Exploring Pinch and Spread Gestures on Mobile Devices

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ABSTRACT
Pinching and spreading gestures are prevalent in mobile applications today, but these gestures have not yet been studied extensively. We conducted an exploratory study of pinch and spread gestures with seated participants on a phone and a tablet device. We found device orientation did not have a significant effect on gesture performance, most pinch and spread tasks were completed in a single action, and they were executed in 0.9-1.2 seconds. We also report how participants chose to sit with the mobile device, variations in gesture execution method, and the effect of varying target width and gesture size. Our task execution times for different gesture distances and precision levels display a surprisingly good fit to a simple Fitts's Law model. We conclude with recommendations for future studies.

Author Keywords
Multi-touch gestures; mobile devices.

ACM Classification Keywords
H.5.2. User Interfaces: Theory and methods

General Terms
Human Factors

INTRODUCTION
Pinch and spread gestures are standard methods of zooming in and out on mobile touch screen devices, but have not been as thoroughly studied as tapping actions. Pinch and spread gestures are important for many reasons, e.g., zooming is critical to viewing large volumes of data on small screens, and some mobile UIs present text and widgets that need to be enlarged before they are accessible. We believe that understanding how people perform pinch and spread gestures on today's mobile devices can inform the mobile UI designs of the future.

To date, there has been little formal examination of pinch and spread gestures on mobile touch-screen devices. We begin to fill this gap by observing participants performing pinch and spread tasks of systematically varied difficulty on both a mobile phone and a tablet. Our participants were seated, but were free to hold and operate the devices in any way they chose, giving us insight into the variety of methods for pinch and spread.

This paper makes two contributions. 1) We present a detailed description of pinch and spread performance on both phone and tablet devices while seated in terms of observed methods, performance time, actions used and overshooting. 2) In an unexpected result, our execution time data were surprisingly well fit by a simple Fitts's Law model. These results have implications for design, training, and predictive performance modeling.

RELATED WORK
Pinch and spread gestures are a standard method of zooming in and out on iOS- and Android-based devices [2,3]. However, they have been most thoroughly studied in the context of large touch-screen surface tables [17,18,21,22,23]. Wobbrock, Morris and Wilson [21] investigated which gestures are most comfortable and intuitive to use for scaling. They created a user-defined gesture set by showing participants an interface effect and asking them to perform the gesture they thought should cause that effect. Scaling actions were performed in several ways: with two palms; two fingers on separate hands; pinching with the thumb and index finger on one hand; and splaying the fingers of one hand outward. This suggests that the pinch action is fairly intuitive. Wobbrock et al. observed that people used reversible gestures for paired actions such as shrink/enlarge, previous/next, zoom in/out, etc.

In general, Wobbrock et al. found that participants did not have a preference for the number of fingers used; however, the use of one hand was preferred over two when performing scaling actions. Ringel Morris, Wobbrock and Wilson [15] found that participants preferred performing gestures that were physically easy and/or less cognitively demanding. They found that use of a single finger was preferred over an entire hand.

Given the small form factor of mobile devices, gestures used on table surfaces may not directly translate onto mobile devices. In a survey, Karlson, Bederson and Contreras-Vidal [10] found a preference for both holding and operating mobile devices with the same hand instead of holding the mobile device in one hand and touching the screen with the other. This preference arose from the need to carry items or interact with the physical environment (e.g. open a door). Pinch and spread gestures require one hand to perform the gesture and the other to hold the device, so do not fit well with users' preferred one-handed interaction mode.

Chourasia et al. [6] explored the effect of sitting versus standing on the use of a mounted touch screen in a button tapping task, finding no difference for targets > 20mm. For smaller button sizes, slower performance and more errors were found while standing.

Tradeoffs between the benefits of larger targets, and provision of space for on-screen information are prominent in mobile design. Parhi et al. [16] observed that mobile interface toolkits rooted in stylus-based interactions can encourage interfaces with targets that are too small to be hit reliably with the thumb. Using larger targets leaves space for fewer widgets. Zooming is an important compensatory strategy, allowing small targets to be expanded for easy tapping.

Most directly related is the work by Kobayashi et al. [11] that studied touch screen gestures exclusively with older adults, including pinch-and-spread tasks. They used both tablet (laying on a table) and phone-size touch screens (held in the hand), with two different sized pinch and two different sized spread tasks, reporting task execution times. They found no effect of device, but that spreading tasks were more difficult than pinching tasks for their participants. Recent work by Findlater et al, [7] compared the pinch and spread performance of older adults to younger adults on an iPad laying flat on a table. They report task execution time and error rates, and found the opposite asymmetry from Kobayashi et al.; their participants were slower on pinching tasks than spreading tasks. The sparsity and contradictory nature of research into how people pinch and spread on mobile devices today, combined with the importance of the functionality associated with those gestures, led us to conduct the empirical study presented here.

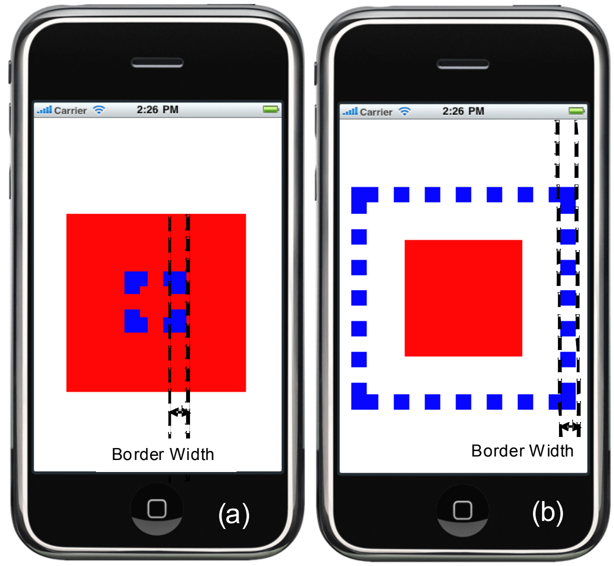

Figure 1. Pinch (a) and spread (b) tasks, showing border width.

PINCH AND SPREAD TASKS

We begin by describing the pinch and spread tasks used in this research, as illustrated in Figure 1. Both tasks present a red square and a blue dashed square border centered on the screen. In the pinch task (Figure 1a), the red square is initially larger than the border, and in the spread task (Figure 1b), the red square is smaller. The goal is to resize the red square to match the blue border.

Figure 2 shows the steps required to complete one spread task. Initially, a large 'tap' button is shown in the center of the screen (2a). Once the 'tap' button is pressed, the gesture task appears (2b). When two digits (fingers and/or thumbs) are placed anywhere on the screen (2c), changes in the

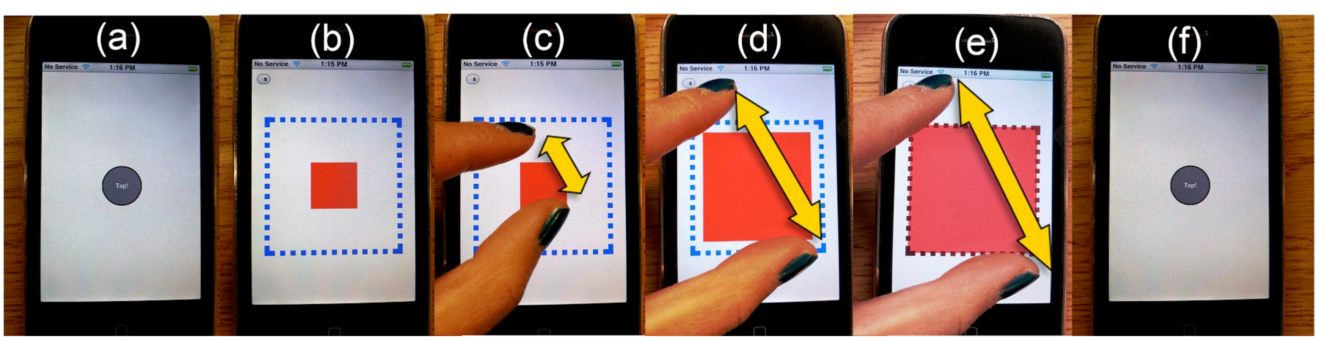

Figure 2. Steps in a spread task. a) Initial tap button, b) Spread task is presented, c) Fingers on screen, d) Fingers moved apart, red square expands, e) Red square fits within border, border color changes, f) Fingers released, next tap button appears

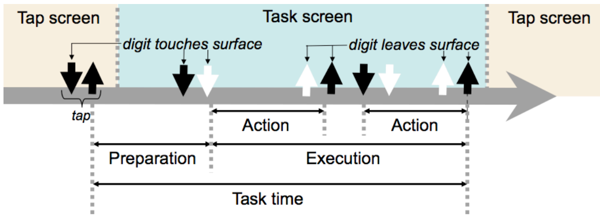

Figure 3. Definition of task time, and its component parts.

distance between those digits are translated into changes in the size of the red square in a 1-to-1 mapping (2d). Thus, moving the fingers 1cm further apart in a spread gesture will increase the diameter of the red square by 1cm, regardless of the angle of the fingers on the screen.

When the edges of the red square are within the blue border, the blue border changes to dark red (2e) to provide visual feedback that the goal has been achieved. Raising the fingers off the screen when in this state completes the task. At this time (2f), another 'tap' button appears, to start the next task.

In state 2e, if the user keeps moving their fingers on the screen until the red square is larger than the border (an *overshoot*), the border color changes from dark red back to blue. To complete the task, the user must reverse the direction of their movement until the red square shrinks back within the border.

The pinch task has the same steps as shown in Figure 2, except that the red square is initially larger than the blue border, and the user must pinch the red square to make it fit within the blue border.

MEASURES

Figure 3 shows a timeline of an example spread gesture, from the tap on the 'tap' screen (Figure 2a), through the task screen (Figure 2b-e), and back to the 'tap' screen (Figure 2f). Colored arrows indicate finger (black) and thumb (white) screen touches and releases. The *task time* begins when the participant raises their finger after pressing the 'tap' button. Task time ends when all digits are released from the screen, and the red square is within the blue border.

Analysis will focus on three measures of interest:

1. *Number of actions*: An action is a period when one or more digits are touching the screen. Completing a task involves at least one action. In Figure 3, the task is completed with two actions.
2. *Overshoots*: The number of times the red square moved out of the border area during a task. Each overshoot requires the participant to reverse their gesture and re-enter the target.
3. *Execution time*: Time from the start of the first action to the end of the task.

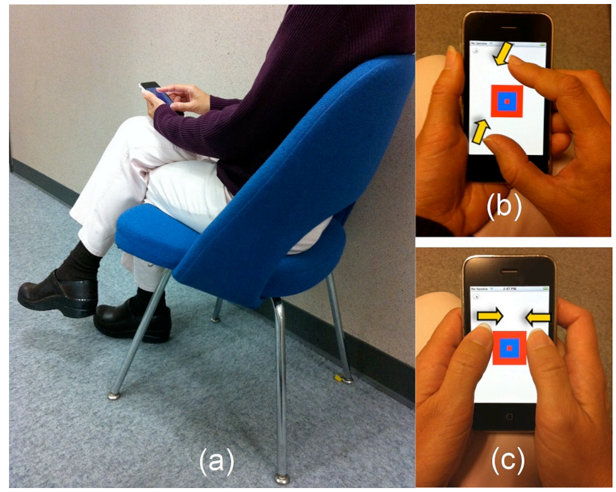

Figure 4. Typical body position and techniques for performing pinch and spread gestures with a phone.

Consideration of errors

The definition of an error is uncertain at this exploratory stage of inquiry. Most of our gestures could have been completed in a single action, given their size relative to our participants' hand span, so any task where two or more actions were used might be considered an error, but using multiple small actions might be a deliberate strategy or personal style and not an error. Overshooting might also be considered an error, but again, this might be a deliberate strategy. Some participants mentioned informally that they did indeed do this deliberately, believing it was quicker overall than making a more precise movement. In pointing research, overshooting with the mouse has been used as a measure of interest [12] but has not typically been treated as an error.

Thus, there are only two sequences of participants' actions that we considered labeling as an error *a priori*. First, if the participant touched three or more digits to the surface of the device, the device stops responding to movement of the first two digits. This happened a total of 48 times (out of 3024, across 11 of 21 participants) and we removed these occurrences from analysis. Second, if the participant resized the square and then tapped the center of the screen, we believe the participant thought the trial was complete and anticipated the appearance of the gray next-trial circle. In practice this happened only 18 times across 12 of 21 participants, almost perfectly distributed across devices and task type; we also removed these from analysis. We will not discuss errors further, preferring to look at number of actions and overshoots as measures in their own right.

STUDY

Participants

Twenty-one participants (10 female, 1 left-handed) with at least 6 months experience on a touch screen mobile device participated. Eight were aged 20-29, seven aged 30-49 and six were 50-69. On average, participants self-reported using a smartphone for 3.4 years and a tablet for 1.3 years. Excluding voice calls, 15 participants used a smartphone for at least an hour a day, and 4 used a tablet for at least an hour a day. Thirteen people used a tablet for less than 3 hours per week.

Apparatus

An iPhone 3GS (320x480 pixel screen, 163 pixels/inch, 0.16mm/pixel) and an iPad 1 (1024x768 pixel screen, 132 pixels/inch, 0.19mm/pixel), both running iOS 5.1.1, were used. The task application was built in HTML, CSS and Javascript, and presented as a full-screen application without the browser's user interface.

A low, four-legged chair with no arms (see Figure 4a), was used. No table surface was made available. A second chair for the experimenter faced the participant at a comfortable distance, and a mirror was positioned to provide an over-the-shoulder view of the participant's screen. The experimenter's recording sheet included a side view sketch of a seated figure on which arms, legs and device were drawn; phone and tablet device sketches on which holding positions were drawn; and sets of two hands on which the digits used were marked. Sessions were not video recorded.

The experimental software presented pinch and spread tasks as described above, using three different gesture sizes and three border widths, as described below. It also recorded user actions with timestamps.

Three gesture sizes on each device were chosen to cover the range afforded by the screen. Gesture size is the total distance (cm) the user's fingers have to move to complete the task. Gesture sizes were 0.8, 1.6 and 2.4cm on the phone (50, 100 and 150 pixels) and 1.9, 4.75, and 7.6cm on the tablet (100, 250 and 400 pixels), chosen such that the red square and blue border both fit within the available screen area. Figure 2b shows the spread task with the smallest border width and the largest gesture size.

Border widths of 10 (Figure 2), 20 (Figure 1) and 30 pixels were used on both devices. We report results with cm measurements of border width, as pixel sizes differ on the two devices (phone: 0.16, 0.32, 0.48cm; tablet: 0.19, 0.38, 0.47cm). A small border width approximates a tightly constrained task, such as sizing an image to fit within a background frame. Larger border widths represent less constrained tasks, such as enlarging text until it is easily readable. Figure 2b shows a pinch task with the 0.16cm border width and 2.4cm gesture size.

Procedure

Participants were instructed to sit in the chair in any position they chose; hold the devices how they liked; and interact with the device with any method they preferred. This allows the study to explore the degree of consistency and range of approaches people used. Sitting with no desk is common in waiting rooms and public transport, and is less fatiguing for participants than standing or walking.

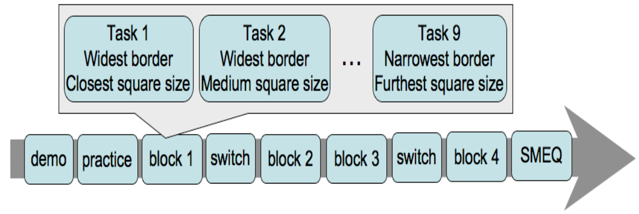

Figure 5. Sequence of events for each type of gesture.

Figure 5 shows the sequence of activities for each gesture. First, a demonstration was given using the finger and thumb as in Apple tutorials [4]. After 10 practice tasks, the participant was instructed to perform the tasks "as quickly as possible." No explicit instruction about accuracy was given, as participants had to complete each task accurately to move on.

A total of 36 tasks in 4 blocks of 9 (3 border widths × 3 gesture sizes) were performed for each gesture. A block began with the widest border and smallest gesture size, moved through three gesture sizes, then repeated for the medium and small border widths. Blocks 2 and 3 were performed in a different orientation (portrait or landscape) to 1 and 4. Users rated the difficulty of performing that gesture using a paper-based Subjective Mental Effort Questionnaire (SMEQ) [19]

Participants completed all tasks on one device before moving to the other. To counteract potential learning or fatigue effects, order of devices, gestures, and device starting orientation were counterbalanced using a Latin Squares design, to the extent possible.

The experimenter recorded the participant's method of sitting, holding the device, and performing the gestures on paper. We also collected the user's demographic information, cell phone and tablet use, and experience with pinch and spread gestures. We measured participant hand size with fingers spread.

RESULTS AND DISCUSSION

A total of 3024 tasks were performed; 1512 on each device (756 pinch and 756 spread tasks per device), and 2955 were retained for analysis after discarding errors and five phone tasks where either the log file or the device failed to register all of the user's finger actions. We used non-parametric statistical analysis since the data does not follow a normal distribution. Mann-Whitney U tests were used for pairwise comparisons, including orientation and task effects, and Kruskal Wallis H tests examined the effect of border width, gesture size and method.

Prior Experience with Pinch and Spread Gestures

Participants reported using pinch and spread gestures on their phones in maps (18), internet browsing (14), camera/photo (14), email (3), Facebook (2), pdf (2), Yelp (1), games (1) and text (1) applications.

On the tablet, pinch and spread gestures were most used in Internet browsing (13), email/notes (6), photo (5), map (5), pdf/books (4), games (2), real estate (1), Yelp (1) and drawing (1) applications.

There were only small learning effects during the course of the study, indicating that our participants' prior real-world experience had brought them to quite a skilled level with these gestures. Comparing results for blocks 1 and 4, we found no statistically significant differences for number of actions and overshoots on either device ($p>0.05$ in all cases). Median execution times decreased by 3-4% (phone: 3.5%, 33.5ms, $p=0.042$; tablet: 3.4%, 34ms, $p=0.201$). Given the small magnitude of this effect, we combine data across all blocks for subsequent analyses.

Effects of device orientation (landscape vs. portrait)

We found no main effect of device orientation (landscape or portrait) on either device (phone or tablet) for any of our performance measures (number of actions, overshoots, or execution time), with p values between 0.057 (overshoots on tablet) and 0.950. Therefore, we will not explore this factor further and will combine the data across device orientation for all subsequent analyses.

Method of Performing Gestures

Body Position

Both devices were held with the non-dominant hand (phone: 85%, tablet: 95%, Figure 4b), or with both hands (Figure 4c), with two exceptions on the tablet: one participant switched to holding the tablet with his/her dominant hand due to fatigue, and another placed the tablet flat on his/her lap throughout the experiment.

Most participants sat with one leg crossed over the other (phone: 76%, tablet: 55%). Men crossed one ankle over the other knee, while women crossed one thigh over the other, as illustrated in Figure 4a. Of the phone blocks, 67% were performed with the arm holding the phone resting on the participant's leg (Figure 4a), and 52% rested the phone on their leg, held at an angle (some did both). No participant placed the phone directly on his/her lap. In contrast, participants most often rested the tablet in their lap, 62% at an angle and 10% flat. The other 28% of blocks were performed with the tablet held in the air, with the arms supported by the participant's legs.

Digits Used

Participants performed 83% of all tasks with the thumb and index finger of their dominant hand (Figure 4b). The other methods observed were:

- Thumb and middle finger of one hand (phone: 2 people for pinch, 1 for spread; tablet: 2 people for pinch, 2 for spread)
- Two thumbs (phone only: 2 people for pinch, 3 for spread)
- Index finger of one hand and thumb or index finger of the other hand (tablet only: 2 people for pinch, 3 for spread)

Digit Movement

In 92% of all tasks, participants moved both digits across the screen. In the remaining 8%, they held their thumb still and moved their finger.

Pinch and Spread Performance Overall

Table 1 summarizes the performance results by device and task type (pinch or spread).

	Phone		Tablet	
	Pinch	Spread	Pinch	Spread
Single Action (% tasks)	94	96	84	92
Tasks with no Overshoot (%)	90	91	84	84
Execution Time (s) Mean, Median, (Std.)	1.09 0.97 (0.57)	1.02 0.91 (0.47)	1.43 1.26 (0.69)	1.32 1.19 (0.56)

Table 1. Overall performance measures for pinch and spread on phone and tablet.

Number of Actions

84-96% of tasks were completed in a single action (top row, Table 1). On the phone, the pinch and spread tasks did not differ significantly (U=277004, $p=0.321$), but on the tablet, pinch tasks required more than one action significantly more often than spread tasks (U=246858, $p<0.001$).

Overshoots

90-91% of phone tasks and 84% of tablet tasks were completed without overshooting (second row, Table 1). There is no significant effect of task (pinch vs. spread) on the number of overshoots on either device (phone: U=277942, $p=0.604$; tablet: U=265057, $p=0.928$).

Execution time

The bottom row in Table 1 gives mean and median execution time values with standard deviations for the tasks. On both devices, the median pinch execution time is approximately 60-70ms longer than the spread execution time. This difference is statistically significant on both devices (phone:U=256895, $p=0.005$; tablet:U=244387, $p=0.009$). However, these values are highly variable, with standard deviations higher than 50% of the median value, so we expect that more data is needed to shed light on relationships found here.

Performance in pinch and spread was asymmetrical in our tasks, with pinch taking longer than spread, similar to the behavior reported in [7]. This result is contrary to Kobayashi's [11], where their overall result is heavily influenced by the smallest target size on the phone-size device and may be an artifact of their experimental procedure.

Our participants used significantly more actions in pinch gestures than spread on the tablet. The distance between the tip of the thumb and index finger among our participants, measured with the hand spread flat and fingers open, was 9-17cm (mean 13.7cm for men and 11.9cm for women), so all participants should have been able to perform even the largest 7.6cm gesture in one action. The additional time used to execute pinch tasks may be related to the additional actions used and the time to move the fingers apart before starting a second pinch action.

Effect of Border Width

Border width effects are summarized separately for each device and task in Table 2.

Number of Actions

There was no significant effect of border width on number of actions (pinch on phone: $\chi^2_{(2,N=21)}$=0.76, p=0.685; spread on phone: $\chi^2_{(2,N=21)}$=1.40, p=0.498; pinch on tablet: $\chi^2_{(2,N=21)}$=3.11, p=0.211; spread on tablet: $\chi^2_{(2,N=21)}$=0.37, p=0.830).

Overshoots

Overshoots decrease dramatically as border width increases, for both pinch and spread (Table 2). These effects are statistically significant on both devices (pinch on phone: χ^2=45.72, p<0.001; spread on phone: χ^2=47.53, p<0.001; pinch on tablet: χ^2=41.67, p<0.001; spread on tablet: χ^2=37.45, p<0.001).

Execution Time

Execution time decreases as border width increases on both devices for both gestures (Table 2). The effect is statistically significant for both tasks on both devices (pinch on phone: $\chi^2_{(2,N=21)}$=75.62, p<0.001; spread on phone: $\chi^2_{(2,N=21)}$=78.23, p<0.001; pinch on tablet: $\chi^2_{(2,N=21)}$=94.31, p<0.001; spread on tablet: $\chi^2_{(2,N=21)}$=60.03, p<0.001). This is not surprising, as more precise targets (smaller border widths) lead to longer execution time in other motor actions. We will discuss this further, below, when we explore preliminary models of pinch and spread.

Initial Finger Distance

When placing the fingers on the screen to start a gesture, there was no significant effect of border width on the initial distance between the fingers (pinch on phone: χ^2=0.68, p=0.71; spread on phone: χ^2=0.89, p=0.64; pinch on tablet: χ^2=0.19, p=0.909; spread on tablet: χ^2=0.20, p=0.904).

Phone

	Pinch			Spread		
Border Width (cm)	0.16	0.32	0.48	0.16	0.32	0.48
1 action %	94	95	95	94	96	96
0 overshoot %	82	90	100	82	93	99
median exec. time (s)	1.11	0.98	0.82	1.08	0.88	0.80
mean initial distance (cm)	5.20	5.21	5.13	2.55	2.56	2.49

Tablet

	Pinch			Spread		
Border Width (cm)	0.19	0.38	0.57	0.19	0.38	0.57
1 action %	82	83	88	91	92	92
0 overshoot %	74	84	95	73	84	94
median exec. time (s)	1.48	1.26	1.00	1.38	1.14	1.06
mean initial distance (cm)	9.68	9.63	9.58	3.62	3.59	3.52

Table 2. Effect of border width on phone and tablet.

Effect of Gesture Size

Gesture size effects are summarized separately for each device and task in Table 3.

Number of Actions

On the tablet, there is a significant effect of gesture size on number of actions, with a 34% decrease in the number of pinch tasks completed in a single action for the largest gesture, compared to the smallest, and a 17% decrease for spread tasks. The effect is highly statistically significant (pinch on tablet: $\chi^2_{(2,N=21)}$=128.77, p<0.001; spread on tablet: $\chi^2_{(2,N=21)}$=46.53, p<0.001). On the phone, the effect is statistically significant, but much smaller, about 5%, (pinch on phone: $\chi^2_{(2,N=21)}$=6.55, p=0.038; spread on phone: $\chi^2_{(2,N=21)}$=9.16, p=0.010).

As can be seen in Table 3, only the 7.6cm gesture size on the tablet showed an impact on the number of actions, indicating that most of these on-screen pinch and spread gestures were easily performed in a single action by our participants, consistent with our report earlier that all our participants' digit span was adequate to perform even the largest gestures in one action. The fact that the 7.6cm gesture evoked more actions may suggest an inability to judge an optimal initial position of the fingers, or may reflect a deliberate strategy shift as gesture size increases. Future research could investigate this phenomenon.

Overshoots

On both devices, as gesture sizes increase, overshoots decrease. The effect is significant for all device/task

Phone

Gesture Size (cm)	Pinch 0.8	Pinch 1.6	Pinch 2.4	Spread 0.8	Spread 1.6	Spread 2.4
1 action %	96	96	91	99	94	94
0 overshoot %	77	97	97	84	93	97
median exec. time (s)	.80	.96	1.13	.78	.89	1.05
mean initial distance (cm)	5.07	5.20	5.28	2.48	2.58	2.55

Tablet

Gesture Size (cm)	Pinch 1.9	Pinch 4.75	Pinch 7.6	Spread 1.9	Spread 4.75	Spread 7.6
1 action %	97	93	63	98	95	81
0 overshoot %	76	88	88	73	88	91
median exec. time (s)	0.94	1.19	1.72	0.92	1.14	1.59
mean initial distance (cm)	9.28	9.61	10.0	3.56	3.55	3.63

Table 3. Effect of gesture size on phone and tablet.

combinations (pinch on phone: $\chi^2_{(2,N=21)}$=79.18, p<0.001; spread on phone: $\chi^2_{(2,N=21)}$=27.41, p<0.001; pinch on tablet: $\chi^2_{(2,N=21)}$=15.19, p=0.001; spread on tablet: $\chi^2_{(2,N=21)}$=34.37, p<0.001).

Interestingly, the percentage of 1.9cm gestures completed without overshooting on the tablet (73-76%) are not in line with the low values of 93-97% for similar (1.6cm and 2.4cm) gesture sizes on the phone. This suggests that these tablet overshoots may be influenced by the set of distances in the overall set of tasks, rather than the physical distance to be moved in the gesture.

Execution Time

Execution times increase as gesture size increases. The effect is significant for both tasks on both devices (pinch on phone: $\chi^2_{(2,N=21)}$=83.93, p<0.001; spread on phone: $\chi^2_{(2,N=21)}$=110.94, p<0.001; pinch on tablet: $\chi^2_{(2,N=21)}$=255.60, p<0.001; spread on tablet: $\chi^2_{(2,N=21)}$=218.98, p<0.001). This is not surprising, as longer distances lead to longer execution time in other motor actions. We will discuss this further, below, when we explore preliminary models of pinch and spread.

Initial Finger Distance

For spread tasks, there is no significant effect of gesture size on the starting distance of the fingers on either device (spread on phone: $\chi^2_{(2,N=21)}$=1.31, p=0520; spread on tablet: $\chi^2_{(2,N=21)}$=0.15, p=0.929).

For pinch tasks, as gesture size increases, the initial distance between the fingers for the first pinch action of the task also increases, but not in direct correspondence with the change in distance to be moved. For instance, when the gesture size increases by 2.65cm between the 1.9 and 4.75cm pinch tasks on the tablet, the initial finger distance only increases by 0.4cm. This suggests that participants took advantage of the ability to touch anywhere on the screen, instead of touching and dragging the edges of the red square. The differences are statistically significant on the tablet but not on the phone (pinch on phone: $\chi^2_{(2,N=21)}$=3.04, p=0.219; pinch on tablet: $\chi^2_{(2,N=21)}$=13.73, p=0.001).

Effect of Gesture Method

Since 27% of participants chose to use a method other than that demonstrated by the experimenter (thumb and index finger), we investigated the effects of gesture method to see if there was any advantage to different methods. Figure 6 summarizes the execution times for participants using different pinch and spread methods.

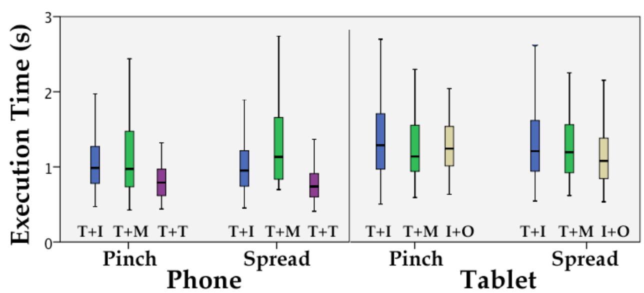

Figure 6. Execution time by gesture method. T+I= Thumb+Index, T+M=Thumb+Middle, T+T=Two Thumbs, I+O=Index + Opposite Thumb/Index. Box indicates 50% of data, center line shows median value, whiskers show 95% confidence intervals. Outliers not shown.

On the phone, the participants who used two thumbs were 23% faster for both pinch and spread (pinch: 2 people, U=13474, p<0.001; spread: 3 people, U=19651, p<0.001), with no significant differences in the number of actions used (p>0.5) or overshoots (p>0.2). For pinch, their thumbs were initially placed 1.15cm (23%) further apart than those using thumb and index finger (U=7368, p<0.001). For spread, their thumbs were initially placed 0.45cm (17%) closer together (U=24680, p<0.001).

On the tablet, participants using the index finger of one hand together with the thumb or index finger of the other hand started both pinch and spread tasks with their digits 28% further apart (pinch: 2.68cm, U=5983, p<0.001; spread: 0.95cm, U=22860, p=0.002). Although no different on pinch tasks, for spread tasks, those who used these methods were 17% faster than those who used thumb and index finger (U=22319, p<0.001), using 6% fewer actions (U=27201, p=0.042) and 56% fewer overshoots (U=26085, p=0.022). The two people who used their thumb and middle finger for spread tasks had 27% more actions than those using thumb and index finger (U=14275, p<0.001), but the 2% difference in execution time was not statistically significant.

Among our participants, those who chose to use two thumbs on the phone were able to perform pinch and spread gestures more quickly and accurately. Their initial placement of the thumbs on the phone screen allowed more room to make the complete gesture in a single action. On the tablet, two-handed techniques allow the digits to move independently. Participants started spread actions with their digits further apart, and achieved better performance for spread but not for pinch. Further work could explore whether this technique is advantageous in real task contexts, and for all users.

TOWARDS QUANTITATIVE MODELS

Quantitative models of movement have been extensively researched and have proved to be useful in UI design for decades. Fitts's Law [8] relates movement time to the distance moved and size of the target for one-dimensional pointing tasks, where a user's hand or finger is moved rapidly from a starting position to a target, or where a mouse or other pointing device is used to perform the same task [13,14,20]. The steering law [1] extends Fitts's Law to two-dimensional movements such as traversing a hierarchical menu. Such models have been useful components in modeling frameworks for larger tasks such as Keystroke-Level Model and GOMS [5], and have been built into modeling tools such as CogTool [9]. We expect that a quantitative model of pinch and spread would likewise be useful when researched sufficiently to understand its scope and generality. We make the first step towards such a model here.

As presented above, gesture execution time decreased for larger border width and increased for larger gesture size. These results suggest a Fitts's Law-type relationship. However, there are important differences between pinching and spreading gestures and pointing, which would not make Fitts's Law an obvious choice. Progress towards the goal is dictated by a relative change in the location of two digits. In our study, both of these are usually moving. This contrasts with a typical pointing task where there is only one moving object. Furthermore, the two moving digits are usually on the same hand, which limits their range of movement relative to each other. Finally, the initial placement of the fingers dictates the available range of movement, and therefore the size of the gesture that can be made. Fitts's Law has not been shown to apply in these circumstances.

Nevertheless, some aspects of these tasks and results suggest that a Fitts's Law analysis may be possible for a useful subset of such gestures. First, because the gesture is defined with respect to the relative locations of two digits, we argue that this can be considered a one-dimensional task. Although the start and end locations of the movement are not fixed as they are in typical pointing tasks, the ending point has a fixed relationship to the starting point.

Second, the majority of gestures were performed with a single action, implying that users did not reach the limit of their hand span. As a result, for tasks within the range afforded by the screen size, it may be possible to describe typical behavior without modeling the use of multiple actions, and the associated finger movements between actions.

Third, the tasks in our study presented a clearly defined target – the blue border – that was visible at multiple screen locations, providing an analogue to the target used in Fitts's Law.

Fitts's Law may therefore be an appropriate way to characterize execution time for pinch and spread gestures on mobile devices. To further explore this possibility, the Fitts's index of difficulty for each border width/gesture size combination was calculated using the Shannon formulation:

$$ID = \log_2(A/W + 1)$$

Where:

W = width of the blue border. (See Figure 7)

A = distance from the edge of the red square to the center of the blue border (Figure 7). This represents the distance that each digit must move to complete the task.

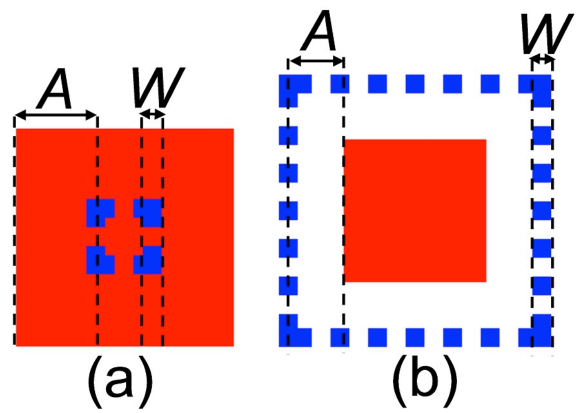

Figure 7. Definition of *W* and *A* in pinch and spread tasks.

In applying Fitts's Law to pinch and spread gestures, our model makes the following simplifying assumptions:

1. *Both* digits move the distance A, at the same time.
2. The starting position of the fingers and hand span of the user allow the task to be completed in a single action.
3. The movement is one-dimensional.

These assumptions are consistent with the typical user behavior we observed. We include in this analysis only the data points where participants were observed to be using their thumb and index finger and moving both digits. It would be instructive to compare models of different gesture strategies. However, reliable comparisons cannot be drawn from these data because only 1-3 people used alternative strategies. We therefore limit our analysis to the dominant

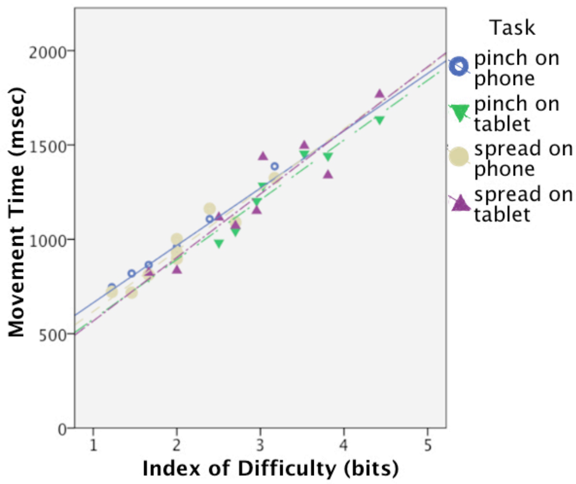

Figure 8. Regression analysis of movement time vs. index of difficulty on phone and tablet.

strategy: Thumb+Index finger, completed in a single action with no overshooting. This is 57% of the original data.

Figure 8 plots the movement time against index of difficulty, for all such data points. Data from phone tasks is indicated with circles, while tablet data is shown as triangles. Linear regression for pinch and spread on phone and tablet gives correlation coefficients (R) between 0.940 and 0.982 (R^2 between 0.884 and 0.964), as shown in Table 4, and the following regression equations:

Pinch on phone: $MT = 360 + 304 \log_2 (A/W + 1)$

Spread on phone: $MT = 295 + 323 \log_2 (A/W + 1)$

Pinch on tablet: $MT = 260 + 317 \log_2 (A/W + 1)$

Spread on tablet: $MT = 231 + 337 \log_2 (A/W + 1)$

	Phone		Tablet	
	Pinch	Spread	Pinch	Spread
R	0.972	0.963	0.982	0.940
R^2	0.945	0.927	0.964	0.884

Table 4. R and R^2 values for execution times for pinch and spread on phone and tablet.

The R^2 values indicate a strong linear relationship in all cases. These results are in line with many Fitts's Law studies, which typically report correlation coefficients (R) above 0.900 [14, p.101]. This suggests potential to use such models as an approximation of single-action pinch and spread performance.

This exploratory study of pinching and spreading did not use the tightly controlled conditions typical of Fitts's Law studies. The goodness of fit to Fitts's Law is, we feel, a surprising and exciting result.

LIMITATIONS

This study has many limitations similar to previous pinch-and-spread studies [7,11] and, like them, does as much to point the way to future work as it does to enrich our current understanding of pinch-and-spread.

Relation of device use in the experiment to real world device use

Our participants were seated, with no table available to use so both the phone and tablet were held without external support. We argue that this situation occurs in many mobile contexts, waiting for a bus or subway, waiting in a dentist's office, or relaxing on a couch. Findlater's tablet was flat on a table [7]; Kobayashi provided a table within reach and the participants chose to hold the phone-sized device in their hands, but typically rested the tablet on the table [11].

Relation of experiment tasks to real world tasks

All three studies of pinch-and-spread ([7,11], and our study) used an object of a given size that had to be resized to within a particular range of acceptable end points denoted by a border. This is probably a necessary first step toward empirically investigating human performance and establishing potentially useful models, but difficult to map to real-world pinch and spread tasks. In real phone and tablet apps there is usually no visible target that can be focused on and 'acquired'. Instead, the user monitors some property of the display, and the gesture is complete when a desired state has been achieved. For example, a real-world goal may be to enlarge some text to make it possible to read while keeping as much text as possible visible. The range of acceptable end points is only loosely defined and certainly not explicitly visible.

Our tasks allowed flexibility in initial finger placement, minimizing the likelihood the fingers would obscure the target. We also provided visual feedback when the task was complete. In some applications, especially when manipulating small objects, users' digits may obscure the display, requiring users to remove their fingers from the screen to check whether their action was sufficient.

Our tasks also required no lateral movement or rotation, commonly used in combination with pinch and spread in applications such as photo editing.

CONCLUSION AND FUTURE WORK

Our study of pinch and spread gestures on phone and tablet devices while seated can aid designers in understanding users' pinch and spread behavior. Our study found that pinch and spread tasks, while similar, are not symmetrical in all respects. Furthermore, device orientation did not have a significant impact in our tasks. Future work should expand on the range of controlled tasks, including larger gesture sizes representative of real world tasks that require multiple actions, combination with other gestures, and a set of tasks more relevant to real world mobile use. Exploring the impact of standing or walking is also important.

Before Fitts's Law was found to be useful in UI design, it had undergone scores of investigations in a myriad of forms. To our knowledge, this is the first application of Fitts's Law to pinch and spread gestures on mobile devices. A good fit to the data was obtained for gesture execution time. This first result is promising, but not definitive. Future studies should more systematically explore a broader range of tasks, as described above. Fitts's Law may stand as a good fit to performance data, but further investigation may also reveal other better fitting models.

Furthermore, the best performance on the phone was observed in the few participants who used two thumbs, which we have excluded from this preliminary model. More data is necessary to explore whether this, or some other model form, best fits this seemingly better gesture method.

Skilled performance time is an important property of mobile tasks, since mobile interactions are by nature brief, and often interrupted. Models that predict performance time could eventually be incorporated into modeling tools for mobile developers that provide insight into application design on specific mobile devices, even before working prototypes are available. We see our preliminary Fitts's Law model of pinch and spread gestures as a first step towards such tools.

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