Multi-Touch Pinch Gestures: Performance and Ergonomics

Eve Hoggan[1], Miguel Nacenta[2], Per Ola Kristensson[2], John Williamson[3], Antti Oulasvirta[4], Anu Lehtiö[5]

[1]Helsinki Institute for Information Technology HIIT and Aalto Science Institute, Aalto University
[2]School of Computer Science, University of St Andrews
[3]School of Computing Science, University of Glasgow
[4]Max Planck Institute for Informatics and Saarland University
[5]Helsinki Institute for Information Technology HIIT, University of Helsinki

ABSTRACT
Multi-touch gestures are prevalent interaction techniques for many different types of devices and applications. One of the most common gestures is the pinch gesture, which involves the expansion or contraction of a finger spread. There are multiple uses for this gesture—zooming and scaling being the most common—but little is known about the factors affecting performance and ergonomics of the gesture motion itself. In this note, we present the results from a study where we manipulated angle, direction, distance, and position of two-finger pinch gestures. The study provides insight into how variables interact with each other to affect performance and how certain combinations of pinch gesture characteristics can result in uncomfortable or difficult pinch gestures. Our results can help designers select faster pinch gestures and avoid difficult pinch tasks.

Author Keywords
Pinch gesture, multi-touch.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Multi-touch displays enable a large number of onscreen touch manipulations, with two-finger rotation, translation and pinch being among the most common. In this note we focus on the pinch gesture, which is a common way to zoom in maps and pictures, or to scale objects. We define a pinch gesture as *a lateral motion expanding or contracting the finger spread* [12].

The pinch gesture has become ubiquitous in touch user interfaces. Previous research has found that many users tend to use pinch gestures when interacting with public displays [2] and tabletops [1,11] As a consequence, researchers have proposed various methods to leverage pinch gestures for a variety of interaction tasks (e.g. [10]) and methods of separating pinch gestures from rotation and translation gestures [8].

The frequent use of pinch gestures makes them worth studying. Although many studies have been conducted to investigate the accuracy and speed of traditional pointing methods, the performance of multi-touch pinch gestures is not well understood despite their ubiquity. Furthermore, our current knowledge about pointing is insufficient, since pinch gestures involve a more complex sequence of movements than simple taps. Therefore it is relevant and timely to look into the ergonomics and biomechanics of such gestures so that we can avoid suboptimal and awkward pinch gestures in future interfaces.

This paper contributes an empirical investigation of multi-touch pinch gestures with a focus on performance. Using an experimental methodology previously used for the study of rotations [3], we investigate the effects of variables such as direction, distance, angle and position. When considering ergonomics, we report the variable combinations that result in gestures that are physically impossible to do with a single continuous movement. The results characterize the effects of within-gesture variables for pinch gestures and can be used to draw implications on gesture design.

RELATED WORK
Multiple researchers have examined pinch gestures with different purposes. For example, when examining user-defined gesture sets, the contraction and expansion of fingers is often used as a gesture for zooming [11]. This result has been confirmed in tabletops [1] and public display settings [2]. Others have investigated the transfer functions between a pinch gesture and the output on a multi-touch display [7, 8].

Single touch targeted movements have been studied extensively with Fitts' law to establish the rate of transmission for different input techniques [6]. In terms of multi-touch movements, Zhao *et al.* [13] combined the Mahalanobis distance metric and Fitts' law to create a model of movement time for translation, rotation, and pinch. The model shows that there is a linear relationship

ITS'13, October 6–9, 2013, St. Andrews, United Kingdom.

http://dx.doi.org/10.1145/2512349.2512817

between movement time and index of difficulty. However, the model does not include gesture position, does not address the possibility of failure, and assumes that only the difference between starting and ending positions for each factor matters, regardless of the absolute point in the scale where the gesture takes place.

This paper focuses on the performance and ergonomics of pinch gestures. Interaction with pinch gestures is based on coordinated movements of the hand and arm. Ergonomic issues need to be addressed when determining the performance space of pinch gestures or we risk creating interfaces that may lead to discomfort. Spreading the fingers in a pinch gesture involves abduction of the fingers. If the end target of the gesture is at a large distance, this means that the users must abduct their fingers to outer positions, which is ergonomically inadvisable [9]. Moreover, the expansion and contraction of the thumb and index finger also requires the major and minor knuckles to rotate. For example, Lozano *et al.* [4] found that such gestures produce index finger interphalangeal joint rotation amplitudes of up to 40 degrees. These factors may affect the performance and physical difficulty of different multi-touch gesture sets.

The experiment in this paper is based on previous work by Hoggan *et al.* [3] on rotation gestures. Their results showed effects of rotation diameter, spatial location and direction on movement time and ergonomic difficulty of multi-touch rotation gestures. This paper furthers this research paradigm by investigating the pinch gesture instead.

METHOD

We conducted a within-subjects experiment to investigate the performance of single-handed dual-finger pinch gestures. The dependent measures were trial completion times and ergonomic failure rate. We study the effects of *Angle*, *Direction*, *Distance*, and *Position*, which cover most of the design space of pinch gestures on a surface.

Participants

Twenty-five participants were recruited with an age range of 19 to 28 (10 female, 15 male). All participants were right-handed, had normal or corrected-to-normal vision and no motor or cognitive disorders. The participants' hand span ranged from 150 to 209 mm with a mean of 171 mm.

Experimental Design

Our design followed a within-subjects design with four factors (illustrated in Figure 1):

- *Angle* (between starting points with respect to the long axis of the table): 0°, 22.5° and 45°;
- *Direction:* expand or contract;
- *Distance:* (start to end distance between fingers, ratio): 60mm to 90mm (2/3), 120mm to 30mm (1/4), 30mm to 120mm (4), 90mm to 60mm (3/2);
- *Position*: 4×3 grid (Figure 1). Grid position determines the center point of each gesture. A tabletop-sized area of 1018×573 mm was divided into grid sectors of 254×191 mm. By moving the tablet to different sectors, we simulated the effect of a larger display.

The number of levels for each factor was selected based on the size of a previous experiment [3], and by balancing out coverage of the design space and participant fatigue.

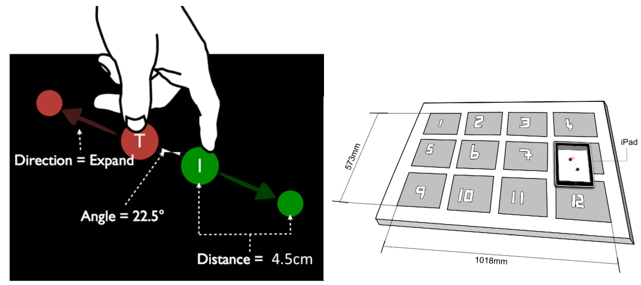

Figure 1. An example configuration of parameters: Angle, Distance and Direction (left), and grid display with tablet in Position 8 (right).

Experimental Apparatus and Setup

The participants sat on a chair positioned so that the participant's navel was leveled with the grid center and 5 cm from the grid edge. All lateral and anterior movement of the participants' upper torso was restricted. Participants performed all trials on a 24.13×18.57 cm Apple iPad 2 tablet. The software used in the experiment recorded movement onset and finger touch-lift events, along with each contact on the table of the thumb and index fingers.

Task and Procedure

The experiment explored the design space systematically, within an aimed movement paradigm, as in related work [3]. Participants had to place the thumb and index finger of their dominant hand on two circles. They then had to expand or contract the fingers towards the target circles (see Figure 1). The factors described above determined the position of the target circles. Each gesture was repeated three times as quickly and accurately as possible whilst ensuring that there was no loss of contact between the fingers and display.

Unsuccessful trials triggered an audio alert for the participants. There were three error types: 1) wrong direction, 2) loss of contact, and 3) too many fingers on display. The participants had two chances to complete each trial correctly. If the trial was too uncomfortable or considered "impossible", it could be skipped. Participants had to touch a target marker on the edge of the display in between trials to 'reset' posture and avoid cross-trial transfers.

RESULTS

We recorded 18,539 trials in total, for which we analyze duration and ergonomic failure rate. Trials that were deemed "impossible" and trials in which there were contact losses are used as an index for an ergonomic failure rate. Overall, 26.8% of the trials produced ergonomic failures. The gesture duration was measured as the time between movement onset and the removal of both fingers from the display. The mean time per pinch gesture was 2.6 seconds.

Repeated-measures ANOVAs of duration and ergonomic failure rate revealed many significant main effects and interactions of the factors. The most noteworthy results are discussed below and the rest are left to future reports.

Angle and Direction

The ANOVA of duration showed a significant main effect for *Angle* ($F_{2,14} = 8.21$, $p < .05$, $\eta_p^2 = .54$), *Direction* ($F_{1,7} = 9.48$, $p < 0.05$, $\eta_p^2 = .58$), and *Distance* ($F_{1,7} = 63.02$, $p < 0.05$, $\eta_p^2 = .90$). The ANOVA of ergonomic failure showed a significant main effect for *Angle* ($F_{1.38,31.83} = 15.16$, $p < .05$, $\eta_p^2 = .397$—with Greenhouse-Geisser correction due to lack of sphericity), *Direction* ($F_{1,23} = 61.31$, $p < 0.05$, $\eta_p^2 = .727$), and *Distance* ($F_{1,23} = 59.62$, $p < 0.05$, $\eta_p^2 = .722$).

Because *Direction* and *Distance* have two levels, the significant main effects do not require post-hoc tests. The results show that larger pinch gestures took longer to perform and had a higher failure rate. Expanding pinch gestures are also slower and more ergonomically demanding than contracting gestures.

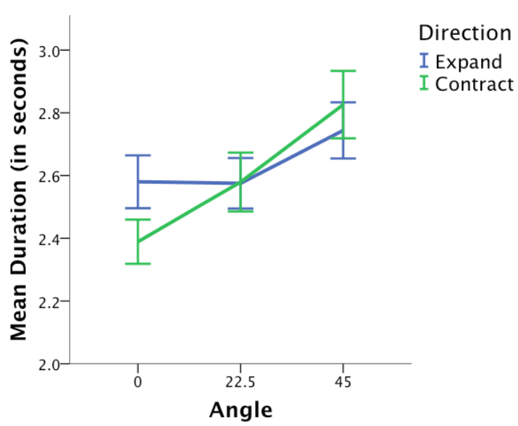

Figure 2: Mean gesture duration (in seconds), for each angle, separated by direction (error bars show 95% confidence intervals).

All angles used in the experiment were achievable. However, the effect of the starting *Angle* differed in duration and ergonomic failure rate. For duration, larger starting angles resulted in longer durations than small angles from 0° to 22.5°. For ergonomic failure rate, starting *Angles* of 0° and 45° led to significantly more failures than 22.5°. The ergonomic failure analyses also showed significant interactions between *Angle* and *Direction* ($F_{2,46} = 15.4$, $p < .05$, $\eta_p^2 = .401$). Interestingly, a crossover in duration between contracting and expanding directions was observed for the 22.5° angle, as can be seen in Figure 2.

This result also echoes results from Hoggan *et al.'s* rotation experiment [3] where clockwise rotations took longer to complete and produced more ergonomic failures than anti-clockwise rotations up to angles of 120°.

Position

The ANOVAs show a main effect of *Position* on duration ($F_{11,77} = 4.01$, $p < .05$, $\eta_p^2 = .36$) and ergonomic failure rate ($F_{4.10,94.5} = 33.9$, $p < 0.05$, $\eta_p^2 = .596$—with Greenhouse-Geisser correction due to lack of sphericity). As shown Figure 3, pinch gestures performed at the left-hand side were more prone to ergonomic failures, especially at the bottom left.

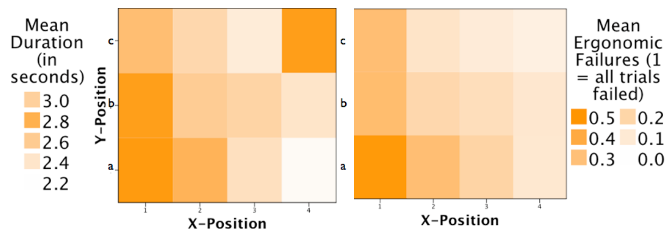

Figure 3: Mean duration and ergonomic failure rate for each grid sector (X-Position: 1= 1000mm, 2 = 750mm, 3 = 500mm, 4 = 250mm. Y-Position: a = 450mm, b = 300mm, c = 150mm).

DISCUSSION AND CONCLUSIONS

This paper has presented a systematic analysis of the effect of four factors (gesture parameters) on pinch gesture completion time and ergonomic failures. The results show that all of the within-gesture variables (*Distance*, *Direction*, *Angle* and *Position*) have a significant effect.

Distance

As the pinch distance increases, so does the duration of the gesture and its ergonomic failure rate. This is somewhat expected for time, but not for failure rate. This could be explained by considering the abduction of the thumb and index finger. Abduction (to move the finger away from the central axis [9]) beyond a certain outer limit is very difficult to maintain, which can lead to contact losses during the gesture. Although we only tested two distances, the optimal maximum extension will likely be below 90mm.

This result parallels what Hoggan *et al.* [3] found for rotation, where large rotation diameters of 70mm took significantly longer to complete and produced significantly more ergonomic failures. The combination of both results is strong evidence to consider carefully the ranges of finger extension in any dual-touch manipulation. It also suggests that further investigation of non-direct mappings between finger distance and zoom or scaling might result in increased efficiency and less ergonomic failures.

Direction

Contracting pinch gestures are, in general, faster to complete and ergonomically easier than expanding pinch gestures, probably because the average rotation amplitude of the index finger interphalangeal joint is lower for contraction than expansion [4]. The ergonomic literature suggest that movements that significantly deviate from a neutral position should be avoided [9]. Together with our results, this means that there is an advantage in selecting contracting gestures when possible, since stability and precision are required towards the end of the movement, which is when the hand is closest to the neutral position.

However, if the interface requires a pinch gesture at an angle beyond 22.5°, the effect on duration is reversed. Designers might want to consider avoiding these angles, or combinations of rotation and pinching that can turn beyond the recommended angles. Additional experiments combining pinch with other gestures such as rotate and translate are left for future investigation.

Position

Contralateral pinch gestures at the closer end of the display are the slowest with the most ergonomic failures. These areas should be avoided for pinch gestures with the dominant hand, especially for expanding gestures. Ipsilateral pinch gestures at the distant corner of the display are the least ergonomically problematic, but close ipsilateral gestures are faster. This finding can potentially be leveraged by tabletop application designers to trade off efficiency and efficacy. However, designers should also take into account the extra duration of the homing arm movement to reach those areas, which our data does not account for. Furthermore, the movement required to reach the distant ipsilateral area of the display involves, besides wrist and finger muscles, the anterior deltoid (for the forward shoulder flexion) and higher levels of shoulder flexion are required to reach across the body [5], which might result in additional sources of fatigue.

Methodology and Generalizations

This paper successfully applies the within-gesture variable methodology used by Hoggan *et al.* [3] to the multi-touch pinch gesture. Like multi-touch rotation gestures, within-gesture variables such as distance, angle, direction and position have a significant effect on movement time and ergonomic failure rates of pinch gestures. However, not all parameters are equally important and not all subsets of gestures are equally prone to ergonomic failure. These findings can help application designers choose gestures that are easier and faster.

The results in this paper complement those by Hoggan *et al.* on rotation [3]. However, further work is required to address more generalizable models of complex motor gestures that account for combinations of actions (e.g., rotation+translation+rotation), and different user postures (e.g., standing).

ACKNOWLEDGEMENTS

The authors would like to thank Aki Reijonen for his help in developing the code for the experimental system.

REFERENCES

1. Beheshti, E., Devender, A. V. and Horn, M. Touch, click, navigate: comparing tabletop and desktop interaction for map navigation tasks. In Proc. ITS (2012). ACM, pp. 205-214.
2. Hinrichs, U. and Carpendale, S. Gestures in the wild: studying multi-touch gesture sequences on interactive tabletop exhibits. In Proc. CHI (2011). ACM, pp. 3023-3032.
3. Hoggan, E., Williamson, J., Oulasvirta, A., Nacenta, M., Kristensson, P. O., Lehti, A. Multi-touch rotation gestures: performance and ergonomics. In Proc. CHI (2013). ACM, pp. 3047-3050.
4. Lozano, C., Jindrich, D. and Kahol, K. The impact on musculoskeletal system during multitouch tablet interactions. In Proc. CHI (2011). ACM, pp. 825-828.
5. Lucas, D. B. Biomechanics of the shoulder joint. Archives of Surgery, 107, 3 (1973), 425-432.
6. MacKenzie, I. S. Fitts' law as a research and design tool in human-computer interaction. Hum.-Comput. Interact., 7, 1 (1992), 91-139.
7. Moscovich, T. and Hughes, J. F. Multi-finger cursor techniques. In Proc. of Graphics Interface 2006 (2006). Canadian Information Processing Society, pp. 1-7.
8. Nacenta, M. A., Baudisch, P., Benko, H. and Wilson, A. Separability of spatial manipulations in multi-touch interfaces. In Proc. of Graphics Interface (2009). Canadian Information Processing Society, pp. 175-182.
9. Nielsen, M., Störring, M., Moeslund, T. B. & Granum, E. 2004. A Procedure for Developing Intuitive and Ergonomic Gesture Interfaces for HCI. *Gesture-Based Communication in Human-Computer Interaction.* Springer.
10. Wilson, A. D. Robust computer vision-based detection of pinching for one and two-handed gesture input. In Proc. UIST (2006). ACM, pp. 255-258.
11. Wobbrock, J. O., Morris, M. R. and Wilson, A. D. User-defined gestures for surface computing. In Proc. CHI (2009). ACM, pp. 1083-1092.
12. Wu, M., Shen, C., Ryall, K., Forlines, C. and Balakrishnan, R. Gesture Registration, Relaxation, and Reuse for Multi-Point Direct-Touch Surfaces. In Proc. International Workshop on Horizontal Interactive Human-Computer Systems (2006). IEEE, pp. 185-192.
13. Zhao, J., Soukoreff, R. W. and Balakrishnan, R. A Model of Multi-touch Manipulation. In Proc. Grand (2011).