure to recall and select a gesture for response (Figure 1B).

**Intrusions** - When the number of gestures imitated exceeds the number of gestures in the model sequence. Note that every model sequence comprised six gestures, a fact brought to subjects' attention before the experiment. For example, if the sequence 2-235-125-1-5-345 were reproduced as 2-235-1235-125-1-5-345, the algorithm would find that gesture 1235 was an intrusion, added in the subjects reproduction, and as such mark one intrusion for that trial. Intrusions likely reflect a corrective response, in this case 1235 was an incorrect response and was corrected to the appropriate gesture 125 (Figure 1E).

**Gesture-level errors** - When a reproduced gesture differs from the matched gesture in the model by one or more digit flexions. For example, if the sequence 2-235-125-1-5-345 were reproduced as 2-235-135-1-5-345, the gesture 135 in the subjects reproduction would be matched to 125 in the model, but one gesture level error would be defined as subjects extended their middle finger instead of their index finger. As Figure 1B suggests, gesture level (GL) errors reflect the recall and selection of an incorrect gesture.

**Sequence-level errors** - When gestures are reproduced in the incorrect order. For example, if the sequence 2-235-125-1-5-345 were reproduced as 2-125-235-1-5-345,

two sequence level errors would be defined, as gesture 125 was produced second instead of third and 235 was reproduced third instead of second. Sequence level errors reflect difficulty in recalling and selecting items in the correct order. (SL errors, in Figure 1B)

As gesture level errors and sequence level errors become more likely as additional gestures are reproduced per sequence, we normalized the values of these variables to the number of gestures produced per sequence. This is an important normalization as Figure 3 shows that over successive repetitions of a sequence, subjects produce more gestures ( $F_{(3,363,53,809)} = 24.701, p < 0.001, \eta_p^2 = 0.607$ ). Additionally, males consistently produce fewer gestures than females ( $F_{(1,16)} = 5.304, p = 0.035, \eta_p^2 = 0.249$ ).

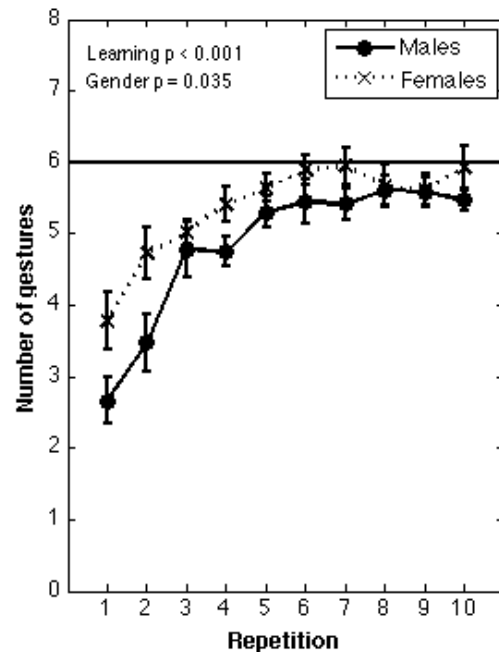


Figure 3. The mean number of gestures produced by subjects over successive repetitions of a model sequence. Subjects produce more gestures as a sequence is repeated, with females producing more gestures than males. The horizontal line at  $y = 6$  represents the number of gestures produced by the model sequence, highlighting that females have better accuracy for this variable than their male counterparts. Error bars are between-subject standard errors. As the condition of feedback (present vs. absent) had no significant effect on the effect of repetition, we collapsed data over the two conditions of feedback.

#### Temporal Components:

**Hold time** - The mean time (msec) that a subjects holds each of the static gestures. This provides a measure of movement preparation time as subjects generate a motor command to move from one gesture to the next (Hold time, in Figure 1C). Note that the value of this variable can be compared to the value of 1000 msec that was the time for which each gesture in a model was held.

**Transition time** - The mean time (msec) that a subject takes to transition from one gesture to the next. This provides a measure of movement execution time (Transition time, in Figure 1D). Note that the value of this variable can be compared to the value of 500 msec, which was the transition time from one gesture to the next for the model sequence.

### Serial Order:

As our task entails serial recall, performance is likely to vary with an item's serial position. Thus, we compared each item in the model sequence to the corresponding item in the reproduction. A correct match was assigned a value of 1, and an incorrect match was assigned a 0. For example, if the sequence 2-235-125-1-5-345 were reproduced as 2-235-125-1, the trial would be coded as correct for serial positions one through four, and incorrect for serial positions five and six. This measure allows us to determine where in a given sequence subjects have particular difficulty producing items, thus providing a measure of both item and order information (Figure 1).

### Statistical Analysis

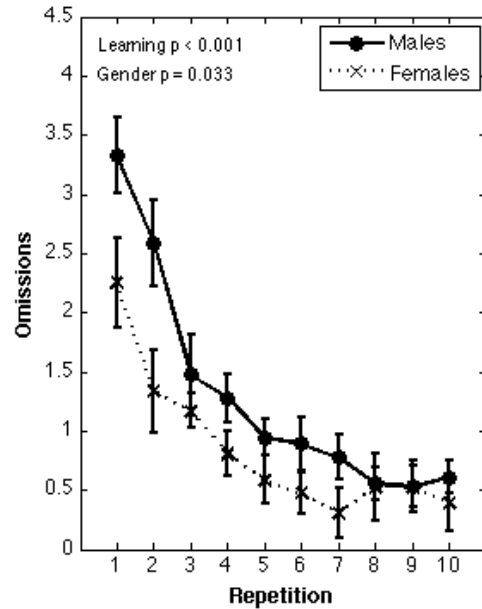
Trials on which a subject failed to begin with an open hand were excluded from analysis because they were likely to have reflected a premature start of the imitation. Trials were also excluded if subjects produced more than ten static gestures, as such responses likely reflected a brief pause during a transition that resulted in incorrectly identifying a static gesture. A total of 96% of trials were included in the analysis. Each dependent variable was subjected to an ANOVA with repetition (1 to 10) and feedback (present or absent) as within-subject factors, and gender (male and female) as the between-subject variable. Partial eta-squared ( $\eta_p^2$ ) was used as our measure of effect size. A significance threshold of 0.05 was used throughout, and Huynh-Feldt corrections were applied where sphericity assumptions were violated. Wherever significant effects or interactions were observed for sequence repetition, a post-hoc analysis using a *t*-test contrasted the first and the tenth repetition, as a measure of learning. For conciseness only statistically-significant findings are reported.

## Results

### Spatial errors

With additional opportunities to view and imitate a sequence, subjects produce more gestures (Figure 3). The number of gestures produced reflects two kinds of influences: omissions and intrusions. Subjects produce fewer omissions (Figure 4) with learning ( $F_{(2,847,45.557)} = 25.946, p < 0.001, \eta_p^2 = 0.619$ ). Post-hoc analysis, comparing the first to the tenth repetition, confirms this finding ( $t = 6.564, df = 17, p < 0.001$ ). In addition, gender significantly influences the number of omissions that subjects make ( $F_{(1,16)} = 5.435, p = 0.033, \eta_p^2 = 0.254$ ), with males omitting more gestures than females. This suggests

a female advantage in recalling and selecting a gesture for response (Figure 1). There was a significant interaction between feedback and repetition for omissions ( $F_{(9,144)} = 2.885, p = 0.004, \eta_p^2 = 0.153$ ). However, post-hoc analysis reveals a significant effect of learning for both the feedback ( $t = 5.649, df = 17, p < 0.001$ ) and no feedback ( $t = 7.445, df = 17, p < 0.001$ ) conditions. There was also a significant effect of learning for intrusions ( $F_{(7,743,123.886)} = 3.358, p = 0.002, \eta_p^2 = 0.173$ ), with subjects producing fewer intrusions for the first (mean = 0.014) compared to the last (mean = 0.194) repetition ( $t = -2.6, df = 17, p = 0.019$ ).



*Figure 4.* Mean number of omissions in a reproduced sequence as a function of a sequence's repetition. Error bars represent between-subject standard errors. Fewer omissions are produced as subjects learn the sequences and females produce fewer omissions than males, reflecting a female advantage in selecting a gesture to produce.

The accuracy of reproducing gestures was also examined. We observed a significant effect of learning for gesture level errors ( $F_{(9,144)} = 3.705, p < 0.001, \eta_p^2 = 0.188$ ). However, a significant interaction between repetition and gender ( $F_{(9,144)} = 2.176, p = 0.027, \eta_p^2 = 0.120$ ) was also observed (Figure 5). Post-hoc analysis revealed that the main effect of learning is driven by a significant reduction in gesture level errors as a function of learning for females ( $t = 3.601, df = 8, p = 0.007$ ) but not for males ( $t = 0.754, df = 8, p = 0.472$ ); this suggests a female advantage in skill acquisition at recalling and selecting an accurate gesture for response. Repetition of a sequence produced a significant reduction in the number of sequence-level errors, ( $F_{(6,123,97.965)} = 4.262, p = 0.001, \eta_p^2 = 0.210$ ); this finding was confirmed by post-hoc analysis ( $t = 3.378, df = 17, p = 0.004$ ) with subjects producing more sequence level errors on the first (mean = 0.282) compared to the last (mean =

0.082) repetition.

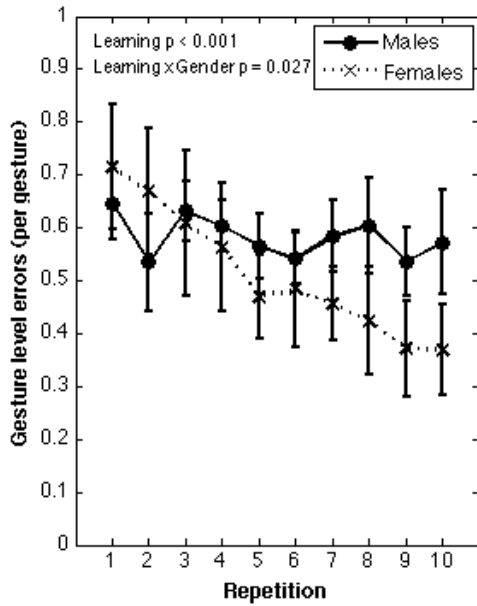


Figure 5. Mean number of gesture-level errors per gesture as a function of model sequence repetition. Error bars represent between-subject standard errors. With repetition, only females produce fewer gesture-level errors, reflecting a female advantage in the acquisition of the sequences.

### Temporal components

No temporal variable showed a significant effect of learning. However, gender did significantly affect the mean hold time ( $F_{(1,16)} = 5.993, p = 0.026, \eta_p^2 = 0.272$ ), with males holding a gesture about 30% longer than females did (Figure 6). In addition, the mean transition time was significantly affected by the availability of feedback during the reproduction of what had been seen ( $F_{(1,16)} = 5.909, p = 0.027, \eta_p^2 = 0.270$ ). In particular, transition times were longer when feedback was available (mean = 726.57 msec) than when no feedback was available (mean = 648.34 msec). This effect of feedback may reflect the fact that when subjects are able to see a display of their own movements, they exploit this visual feedback in order to fine-tune their movements in real-time.

### Serial position

An analysis of the serial position curves (Figure 7) showed main effects of repetition ( $F_{(1,16)} = 59.730, p < 0.001, \eta_p^2 = 0.789$ ) and of a gesture's serial position ( $F_{(5,80)} = 4.906, p = 0.001, \eta_p^2 = 0.235$ ). Furthermore, there was a significant interaction between repetition and serial position ( $F_{(5,80)} = 4.011, p = 0.003, \eta_p^2 = 0.200$ ). This is due to a large primacy effect (i.e., increased accuracy for items that appear early in the sequence) for the first repetition (Figure 7, left). However, by the tenth

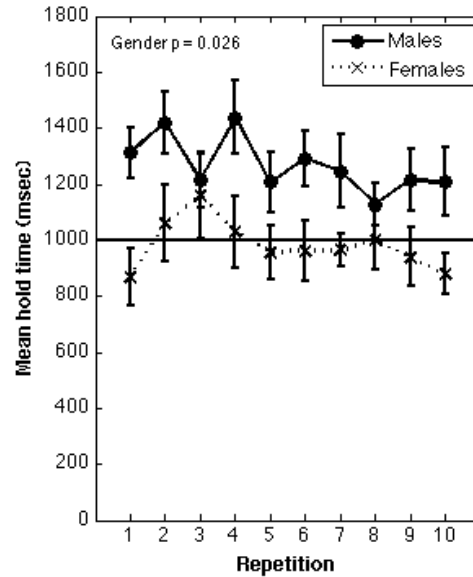


Figure 6. Mean hold time as a function of the repetition of a model sequence. Error bars show between-subjects standard error. This illustrates that males tend to hold each static gestures longer than females did, reflecting a female advantage at movement preparation; this is highlighted by the fact that the average hold time of the model was 1000 ms, which corresponds to the horizontal line at  $y = 1000$ .

repetition the primacy effect has disappeared (reflected by a flattening of the serial position curve) as subjects learn the later segments within the sequence (Figure 7, right). Gender's significant main effect on the serial order curves ( $F_{(1,16)} = 6.648, p = 0.02, \eta_p^2 = 0.294$ ) shows that the female advantage on the imitation of these sequences is independent of how familiar the sequence is (that is how many times the sequence has been repeated), and holds over the entire sequence (that is the shape of the curve is not altered by subjects' gender).

## Discussion

Our task requires a subject to view a sequence of gestures, and then reproduce this sequence, while paying attention to item information (i.e., what each component gesture in a sequence was) and also order information (i.e., the order that items occupy in a sequence). Performance on this task involves a series of computations, which are identified in Figure 1. Our analysis of subjects' performance exploited a battery of dependent measures, each believed to reflect a distinct computation. Overall, our results confirm the female advantage observed previously in the reproduction of hand movements (Chipman & Hampson, 2006), and extend this finding to the acquisition of novel movement sequences. In addition, the detailed spatio-temporal analysis afforded by our paradigm and analytical algorithm allows us to isolate the components of

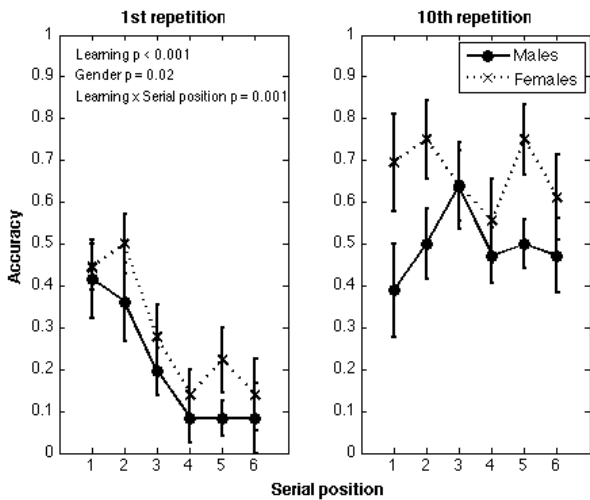


Figure 7. Serial position curves for the first (left panel) and last (right panel) repetition of a gesture sequence. Note that a higher value on the y axis represents increased accuracy. This data illustrates a large primacy effect for the first repetition, which disappears by the tenth repetition as subjects learn the latter gestures within the sequence.

gesture production where females are more efficient.

Our results show that males omit more gestures from their reproductions than females do (Figure 4). We believe that this difference reflects a female advantage at the level of individual items, that is, when it comes to gesture recall and selection. In addition to this generalized female advantage, females develop a further advantage over male participants as the sequences are learned. In particular, despite the fact that males produce more gestures as they view the sequences (Figure 3), they show no learning curve for gesture level errors (Figure 5); this shows that the additional segments they are attempting to imitate are produced with errors. Contrariwise, with successive repetitions of a sequence, females produce more gestures (Figure 3), and produce these with increased accuracy (Figure 5). The results with both omissions and gesture-level errors demonstrate a female advantage at the level of gesture recall and selection.

An analysis of the temporal data showed that males hold each gesture about 30% longer than females do (Figure 6). In the model sequence, each gesture was held for 1000 msec, which was very close to the female subjects' mean hold time. The male subjects, on the other hand, held each gesture for ~1300 msec, suggesting that they hesitated more than females did before initiating the next component in a sequence. We posit that this hesitation reflects difficulty with movement preparation, in other words generation of the motor command to move from one component gesture to another. One other potential explanation for this finding is that the males overestimated the time that the model held each of the gestures. We do not believe that this can account for this finding as we observed no

effect of gender on transition times and it seems unlikely that males would overestimate hold times but not transition times.

It is also important to consider the components of the task on which female subjects did not show an advantage. An analysis of the sequence-level errors shows no gender-related difference, suggesting that the female advantage is specifically associated with the reproduction of item information, and not with order information. We also found no influence of gender on the number of intrusions into a reproduced sequence. This suggests the general advantage that females enjoyed in our task cannot be accounted for by some advantage in monitoring and correcting the movement. Finally, we showed that females and males did not differ in their time taken to transition from gesture to gesture, which reflects movement execution. Overall, the dependent variables unaffected by gender suggest that the female advantage does not lie at the level of movement execution, or ordering.

The serial position results (Figure 7) also provide important insights into the gender differences in this task. Although the heights of the serial position curves show a general female advantage with item information, the shapes of those curves show no systematic difference between genders. This demonstrates that females' general advantage in performance does come from more accurate information about item order. The shapes of these curves may also be informative for understanding how subjects are learning the gestures, as they indicate that subjects first learn gestures that appear early in the sequence, and then build on this information as they learn gestures later in the sequence during later repetitions. Importantly, both males and females appear to use this strategy to learn the sequence.

We also examined visual feedback's influence on performance. In doing this, we were especially interested in how feedback might differentially influence acquisition of this task by males and females. A previous study with a different praxis task showed that males seem to rely more heavily on visual feedback than females do (Chipman et al., 2002). However, our results showed no such gender difference in the effect of visual feedback on behavioral performance. Our results did show that subjects took longer to transition between component gestures when visual feedback was available, presumably because they used the visual feedback to fine-tune the execution of their movements. Consistent with our behavioral data, an equal number of males and females reported that they found the feedback helpful.

Our task clearly calls upon multiple cognitive processes including perception, attention, working memory and motor skills. Therefore our results could reflect female subjects' advantage in one or more cognitive processes for which gender differences have been already demonstrated (for review, see Halpern, 2000). As a task like the one used here calls upon so many cognitive processes, it is difficult to isolate their independent contributions to the errors we observe. However, our data demonstrate that the female advantage on praxis tasks manifests itself in females' su-

perior motor selection and preparation, which is observed not only in the production, but also in the acquisition of praxic movements. By localizing the female advantage to particular sources of error, and illustrating that the advantage includes skill acquisition, it will be possible to develop strategies that could compensate for the male disadvantage(s). This development will be useful in optimizing neuro-rehabilitation programs, and in many other instructional settings as well. For example, an instructional strategy that gave stronger emphasis to encoding time might very well help to overcome males' disadvantage in recall, selection and response preparation. Future research in our laboratory will focus on strategies to improve male performance on praxis skills and the acquisition of such skills.

Our findings are consistent with reports of an anatomical difference in the organization of the system that supports the behavior tested in our study. In particular, Kimura (1983) has shown that apraxia is more often seen in females following left hemisphere lesions anterior to the central sulcus, whereas there is no anterior/posterior distinction for male apraxia patients. Our findings, taken together with Kimura (1983), suggest that the male disadvantage on praxis tasks arises from deficits with motor selection and movement preparation, functions that depend upon anterior neural regions. This position is supported by findings that indicate a role of the left premotor cortex in movement selection (see Rushworth, Johansen-Berg, Gobel, & Devlin, 2003, for a review). Our results also support some recent research demonstrating gender differences in the human mirror neuron system (Cheng et al., 2008).

To conclude, our results support Chipman and Hampson (2006)'s demonstration of a female advantage in the reproduction of gesture sequences. However, our results suggest that this female advantage operates at the level of motor selection and movement preparation, and cannot be accounted for by a gender-advantage on processes such as motor execution or sequencing. In addition, our results show that the female advantage on praxis tasks is not limited to well-learned movements; the female advantage extends to novel movement sequences, and to the acquisition of such sequences. This claim about the breadth of the female advantage is consistent with the demonstration of a female advantage on gesture imitation for non-representational gestures as well as everyday gestures in preschoolers (Chipman & Hampson, 2007). Our findings, along with this prior research, suggest that teaching strategies should take account of this gender difference. Moreover, future research might focus on ways in which the male disadvantage that we observed in motor selection and preparation could be compensated for. Finally, our data suggest that male and female apraxia patients may benefit from different rehabilitation techniques, and future research should attempt to isolate the best gender-sensitive strategies for rehabilitation.

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