Orientation Matters: Efficiency of translation-rotation multitouch tasks

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ABSTRACT
The translation and rotation of objects with two fingers is a well explored multitouch technique. However, there are some unsolved questions regarding the optimal conditions under which this technique functions best. Does it matter in which direction the movement is oriented? Does parallel or sequential performance of the two operations work best? This study attempts to answer this question using a typical Fitts' Law setup but with varying translation-rotation orientation combinations. The results show that right-oriented movements were faster and easier than left-oriented ones. Movement combinations which went in different directions (translation right, rotation left, and vice versa) were found more tiresome and resulted in more strategy switches compared to equi-directional combinations. Our findings can inform positioning decisions in interaction design and contribute to theoretical adjustments to Fitts' Law.

Author Keywords
Multitouch interaction techniques, Fitts Law, 2D translation and rotation

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

General Terms
Human Factors; Design; Measurement.

INTRODUCTION
Research on multitouch interaction techniques has resulted in many significant findings, especially for fundamental operations like translation and rotation, either in two dimensions (cf. Rotate'N Translate [7]) or three dimensions (cf. Sticky Fingers [3], Screen-Space [10]), DS3 Depth-Separated Screen Space [9]).

However, there are open questions regarding the optimal usage conditions and execution strategies. Translation and rotation can be either performed in parallel or sequentially which is often examined with matching or docking tasks. Parallel execution is essential for applications where multiple degrees of freedom must be orchestrated (e.g. in real-time character animation) [6, 13, 14]. However, in other contexts studies suggest that a clear separation of translation and rotation, i.e. performing the operations sequentially, is more intuitive and easier to use [9, 12]. Most studies evaluate the interaction with specific tasks or applications such as moving or translating images or other objects [10] or controlling and moving an arm of a virtual puppet [6]. This context specificity makes it hard to generalize the results.

In contrast, several studies devised abstract task designs based on the original work by Fitts. The aim was to extend or adapt Fitts' law for special conditions (e.g. from 1D to 2D or for finger touch input) [1, 8, 2]. Hoggan et al. conducted a study where the angle, direction, diameter (distance between index-finger and thumb), and position of rotations were systematically manipulated [5].

Stoelen and Akin show that rotation and translation have the same difficulty and complexity which may indicate that parallel execution is efficient [11]. They used a magnetic sensor system instead of multitouch. In this study, 12 out of 13 participants performed the combined movements in parallel, and 1 performed them strictly serially. A reason for the often parallel excution could be the fixed configuration in terms of movement direction: translation was always to the right, rotation always counter-clockwise. It is possible that changing the orientation of these operations (translation to the left, rotation clockwise) modulate the results which may in turn explain the inconsistent research finding with regard to parallel vs. sequential execution.

Our study intends to fill a gap in existing work by systematically examining the effects of combining translation and rotation under varying conditions and looking at execution strategies by the users. We took Stoelen and Akin's experimental design and varied movement direction. We evaluated performance, subjective impression and choice of strategy. We consider our work a puzzle piece in the search for theoretical models that explain and predict such conditions.

EXPERIMENT
We designed an experiment where participants had to move objects to a target position using 2-finger translation (left or right) and rotation (clockwise or counterclockwise), where the index finger was assumed to be the pivot for rotation. For

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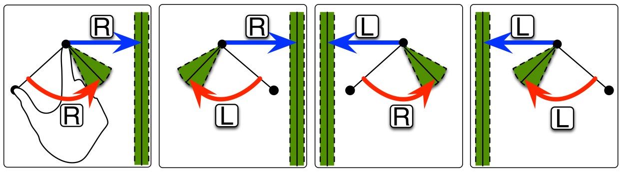


(a) RR (b) RL (c) LR (d) LL

Figure 1: Four tasks - the blue arrow shows the translation direction, the red one the rotation direction

investigating the effect of different movement orientations we devised four variants of the basic task (Fig. 1):

(a) *RR*: Translation right, rotation right (counterclockwise)

(b) *RL*: Translation right, rotation left (clockwise)

(c) *LR*: Translation left, rotation right (counterclockwise)

(d) *LL*: Translation left, rotation left (clockwise)

Here, 'rotation right' means that the thumb moves to the right (same for 'rotation left') which makes sense when comparing whether translation-rotation is performed in the same direction (equi-directional: RR, LL) vs. in different directions (counter-directional: RL, LR).

Apparatus

We used a 22-inch multitouch screen (3M model M2256PW) with 1680x1050 pixels and <6ms touch response time, positioned in front of the subject on a low table. The screen was titled 50 degrees relative to a vertical display which was found optimal in a pre-study about visibility and comfort.

Participants

16 participants (7m, 9f), aged 21–31, were recruited via notice boards, facebook and email lists and were paid 8 EUR. One was left handed, all others right handed. The left-handed one used the mouse with his right hand. In our questionnaire participants said to have experience with single- or multitouch devices. Eight used such devices often or very often, the other eight rarely or very rarely.

Experimental Design

In our experiment participants had to move an object (circle plus line) into a target translation zone and rotation zone, both colored green. The object had to be dragged with the index finger into the green target translation zone, depicted by a center line with dashed boundary lines. We define the distance as shortest path from the circle to the center line. For rotation, a line that is attached to the circle had to be rotated with the thumb into a green rotation zone (see Fig. 1).

All participants performed all four task variants. We generated 16 different task configurations (two distances, two target rotations and two tolerance levels). We decided to use only two values for translation and rotation to keep the experiment feasible. A similar design was used by Hoffman et al. [4] and Stoelen/Akin [11] who also used 16 configurations. The difficulty of each configuration (Table 1) was measured

Translation			Rotation		
Distance	**Tolerance**	**ID**	**Angle**	**Tolerance**	**ID**
± 12.7 cm	0.8 cm	4.08	± 50°	4°	2.18
± 4.8 cm	0.8 cm	2.81	± 50°	12°	1.12
± 12.7 cm	1.6 cm	3.16	± 130°	4°	3.35
± 4.8 cm	1.6 cm	2.00	± 130°	12°	2.02

Table 1: Configurations with ID (index of difficulty).

using the Index of Difficulty (ID) with the Shannon formula because it always gives a positive rating for the index of task difficulty [8]. Each participant did 256 trials (each configuration repeated 4x). Trial order was balanced across subjects using a Latin Square design.

Procedure

All participants completed a practice phase with 48 trials up front. In the actual study, 256 configurations were presented in 4 blocks of 64 trials each with a 15-second break between blocks. Participants could make additional breaks at any time.

The subjects were instructed to perform the task as quickly and as error-free as possible. During practice the error rate was displayed to make the participants more aware of their current performance and to motivate them to reduce errors. During the actual study, the error rate was not displayed.

A trial was started when the finger touched the cursor on the multitouch screen. Then, the color of the objects on screen changed from white to blue when the first finger touched the first cursor. They became green when the second finger touched the second cursor. Time measurement started when objects were actually moved. In the pre-studies we fixed the finger distance but the participants wished for more flexibility because a fixed distance can lead to uncomfortable poses, so that the finger is lifted which caused errors.

One trial ends as either (1) **success**: object is in the target zone when fingers are lifted. A green check mark appears and an high tone is played. (2) **error**: object is outside the target area when fingers are lifted off. A red cross mark appears and a low tone is played, (3) **interruption**: a finger is lifted without moving the cursor. A yellow exclamation mark appears and a sound is played. The interruptions were logged but were not counted as errors to avoid counting unintentional interruption. Some participants e.g. touched the cursors and lifted the finger immediately to dry their fingers.

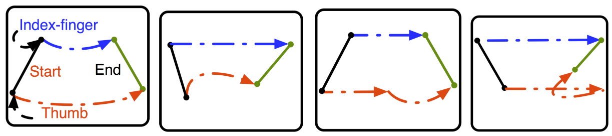
In case of error/interruption the participant repeated the trial. After the experiment, the participants completed a questionnaire. Each session took between 25–60 min.

Hypotheses

This experiment was designed to test two hypotheses:

1. Interactions with translation to the right are faster than ones with translation to the left

2. Interactions with the same direction for translation and rotation (equi-directional) are faster than interactions with different directions (counter-directional)



(a) RR (b) RL (c) RR (d) RL

Figure 2: Expected strategies for parallel (2a, 2b) and sequential (2c, 2d) execution with translation first for movements with translation to right. We expected the mirrored version of these strategies for movements with translation from from right to left. The black line indicates the start position of index-finger (top) and thumb (bottom). The green line the end positions.

On top of this, we wanted to explore the strategies the participants would use to perform the tasks. We expected two main categories (see Fig. 2):

1. Parallel strategies (a, b)

2. Sequential strategies: with the two subcategories *translation first* (c, d) and *rotation first* (looks like c, d but with reversed direction of the arrows).

Results

Performance

Task RL was performed fastest (M = 2.45s, SD = 0.85), followed by RR (M = 2.51s, SD = 0.77). Slowest was LL (M=2.89s, SD=1.08) after LR (M=2.60s, SD=0.96). A multivariate analysis of variance MANOVA on execution time shows a significant main effect for translation direction, with right-oriented translation being faster than left-oriented ones, $F(1, 15) = 15.01, p < .001, \eta^2 = 0.50$. Neither the main effect for rotation nor the interaction between translation and rotation were significant, both $Fs(1, 15) < 2.59, ps > .13, \eta s^2 < 0.15$.

Used strategies

To identify the used strategies motion paths were manually analyzed and discussed with at least two people. We agreed on five strategies (examples in Fig. 3). Remember that, by default, participants should use the index finger for translation and the thumb for rotation (around the index finger).

1. *Parallel*: parallel execution of translation and rotation.

2. *Parallel-Changed-Pivot*: rotation was performed around the thumb instead of the index finger, achieving translation and rotation simultaneously with little effort.

3. *Sequential-Trans-Rot*: translation of both index finger and thumb and a final rotation around the index finger.

4. *Sequential-Rot-Trans*: first a rotation, then the translation.

5. *Sequential-Rot-Trans-Rot*: a rotation, a translation and a final rotation.

Distribution of strategies

The main strategy for LL was the sequential strategy *Sequential-Rot-Trans* (52% of all trials for LL was performed with this strategy). But for configurations with a small rotation *Parallel* was preferred (51%), for large rotations *Sequential-Trans-Rot* was the most common strategy (62%). For RR the participants worked more in parallel and used the strategy *Parallel* in 56% of the trials. However the second most common case for RR was *Sequential-Rot-Trans* (26%).

For the counter-directional movements RL and LR the participants switched more between strategies. The main strategies for RL and LR were *Parallel-changed-Pivot* (42%), *Parallel* (18%), *Sequential-Rot-Trans* (42%). *Sequential-Trans-Rot* and *Sequential-Rot-Trans-Rot* was used very rarely (4% and 0.2%). In LR *Parallel* was used five times more often for short translation movements (20%) than for long translation movements (4%).

The most commonly used strategy for long distances in RL was *Parallel-Changed-Pivot* (60%). In contrast *Parallel* was used just in 8%. But for short distances *Parallel* was the most used strategy (42%) and *Parallel-Changed-Pivot* the second fewest (26%).

Strategy switching

As an indicator for task complexity we measured the average number of different strategies a user would utilize per task across trials. For the counter-directional RL, for example, participants used 2.48 strategies on average. In contrast, for the equi-directional RR they just used 1.7 different strategies. The complete order was 1. RL (2.48), 2. LR (1.94), 3. LL (1.77) and 4. RR (1.70). In a one-tailed t-test the counter-directional tasks RL and LR showed significantly more strategy switching than the equi-directional tasks LL and RR ($t(15) = 3.79, p < 0.005$).

DISCUSSION

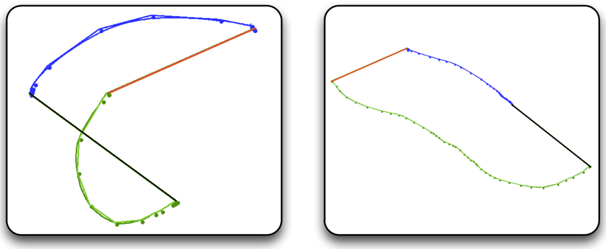
This experiment indicates that right-oriented movements were performed faster than left-oriented movements. One possible explanation for this phenomenon could be the right-handedness of all participants except for one and also the habit of reading and writing from left to right. To our surprise the participants used two strategies we did not expect:

1. *Parallel-Changed-Pivot* (see Figure 3a) was used for counter-directional tasks RL (43%) and LR (51%). Changing the pivot finger to rotate around the thumb may have been more economic in certain configurations.

2. *Sequential-Rot-Trans-Rot* (see Figure 3b) was used in a few cases.

Right-oriented movement are also found easier and less tiresome than left-oriented ones. In the questionnaire, participants found that LL was the hardest and most tiresome task, followed by LR. RL and RR were the easiest and least tiresome tasks. For RR the participants used mostly parallel strategies, whereas for the other cases the used sequential strategies. It seems to be clear that right-oriented movements yielded better performance and subjective judgment than left-oriented ones.

In terms of strategies, an interesting observation is that *Sequential-Trans-Rot* was used just in 8% of the trials. On



(a) *Parallel-Changed-Pivot* in a LR-movement (b) *Sequential-Rot-Trans-Rot* (RR)

Figure 3: Path of the unexpected used strategies.

the other hand *Sequential-Rot-Trans* was used in 35% of the trials. It seems to be preferable to rotate first. Looking at strategy switching, counter-directional movements showed much more switching. This could be an indication for the higher complexity of this kind of task so that participants are uncertain which strategy is the best one.

CONCLUSION AND FUTURE WORK

Our study explored the conditions under which a combined translation-rotation movement with a common 2-finger multitouch technique performs well and which execution strategies are used. We found two effects. First, right-oriented movements were performed faster and perceived as easier than left-oriented ones. Second, counter-directional combinations (translation right, rotation left, and vice versa) were found more tiresome by users and resulted in more strategy switches compared to equi-directional combinations.

These findings could guide interaction designers when deciding on placement of interactive elements, or make performance predictions about existing interfaces. Adaptable interfaces could use our results to automatically adjust interface elements, their parameters (rotation gain) or the view perspective to optimize conditions for translation-rotation.

How can these findings be used to adjust Fitts' law? We suggest to introduce a weights α that modifies the Index of Difficulty (ID) part of the formula (similar to [1]). α indicates the difficulty of movement direction with $\alpha > 1$ for left movements and $\alpha < 1$ for right movements.

$$MT = a + blog_2 \sqrt{\alpha \left(\left(\frac{A_t}{W_t} \right)^2 + \left(\frac{A_r}{W_r} \right)^2 \right)}$$

with A_t for translation distance and W_t for translation tolerance (A_r and W_r for rotation), assuming equal difficulty for translation and rotation. We intend to investigate the precise relationship between translation and rotation difficulty in the future.

Another future issue is the question of how handedness influences our findings which can only be held valid for right-handed people for the moment.

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