Exploring Two-handed Indirect Multi-touch Input for a Docking Task

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ABSTRACT

To better understand the characteristics of two-handed indirect multi-touch input, we conducted a docking task experiment that asked participants to align two squares using one-finger dragging as well as two-finger pinch-to-zoom and rotation gestures in three conditions: (1) using the dominant hand only, (2) using the non-dominant hand only and (3) using both hands simultaneously. Our experiment was based on a conventional desktop computer setup, extended with a pair of tablet devices that were placed left and right of the keyboard. Most importantly, the results indicate that the two-handed condition yields the fastest results and the participants' actions exhibited Guiard's well-known principles of asymmetric bimanual interaction. Further, we observed that the performance of the non-dominant hand was on par with the dominant hand, suggesting that designers of two-handed multi-touch input techniques can assume a comparable level of dexterity for both hands.

CCS Concepts

•Human-centered computing → Interaction techniques; Gestural input;

Keywords

indirect touch; two-handed input; desktop computing

1. INTRODUCTION

Two-handed (or bimanual) interaction is a well researched topic within the field of human-computer interaction and it has been shown that carefully designed two-handed computer input can exhibit beneficial effects on both performance and cognition compared to single-handed input (e.g. [8]). While we cooperatively use both hands during a wide variety of real-life activities, two-handed command specification and invocation in desktop computing settings have been confined to certain patterns: both hands cooperate for text input and in the interplay of mouse input and modifier keys. This may largely be due to the still prevailing *WIMP* (Windows, Icons, Menus, Pointer) interaction model that fosters the role of indirect pointing devices providing a tracking state, such as the mouse or track pads.

Neither the rich history of research on (multi-) touch input, touchscreen devices and adequate interaction models, nor the commercial breakthrough of mobile touchscreen devices have had a major influence on desktop computing. While mobile touchscreen interaction models are based on one-handed input due to the necessity of a device-supporting hand (that still can be engaged for two-handed input techniques [13]), self-supporting interactive surfaces, such as tabletop displays, can naturally be operated by two (or more) hands. Prototypes like Curve [14] or the MagicDesk [3] exemplify how touchscreen technology integrated into the top of desks might transform the desktop computer, but they primarily demonstrate the technical feasibility of certain form factors. In particular, there is little evidence how such a transition of shape might be adequately reflected in new interaction models that ideally both exhibit backwards compatibility with existing software and support new input streams. For such future desktop workplaces, ergonomic considerations at least suggest the predominant use of indirect touch input to prevent physical discomfort (i.e. arm fatigue, stiff neck).

Available touchpads such as the Apple Magic Trackpad already support indirect multi-touch gestures that extend the available input vocabulary, allowing high-bandwidth direct control of specific functions (e.g. two-finger zooming in documents). Extending desktop computer setups with larger horizontal interactive surfaces opens up new design possibilities to support this input channel in more flexible ways, e.g. for tasks that involve many modes and degrees of freedom

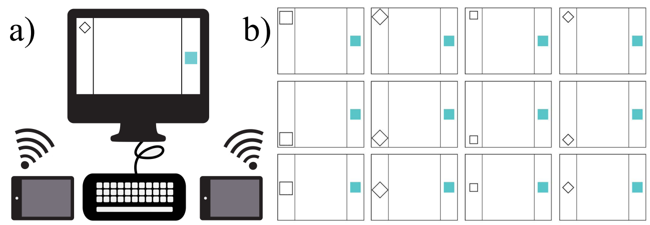

Figure 1: a): overview of the experimental setup. b): the 12 different docking tasks for right-handed and two-handed input. For left-handed input, the layout was flipped.

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such as 3D manipulation (e.g. [10]). Particularly, a systematic understanding of our hands' ability to both individually and cooperatively perform well-established two-finger touch gestures can inform the design of new two-handed indirect touch input techniques that go beyond known bimanual interaction setups based on specific input devices.

In this paper, we present the result of an experiment during which we extended a standard desktop computer with two tablet devices placed left and right of the keyboard in order to explore our hands' ability to perform a 2D rectangle docking task both individually and cooperatively. The task required participants to align one square with another one by means of translation (one-finger drag), scaling (two-finger pinch) and rotation (two-finger rotation). In particular, the results indicate that

- participants perform the docking task with their non-dominant hand as fast as with their dominant hand,
- performing the task with both hands cooperatively yields a significantly faster performance than single-handed input,
- the two-handed input follows Guiard's principles of asymmetry [7].

2. RELATED WORK

Since Buxton's first demonstration of two-handed input's potential benefits [5] – gathered in an experiment similar to ours – a lot of research on bimanual interaction has been conducted. Guiard's three principles on asymmetric division of labor in bimanual action [7] have informed the design of many two-handed interaction techniques (e.g. [8, 2, 4]): (1) the non-dominant hand's actions precede and (2) set the frame of reference for the dominant hand's actions, and (3) the hands operate in different spatio-temporal scales. In contrast, symmetric bimanual actions describe tasks that assign equivalent roles to each hand and suit certain computer tasks well (e.g. [1]). Multi-touch input introduces a further complexity: while many studies on bimanual input assumed two single-point input devices (e.g. mouse, stylus, puck, finger), two points of input are easily provided by one hand (e.g. pinch gesture). In this regard, Moscovich and Hughes [9] provide insightful details on the relation of visual task perception and adequate indirect touch input mappings.

Indirect touch input can mitigate shortcomings of direct touch, e.g. occlusion, reachability or fatigue [9]. However, the technology-inherent lack of a tracking state challenges its application as general purpose input modality especially for novel settings: Schmidt et al. [11] used surface-hovering to emulate tracking which was complex to coordinate and led to a decreased performance compared to direct touch. Voelker et al. [12] evaluated several alternative state-switching methods allowing to rest arms and fingers on the surface for tracking and found lift-and-tap to be most promising.

3. EXPERIMENT

The goal of our experiment was to explore the characteristics of two-handed indirect multi-touch input applied to a desktop computing environment. Moscovich and Hughes [9] findings show that for a square docking task, the integral control of position, scale and orientation with one-handed two-finger gestures is superior compared to using one finger of each hand. Therefore, we were interested how non-dominant hand input able to integrally control the target square's position, scale and orientation influences docking task performance. To capture two-handed multi-touch gestures, we used a pair of tablet devices that resemble the touch input areas suitable for desktop computing proposed by Bi et al. [3]. Based on Guiard's principles of asymmetric bimanual cooperation [7], we formulated the following hypotheses:

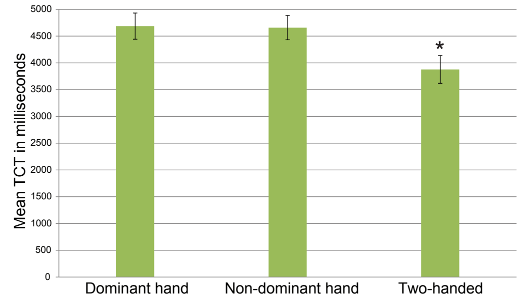

Figure 2: Mean task completion times per input condition. Error bars indicate SEM.

H1 Two-handed multi-touch input will result in the fastest docking task performance.

H2 Two-handed multi-touch input follows the principles of Guiard's kinematic chain model.

3.1 Participants

We recruited 20 participants (11 female) aged from 20 to 37 (mean = 23.85, SD = 3.53). All participants were right-handed, students and used touch input devices on a daily basis. Their participation was compensated either with a voucher for an online retailer or extra credits for their study program.

3.2 Task and Conditions

Our experiment was based on a simple docking task, which is a well-established task in research on multi-degree-of-freedom input devices. It asked participants to repeatedly align a given turquoise starting square with a target square by means of translation, scaling and rotation. Translation was controlled by one-finger dragging gestures, scaling and rotation by two-finger pinch and rotation gestures. Participants performed the docking in three conditions: using their dominant hand only (*DH*), using their non-dominant hand only (*NDH*), and using both hands cooperatively (*2H*). In the two-handed condition, both starting and target square could be manipulated simultaneously: the left hand could control position, scale and orientation of the left square and the right hand controlled the right square accordingly. In the one-handed conditions, only the starting square was manipulated. We used a relative mapping and a linear transfer function with a gain factor of 1.

The starting square always had the same position, size and orientation and was vertically centered on one side of the display. The target square was displayed on the other side of the display and varied in position (top, middle, bottom), size (large, small) and orientation (0°, 45°), resulting in 12 distinct target squares. To enable a consistent measurement of task completion time, two vertical lines marking a starting and target area were displayed and time measurement started only as soon as one rectangle had passed its corresponding line (figure 1 b). To ensure perceptual compatibility – a decisive factor for the design of bimanual input techniques [9] – the visual task layout always allowed a clear hand-to-square correspondence, i.e. in the one-handed condition the starting square was always displayed on the side of the manipulating hand.

In the two-handed condition, the task could only be completed once both rectangles had crossed their corresponding lines, in order to enforce the use of both hands. We measured task completion time as the time from initial line crossing (either starting or target square in *2H*) until successful square alignment. For the square alignment itself, we introduced an accuracy threshold that recognized the alignment as successful as soon as 95% congruency was reached for translation, scale and rotation of both squares. Further, we recorded the screen location, square properties and the input source of the successful alignment.

3.3 Experimental Setup

The experimental setup consisted of a standard desktop computing system comprising an Apple Mac Mini, a 23 inch Dell monitor with full HD resolution (ST2340) and a conventional QWERTY keyboard. Further, we used two 7 inch Samsung Galaxy Tab 2.0 tablet devices running Android 4.0 as additional multi-touch input surfaces (figure 1 a). The tablets were placed to the left and right of the keyboard and allowed participants to perform the touch gestures while resting their forearms on the desk. Participants were seated in front of the monitor and were able to adjust the height of the chair in order to achieve a comfortable position.

The docking task implementation consisted of two applications: (1) an Android application displayed a blank white screen, detected touch gestures and sent them via Open Sound Control messages to (2) a JavaFX application running on the Mac Mini responsible for generating the visual display for the docking task and logging data. In particular, the JavaFX application received and interpreted the touch gesture data from the tablets and accordingly updated the position of both starting and target square and logged timestamps, input sources (left and right tablet) as well as square positions, sizes and orientation.

3.4 Procedure

We designed a within-subjects repeated-measures experiment with input technique as independent variable with the levels *DH*, *NDH* and *2H*. Participants started with their right hand, continued with their left hand and ended with the two-handed condition. Each participant had to perform the 12 individual dockings (figure 1 b) 4 times per input technique, resulting in 4 blocks of 12 dockings in randomized order for every input condition. For each condition, we regarded the first two blocks as training and used only the last two blocks for data analysis. Therefore, our data analysis is based on 480 invidual dockings per input condition (2 blocks x 12 dockings x 20 participants).

In the beginning of the experiment, we collected demographic data via an online survey. To assess workload, participants filled out a raw (unweighted) NASA TLX questionnaire after each input condition, which is less time consuming than the original NASA TLX and yields comparable results [6]. Upon completion of the experiment, we shortly interviewed the participants. Particularly, we asked them for their preferred input condition, for a performance self-assessment as well as for their final assessment of mental demand. Overall, the experiment lasted about 30 minutes.

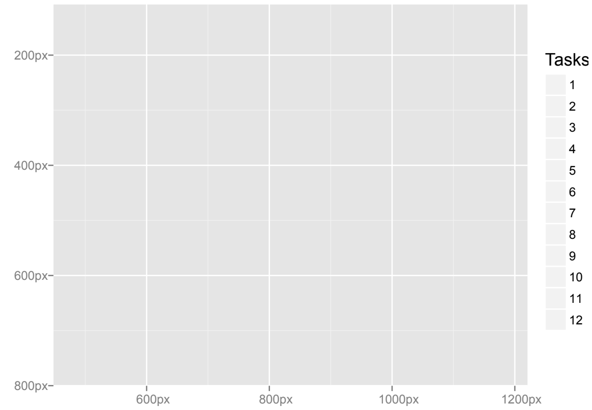

Figure 3: Successful square alignment locations in screen pixel coordinates per docking (detail).

3.5 Results

3.5.1 Task Completion Time

The mean task completion time per docking was 4686.9 ms (SD = 1096.5) for *DH*, 4658.6 ms (SD = 1014.12) for *NDH* and 3877.27 ms (SD = 1156.67) for *2H* (see figure 2). A repeated measures ANOVA with a Greenhouse-Geisser correction determined that task completion times differed significantly between input conditions ($F(1.770,33.63) = 8.930$, $p < 0.005$). Post hoc tests using the Bonferroni correction revealed that *2H* resulted in a significantly faster mean task completion time than both *DH* ($p = 0.002$) and *NDH* ($p = 0.018$). No significant difference was observed between *DH* and *NDH*.

3.5.2 Square Alignment

In order to investigate Hypthesis 2, we analyzed the square manipulations for *2H* in more detail. From the 480 dockings performed in this condition, 390 were concluded by the dominant and 90 by the non-dominant hand. Further, we observed that most of the participants first moved the target square with the non-dominant hand towards the starting square and subsequently performed further adjustments of position, scale and rotation with the dominant hand. This procedure can also be observed in figure 3, where we plotted the screen coordinates of the successful square alignments. It shows that a large part of the distance between the squares is covered by left hand movements and that the final alignment occurs in the center of the display, at a vertical position similar to the starting square's initial position. These findings indicate that participants operated in concordance with our assumptions based on the Kinematic Chain Model: the non-dominant hand's action precedes the dominant hand's action and is responsible for coarse manipulations used to frame the more fine-grained manipulations of the dominant hand.

3.5.3 Workload and Subjective Data

The results of the Raw TLX questionnaire indicate that *2H* causes most workload (3320 points), closely followed by *NDH* (3315 points). *DH* causes least workload (2785 points). These ratings are reflected by the users' subjective assessment of mental demand in the concluding interviews: half of the participants (n = 10) stated that *2H*, almost the other half (n = 9) that *NDH*, and one that *DH* was most demanding for them. Vice versa, 15 participants stated that *DH* was least demanding (n = 3 for *2H*, n = 2 for *NDH*).

The question for personal preference revealed that *2H* is preferred by 16 and *DH* by 4 participants. Vice versa, 15 participants indicate that *NDH* as least preferred condition, followed by *DH* (n = 3) and *2H* (n = 2).

The self-assessment of performance shows that 10 participants think they performed best with *DH*, followed by *2H* (n = 9) and *NDH* (n = 1). Vice versa, 14 participants thought they performed worst with *NDH*, followed by *2H* (n = 4) and *DH* (n = 2).

4. DISCUSSION AND FUTURE WORK

First of all, the results of our study suggest to confirm H1: two-handed input resulted in the shortest task completion times. This is in line with the related work and was expected, but goes beyond previous findings by indicating that one-handed input performance for continuous multi-degree-of-freedom input (e.g. two-finger pinch and rotation gestures) can still be increased by employing the second hand, at least as long as the task's visual feedback exhibits perceptual compatibility. In previous studies, the choice of input devices often reflected the underlying concept of bimanual cooperation: two different input devices were used for asymmetric roles in Guiard's sense and two identical ones for symmetric two-handed input. In our case, the input devices and indirect touch mappings were identical for both hands, but still we observed that participants operated the task in an asymmetric fashion – which supports H2. This strengthens the importance of task nature for the cooperative roles of our hands. Indirect touch seems to be a promising modality for this matter as it does not confine the hands' roles or gesture vocabulary, and thus allows flexibility to oscillate between symmetric and asymmetric styles. This is crucial to account for the wide variety of tasks and the still not well-understood nuances decisive for the choice of adequate indirect touch mappings [9].

We attribute the strong preference for the two-handed condition to a novelty effect – in combination with the workload ratings and mental demand assessment, the results suggest that, although input with the non-dominant hand and with two hands increases mental demand, the increase is not high enough to decrease performance. In particular this indicates that the operation of simple and well established touch gestures can be transferred to the non-dominant hand and that two-finger gesture input of the dominant hand can be extended with one-finger touch input gestures from the non-dominant hand without exceeding cognitive abilities.

We address two limitations of our experiment: first, we did not counterbalance the order of input techniques. Due to the simplistic nature of the docking task, the training for each condition and the randomization of task order, we did not expect learning effects between input conditions. Second, we acknowledge that moving two squares simultaneously is a disputable comparison to one-handed input with equal translation distances. The reason for this was that we aimed to find out how parallel indirect multi-touch input and the resulting motor and cognitive efforts would affect the task completion time in the case of 2D docking.

Future experiments could explore characteristics of symmetric multi-degree-of-freedom input more systematically by investigating tasks that strictly require two-handed two-finger input. Moreover, our experiment involved only a linear transfer function without gain – little is known about how established non-linear transfer functions affect two-handed input techniques.

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