A Left-Hand Advantage: Motor Asymmetry in Touchless Input

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ABSTRACT

Touchless gesture is a common input type when interacting with large displays or virtual and augmented reality applications. In touchless input, users may alternate between hands or use bimanual gestures. But touchless performance in nondominant hands is little explored—even though cognitive science and neuroscience studies show cerebral hemispheric specialization causes performance differences between dominant and nondominant hands in lateralized individuals. Drawing on theories that account for between-hand differences in rapid-aimed movements, we characterize motor asymmetry in touchless input. Results from a controlled study (n = 20, right-handed) show freehand touchless input produces significantly smaller between-hand performance differences than a mouse in pointing and dragging. We briefly discuss the HCI implications of motor asymmetry in an input type.

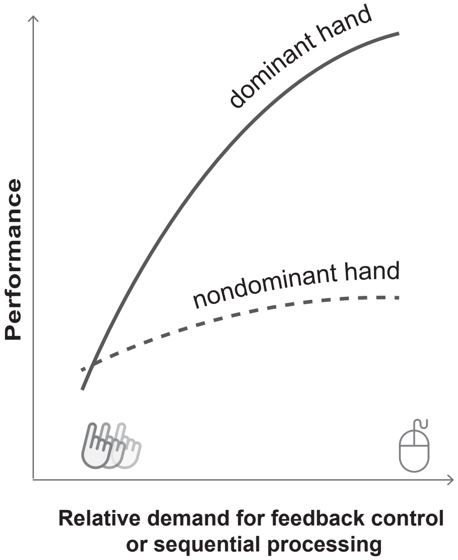

Figure 1: With all other conditions being equal, input types demanding more feedback control will have greater degradation between hands in lateralized users.

INTRODUCTION

Characterizing user performance of computer input devices is a hallmark of HCI research. Mouse, pen (or stylus), and touch input have been investigated extensively (e.g., [6]). Lately, user performance of (touchless) gestural input has been studied in different tasks, such as pan-and-zoom, data visualization, and text entry [8]. Notwithstanding its limitations, gestural input remains useful in interacting with

KEYWORDS

Touchless input; mid-air gestures; user performance; nondominant hand; motor asymmetry.

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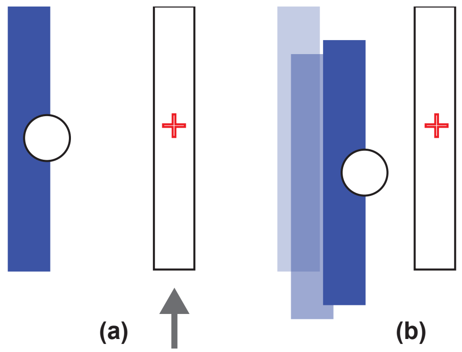

Figure 2: Participants (n = 20) performed one-dimensional reciprocal pointing (a) and dragging tasks (b) with mouse, stylus and touchless input using both hands.

Figure 3: Experimental setup.

large displays, virtual reality, and augmented reality [2, 8]. During these interactions, users may alternate between hands [7] or use bimanual gestures [1], which is why it is important to understand and characterize touchless performance in nondominant hands.

User performance in nondominant (or non-preferred) hands when using different input devices has been studied in the past. When comparing a mouse, trackball, and stylus, trackball had the least degradation across hands in pointing and dragging; and although the dominant hand was superior for small distances and small targets, between-hand performance differences almost disappeared for larger targets and larger distances, i.e., when the ballistic phase (little or not controlled by feedback mechanisms) increased [6]. Such a left-hand advantage in right-handers supports Todor and Doane's theory that "the performance of the nondominant hand mirrors the functional capacity of the contralateral right hemisphere" [10]. It is well known that the left hemisphere of the brain specializes in sequential processing while the right is dominant for parallel processing (Table 1). This notion of functional motor complementarity, i.e., the fact that the two hands of lateralized persons have complementary and specialized roles, is largely accepted in cognitive science and neuroscience [4, 10].

Table 1: Two types of movement control in skilled motor performance [4, 10].

Feedback control/ sequential processing	actions where feedback is processed to make corrective alterations; closed-loop
Preprogramming/ programmed control/ parallel processing	actions where a set of muscle commands are structured before a movement sequence begins allowing the entire sequence to be carried out uninfluenced by peripheral feedback; open-loop

In HCI, besides the task condition, the input type would also determine whether an action requires greater feedback control or preprogramming. For instance, touch input lacks the tactile feedback of a physical keyboard while device-less touchless gestures lack any haptic feedback and must rely solely upon visual feedback and proprioception. The lack of control or guidance due to insufficient feedback in touchless input has been deliberated extensively since its rise to (in)fame(y) (e.g., [8]). Hence, we argue that freehand touchless input demands more preprogramming or parallel processing than feedback control or sequential processing and would offer a left-hand performance advantage for right-handers when compared with other input types demanding greater feedback control.

Now although we argue a left-hand advantage in touchless input, it is unlikely to compensate its lack of guidance entirely that is available in other input types such as the mouse [5, 8]. However, within each input type, between-hand performance differences may be studied systematically to understand the relative demand for preprogramming and feedback control. On this basis, we hypothesize that touchless input will produce smaller differences between hands than a mouse or stylus (**H1**). H1 is tested for pointing and dragging (Figure 2) in a large-display setting (Figure 3).

METHOD

Twenty right-handed participants performed Fitts's one-dimensional (1D) reciprocal pointing and dragging task using their left and right hands. Participants were seated in a chair about 8 feet away from a high-resolution tiled large display–and was asked to rest their elbow on a table at all times (12 tiles, where each tile was 1366 x 3072 pixels with 75 x 75 DPI; Figure 3). A within-subject design was followed (details in the sidebar). As input modalities, we used a wireless mouse (Logitech M185), a Wacom tablet and stylus (Intuos Pro Medium), and a touchless pinch gesture (Figure 4).

Our touchless gesture recognition algorithm used marker-based tracking—passive infra-red markers and a VICON motion capture system. VICON is a sub-millimeter accurate tracking system and provides more reliability than off-the-shelf markerless sensor solutions such as the Kinect or Leap Motion. As we expected small-to-medium effect sizes, the apparatus was chosen to increase the internal validity of the experiment—while trading off some ecological validity. The control-display ratio was adjusted for touchless input: $CD_x = 3.5, CD_Y = 1$.

Experiments were conducted on two days, at least one day apart, with each participant using one hand a day. The order of hands, input types, and amplitude-width combinations were randomized, and tasks were counterbalanced using a Latin Square. Before logging data for the analysis, participants practiced with the three input types for about 10 minutes. Each experiment lasted for about 2 hours and was approved by the university-wide IRB. We calculated the effective Index of difficulty (ID_e) as: $\mathrm{ID_e} = \log_2\left(\frac{\mathrm{A_e}}{\mathrm{W_e}} + 1\right)$ with A_e as the actual distance traveled and W_e as 4.133 x SD_x. Throughput (TP) was calculated as: $TP = ID_e/MT$

RESULTS AND DISCUSSION

Empirical Results

Twenty right-handed individuals (7 females, M_{age} = 28.8, SE_{age} = 1.87) participated in the experiment. 75% had prior experience with touchless input; all participants were regular computer users. We report movement time (MT), throughput (TP), and error rate. As expected, MT was positively skewed and log transformed. Replications of unique experimental conditions were represented by their median. We used GLMM with standard repeated measures REML technique and handled participants as a random factor. We report *F*-statistic using type III ANOVA with *Satterthwaite approximation*, and pairwise comparisons (using pooled variance) with *Bonferroni* correction. *Holm-Sidak* tests on the block averages at each *hand x mode x task* revealed that the first block differed significantly than the rest, but the rest did not differ among themselves; so data from the first block were discarded. On the

Total Number of Trials

20 participants x
10 repetitions x
16 amplitude-width combinations x
3 input types x
2 hands x
2 tasks =

38,400

Study Design (within-subject)

Independent variables:
Input type (mouse, stylus, & touchless)
Task (pointing & dragging)
Hand (right & left)

Dependent variables reported:
Movement time (MT)
Error rate
Throughput (TP)
Effective width (W_e)

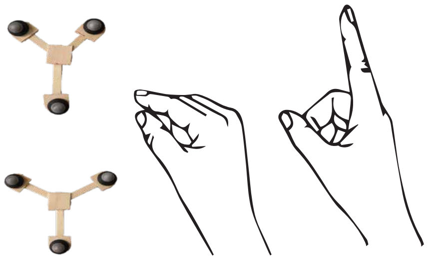

Figure 4: Pinch gesture; two IR markers were worn on the thumb and index finger.

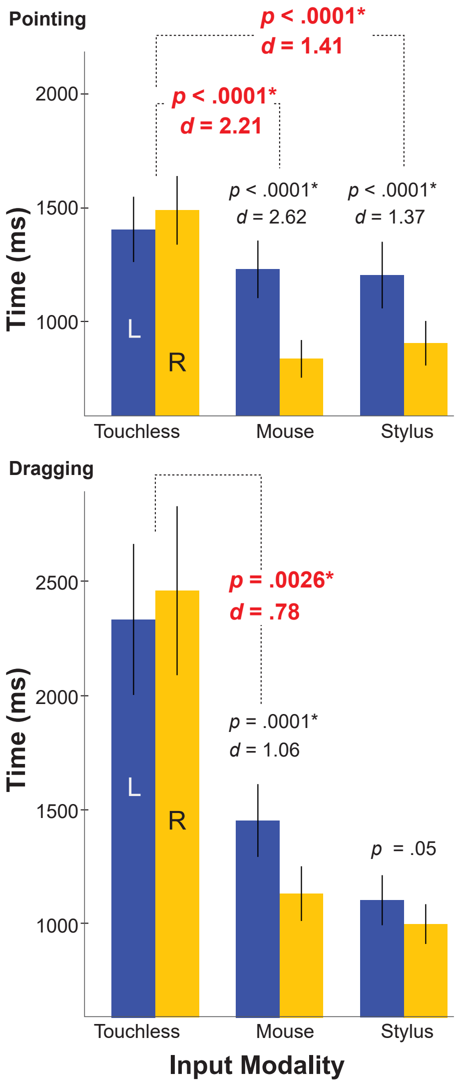

Figure 5: Mean MTs (error bars = 95% CI).

remaining data, outlier trials were eliminated following a multivariate analysis where values exceeded more than four times the *Cook's distance* from the mean [3]. Trials immediately following the deviate trials were also eliminated (see [9]). Overall, .0003% of the data were eliminated from the analysis.

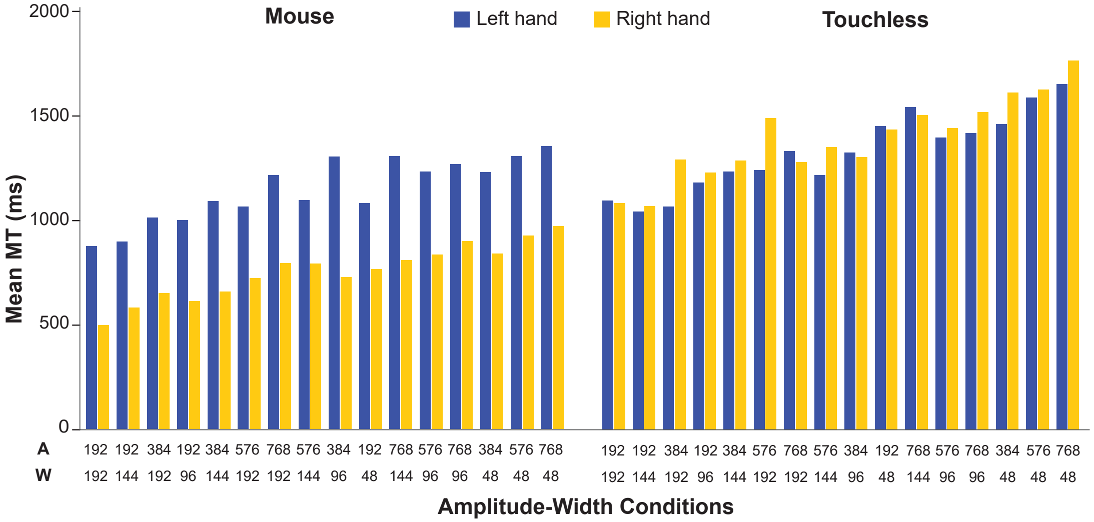

Figure 6: Mean MT (ms) by amplitude, width, and hand for pointing. Note the right-hand advantage for mouse and how it disappears for touchless input. Touchless performance in the nondominant hand was almost similar to the dominant hand in the pointing task.

Movement Time. A linear mixed effect model (LMM) found a significant main effect of INPUT TYPE $F(2, 209) = 192.48$, $p < .001$, TASK $F(1, 209) = 89.92$, $p < .001$, and HAND $F(1, 209) = 34.44$, $p < .001$ on MT. Significant interaction effects were found for INPUT TYPE x HAND, $F(2, 209) = 18.81$, $p < .001$, and INPUT TYPE x TASK, $F(2, 209) = 28.37$, $p < .001$. The overall effect size of the fitted model was large, $\Omega_0^2 = .78$. Planned comparisons found significant between-hand differences between mouse and touchless input, $t(39) = 7.52$, $p < .0001$, $d = 1.19$, and stylus and touchless input, $t(39) = 4.44$, $p < .0001$, $d = .70$ across pointing and dragging. But there was no significant between-hand differences between touchless and stylus input for dragging (Figure 5). Results supported **H1** for pointing and partially for dragging. Figure 6 shows a right-hand advantage in mouse but not in touchless for pointing. Figures 7 and 8 show how throughput varied across the effective index of difficulty (ID_e) for mouse and touchless input in the pointing task, respectively (W_e for mouse and touchless input in Table 3).

Table 2: Mean error rates (%).

Right Hand	Point	Drag	Both
mouse	3.5	10	6.75
stylus	6	13.5	9.75
touchless	23	32	27.50
M	10.83	18.50	14.67
Left Hand	Point	Drag	Both
mouse	5.5	19	12.25
stylus	15	21.50	18.25
touchless	24	26.5	25.25
M	14.83	22.33	18.58
Both Hands	Point	Drag	Both
mouse	4.5	14.5	9.5
stylus	10.5	17.50	14.00
touchless	23.5	29.25	26.38
M	12.83	20.42	16.63

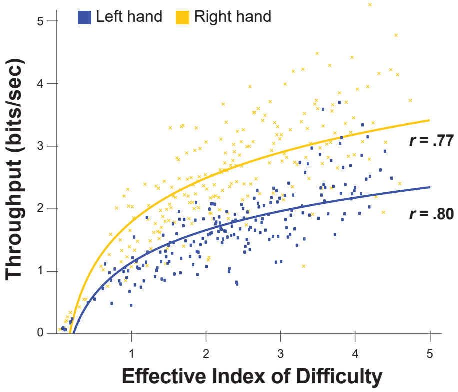

Figure 7: Mouse pointing performance.

Error Rate. Similar to MT, an LMM ($\Omega_0^2 = .44$) found significant main effects of HAND, $F(1, 209) = 5.33$, $p = .022$, INPUT TYPE, $F(2, 209) = 35.35$, $p < .001$, and TASK, $F(1, 209) = 19.96$, $p < .001$, and a significant interaction effect of INPUT TYPE X HAND, $F(2, 209) = 3.19$, $p = .030$. In support of **H1**, error rates between the right and left hand differed significantly for mouse, $Z = -3.15$, $p = .002$, $r = .50$, and stylus, $Z = -3.54$, $p < .001$, $r = .56$, but not for touchless (Table 2). As expected, both hands were more accurate during pointing than dragging. Interestingly, in touchless-dragging, the left hand was superior—similar to prior results for trackball-dragging [6].

Motor Asymmetry and Input Types: Implications for HCI

Implications for Research. When investigating between-hand performance differences in HCI, prior research mostly focused on different task conditions, e.g., systematically varying the relative demand for preprogramming and feedback control within rapid-aimed movements by varying target sizes and amplitudes [6]. Besides that, it is also important to investigate how motor asymmetry affects user performance of different input types differently—especially with the increasing variety of new input types, such as gaze or muscle activity. While cognitive science and neuroscience emphasize a functional motor complementarity between hands of a lateralized user, we hardly know the specific dimensions of motor activity that provides a dominant or nondominant hand advantage [4, 5].

The *input type* and *task condition* are two important factors that together decide the relative demand for preprogramming or parallel processing and feedback control or sequential processing, thereby producing either a left or a right-hand advantage in a specific interaction. For example, in tasks (pointing and dragging) of equivalent difficulty, right-handers showed a right-hand advantage for target width while a left-hand advantage for amplitude [6]. In our results, across pointing and dragging tasks of different difficulties, right-handers showed a right-hand advantage for mouse and a left-hand advantage for freehand touchless input (Figures 6, 7, 8, and 1). Further studies are needed to characterize how different input types offer advantages to different hands, both in right- and left-handed individuals.

Implications for Design. Now, why is it important to know whether a particular task and input type offers a right- or left-hand advantage? Knowing that can help us design interaction techniques that will leverage the complementary and specialized motor roles of the two hands in lateralized individuals. For instance, seminal HCI works explored and quantified the extent to which hand movements occur in parallel in two-handed tasks, thereby providing design insights for symmetric and asymmetric bimanual interfaces. More recently, [8] reported that in pan-and-zoom tasks, freehand touchless input is more efficient with bimanual gestures than unimanual gestures.

Exploring motor asymmetry in input types, particularly those fairly new, may help us design better interaction techniques, especially multimodal and bimanual techniques. For example, we could

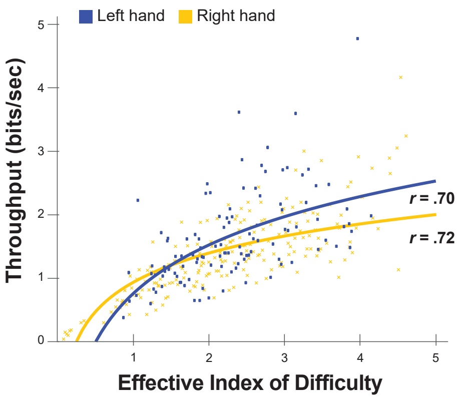

Figure 8: Touchless pointing performance.

Table 3: Mean effective target width (pixels) for mouse and touchless pointing.

Mouse	**Right Hand**	**Left Hand**
W = 48	48.74	47.81
W = 96	100.96	99.84
W = 144	149.78	148.22
W = 192	228.77	213.64
∀ W	131.85	127.38
Touchless	**Right Hand**	**Left Hand**
W = 48	50.17	48.01
W = 96	106.38	103.54
W = 144	161.18	153.06
W = 192	225.67	218.36
∀ W	135.85	130.74

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coordinate the hand advantage with a specific input type in a multimodal interaction technique to better performance, such as mouse or pen input in the right hand and touchless in the left hand.

CONCLUSION AND FUTURE WORK

We showed a left-hand advantage in touchless input for pointing and dragging compared with mouse and stylus. Touchless input or mid-air gestures have been shown to be generally less efficient than device-based input techniques [8]. We further characterize this efficiency between hands by drawing on motor asymmetry and handedness [4, 10]. Results do not suggest an overall advantage for touchless input when using nondominant hand over other device-based input techniques in pointing and dragging tasks. But both hands performed almost the same with touchless input—which can inform design decisions for bimanual or multimodal interaction techniques.

As future work, we plan to analyze the speed-accuracy trade-off in touchless input in both hands and test motor asymmetry in other tasks (e.g., pan-and-zoom, steering). Furthermore, these questions will need to be explored in the context of real-world activities, such as data visualization and mixed-reality environments.

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