Screen Scaling: Effects of Screen Scale on Moving Target Selection

Graeme Browning
McMaster University
1280 Main St. West
Hamilton, ON L8S 4K1 CA
brownigh@mcmaster.ca

Robert J. Teather
McMaster University
1280 Main St. West
Hamilton, ON L8S 4K1 CA
teather@mcmaster.ca

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Abstract
We examine the effects of screen size and target movement on selection performance using an experiment based on Fitts' law. Results indicate that small screen sizes reduced pointing throughput by around 20%. Target movement also negatively impacted performance, but the performance difference between static and moving targets was lower on small screen sizes.

Author Keywords
Screen scale; Fitts' Law; selection; visual scale; moving targets

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

Introduction
There is great variety in modern computing devices. Today, these include traditional desktop computers, laptops, console gaming systems, tablets, and smartphones. All use wildly different display types and sizes. This has recently become a major issue in the game industry as developers now design games that work across multiple platforms. The effect of screen size (scale) on performance seems to be understudied relative to its importance. We thus investigate the

effects of scaling on target selection using fundamental pointing tasks common to most games. These are well-understood [7] and well-modeled by Fitts' law [3] which predicts movement time based on pointing task difficulty. ISO 9241-9 [5] prescribes a standardized methodology for evaluating pointing devices. This includes calculation of throughput, a performance measure which captures the speed-accuracy tradeoff in pointing tasks. We employ this method in our study.

Several factors are involved in evaluating scaling: physical screen dimensions (e.g., in inches), pixel density (e.g., resolution in pixels per inch), and the distance between the user and the display. Our long-term goal is to empirically evaluate visual scaling on selection tasks by isolating each factor. Our intent is to help developers adapt games to different display sizes. The current study focuses on physical screen dimensions, and the influence of target movement as most previous studies include only stationary targets.

Related Work

Several researchers (e.g., [1, 2, 6]) have employed Fitts' law in the evaluation of factors relating to scale. Accot and Zhai [1] systematically adjusted trackpad size to study control area in steering tasks. This isolated human movement scaling by using identical display conditions but varying input scale. They found a "U-shaped" performance curve: small and large trackpad sizes performed worst. They attributed this to human motor precision [1]. Similarly, Chapuis and Dragicevic [2] looked at motor scale, visual scale and small target acquisition. They found that target acquisition performance was worst with small targets. These results indicate that selection performance is affected by human movement scale.

There is also evidence that visual scale affects performance [2, 6]. Chapuis and Dragicevic [2] found that performance was worse for targets 4 pixels or smaller. Fitts' law was ineffective at modeling pointing on very small screen sizes. Kovacs et al. [6] studied screen size independent of human motor precision. They hid the user's arm, and fixed arm movement to elbow extension. Participants performed a series of pointing tasks with different screen sizes, measuring screen size using visual angle in the field of view. Fitts' law held for small and medium displays, but not for large displays [6]. This suggests that display size affects our movement planning ability.

The distance between the viewer and display also influences target scale due to perspective. A study by Hourcade and Bullock-Rest [4] used selection tasks at different display distances, yielding different visual angles. Accuracy and speed were significantly lower for small visual angles, i.e., larger distances [4].

Wang et al. [8] compared pointing across four different display sizes, each with three visual angles. Movement time increased with display size, but accuracy was constant [8]. Their results suggest that as screen distance and size increase, performance decreases. However, they did not evaluate the screen distance and size independently, confounding the two effects.

It is interesting to note the effect of small *visual* scales [2, 4] on selection task performance. This appears to be different from the effect of human movement scaling [1, 2], yet both forms of scaling decrease performance.

A major challenge of studying scale is that many factors influence each other. For example, Wang et al.

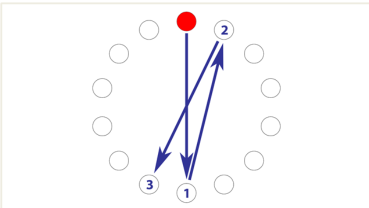

Figure 1. FittsCircle multi-directional selection task. Arrows show first three target orderings.

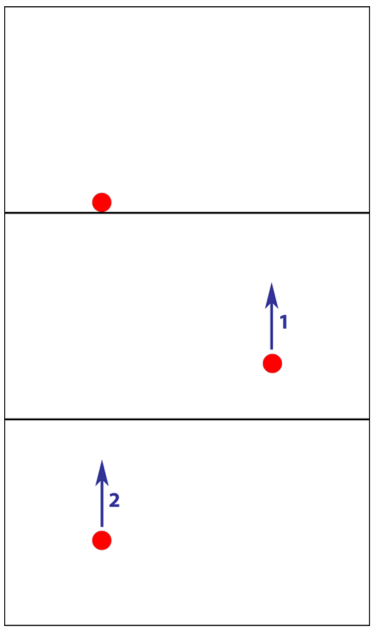

Figure 2. MovingTarget task, showing the first three sequential target selections. Targets start at the lower screen edge and move up. Subsequent targets reciprocate between two starting positions.

scaled physical screen size while keeping field of view constant, changing viewing distance [8]. In contrast, Kovacs et al. scaled physical screen size with constant viewing distance, thus changing the field of view [6].

Method

Participants

Eight (aged 20 – 22 years, four female) volunteers participated in the study. All were university students.

Apparatus

The experiment was conducted on a Dell laptop with an Intel Core i7 CPU, 8GB RAM, and an ATI Mobility Radeon HD 5730 graphics card. The display measured 15.6 in. diagonally, at a 1920 x 1080 pixel resolution, and 16:9 aspect ratio. We used a Corsair Vengeance M60 mouse, with a precision of 2000 DPI. Pointer speed was set to one level lower than default, and enhance pointer precision was disabled to avoid confounds due to CD gain. CD gain was constant across all conditions. The display was positioned 17.5” from the table edge.

The software was written in HTML5 and JavaScript, and ran on Chrome in full-screen (Kiosk) mode. We used two tasks. The FittsCircle task used the ISO 9241-9 multi-direction tapping task [5], see Figure 1. The participant had to select the red highlighted target using the cursor. Figure 1 depicts the target ordering. The first target (at the “12 o’clock” position in Figure 1) started the sequence. After successfully clicking it, all subsequent trials were timed.

The MovingTarget task also involved target selection but used moving targets instead of stationary ones. See Figure 2. The first target (Fig. 2, top) started the sequence, and did not move. Upon clicking it, the next target would appear at the bottom of the screen at a fixed distance, and then move upward at a constant speed (Fig. 2, middle). Each subsequent selection proceeded this way (Fig. 2, bottom). The speed was set so targets took 1365 ms to reach the top of the screen, regardless of display scale. Hence targets moved at the same *proportional* speed over all scales, although their actual speed varied with scale. Upon clicking (regardless if the click missed or hit the target) the next target appeared at the bottom of the screen at a specific (for this condition) horizontal distance from the first target. The targets always appeared starting from two points on the screen, similar to a 1D Fitts’ law task. There were fourteen target selections in a sequence.

The software varied target size and distance, yielding six indices of difficulty (*ID*s) presented in a random order for each condition, see Table 1. To scale the display, the task window size was reduced and a black border filled in the rest of the window, see Figure 3. Aspect ratio was kept constant.

The software for both tasks logged movement time (*MT*), error rate (misses) and cursor motion trails. It also computed throughput as ID_e/MT according to ISO 9241-9 [5]. The effective index of difficulty (ID_e) is *ID* adjusted to account for the speed-accuracy tradeoff. This employs a post-experimental adjustment for accuracy that fits the experiment to a 4% error rate. Details are omitted due to space constraints, but are discussed elsewhere [5, 7].

Procedure

After a verbal explanation of the experiment, participants were instructed to select the targets as quickly and accurately as possible. They were then

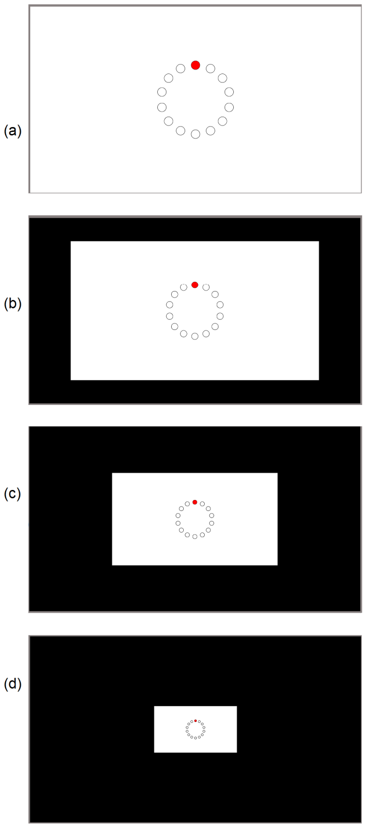

Figure 3. FittsCircle task shown at each level of screen scale used in the experiment: (a) Large (entire window) scale; (b) Medium (three-quarters of the window) scale; (c) Small (half the window) scale; (d) ExtraSmall (one quarter of the window) scale). The window size was held constant, while the actual task space reduced in size.

given a (non-recorded) practice round for each task with each screen scale. These practice rounds used an *ID* of 1, which was much easier than any of the experimental *ID*s. The experiment was then performed on all four screen sizes as described in the preceding section. Between each screen scale condition participants took a 1 minute break.

Design

The experiment used a 4x2x6 within-subject design. The independent variables were screen scale (large, medium, small, extra small), task type (FittsCircle, MovingTarget), and *ID* (Fitts' index of difficulty, in bits), see Table 1. The large screen scale filled the entire display (i.e., 15.6 in. diagonal). The medium, small, and extra small screen scales used ¾, ½, and ¼ the width and height of the display respectively. See Figure 3, and Table 1 for physical sizes. Physical sizes are given as diagonal measurements. Screen scale order was counterbalanced via a 4x4 balanced Latin square.

Task type order was not counterbalanced due to the large differences in the tasks. The FittsCircle task used stationary targets, and was thus expected to be easier. Hence, it was always presented first to help "train" participants for the harder MovingTarget task.

ID levels are shown in Table 1 and were calculated as $ID = \log_2(A/W + 1)$ where A is the amplitude (distance) of movement, and W is the target size (width). Note that while actual A and W parameters varied across different screen scales, *ID* levels stayed constant as *ID* is based on the ratio between A and W. This ratio is constant if both A and W scale by the same factor. *ID* levels were presented in random order within each screen scale. There were 14 target selections for each

ID (bits)		**Screen Scale** (pixels)			
		Large (15.6 in.)	Medium (11.7 in.)	Small (7.8 in.)	Extra Small (3.9 in.)
2.32	*A*	400	300	200	100
	W	100	75	50	25
2.81	*A*	600	450	300	150
	W	100	75	50	25
3.16	*A*	400	300	200	100
	W	50	37.5	25	12.5
3.32	*A*	900	675	450	225
	W	100	75	50	25
3.70	*A*	600	450	300	150
	W	50	37.5	25	12.5
4.25	*A*	900	675	450	225
	W	50	37.5	25	12.5

Table 1. Indices of difficulty (in bits) used in the experiment and the corresponding target amplitude (A) and width (W), in pixels, for each screen scale. Physical diagonal measurements (in inches) given for each screen scale.

ID. Excluding the practice round, each participant completed 4 screen sizes x 2 task types x 6 *ID*s x 14 selections = 672 selections, for a total of 5376 trials.

Results & Discussion

Throughput

Mean throughput scores for each condition are shown in Figure 4. Throughput was compared using repeated measures ANOVA. There was a significant main effect of screen scale on throughput ($F_{3,21} = 3.3$, $p < .05$).

The main effect for task type was also significant ($F_{1,7} = 44.3$, $p < .001$) – MovingTarget task throughput was lower than FittsCircle task. The interaction effect

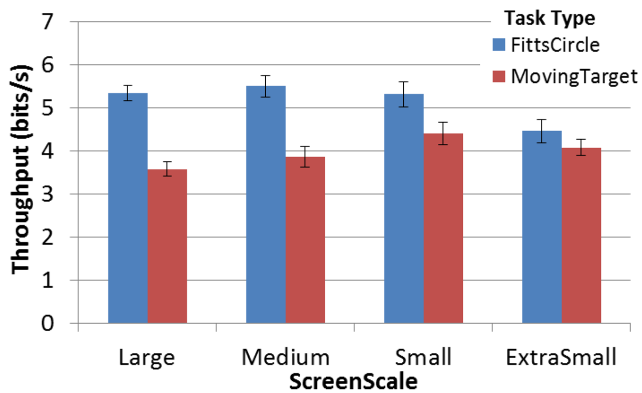

Figure 4. Mean throughput for each task and screen scale condition. Error bars show ±1 standard error.

between task type and screen scale was also significant ($F_{3,63}$ = 20.2, p < .0001). Tukey Kramer post hoc comparison revealed that the extra small screen scale had significantly lower throughput than medium screen scale for the FittsCircle task. Throughput differences between screen scale levels for the MovingTarget task were not significant ($F_{3,21}$ = 2.24, ns).

Movement Time

Regression models were built for each level of screen scale for the FittsCircle task. These models are depicted in Figure 5. The R^2 values are very high, demonstrating good adherence to Fitts' law for most levels of screen scale. Only the extra small screen scale has an R^2 lower than 0.9, and a high intercept as well. This result is consistent with throughput results: the extra small screen scale performs worse overall, and is less-well predicted by Fitts' law than larger screen scales.

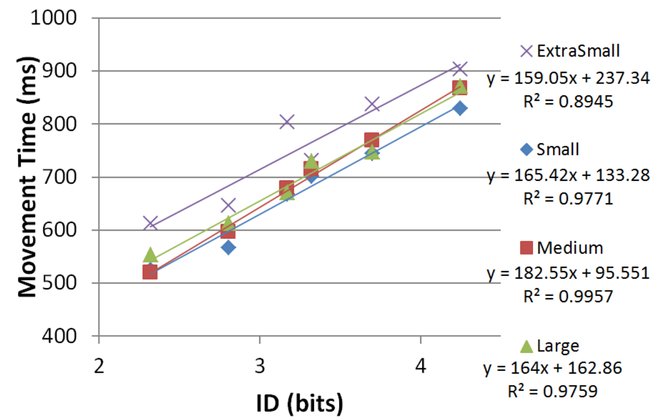

Figure 5. Regression models for each screen scale condition.

Discussion

The significant throughput difference between medium and extra small screen scale indicates that scale affects selection performance. This is consistent with the lower half of the "U-shaped" performance curve reported by by Accot and Zhai [1]. Larger scale differences may yield stronger affects. A larger screen scale might further uncover the upper half of the "U-shaped" curve.

It is not surprising that performance was higher with the FittsCircle task than the MovingTarget task. This difference may be larger with higher movement velocities, or less predictable target motion. Note that the interaction effect between screen scale and task type shows this difference is much smaller (and non-significant) for the extra small screen scale. This suggests that target movement hurts performance less on smaller displays. Future studies could focus on additional small levels of screen scale and target motion patterns to determine if this result changes. Similarly, it would be interesting to examine target movement *speed*. This would be especially beneficial to game developers to help maintain constant game difficulty across screen sizes. Higher speed would likely decrease performance further, especially on small screens. Since the current study used a constant (proportional) speed, we are unable to verify this.

It is noteworthy that the extra small screen scale had the worst fitting model, and was significantly worse than medium scale in the FittsCircle task. This result is similar to that of Chapuis and Dragicevic [2] who report that Fitts' law did not hold for very small displays. Smaller screen scales may yield worse still models.

Conclusions

We report findings of a study on screen scale and target movement in selection tasks. Using the Fitts' law experimental paradigm, we found that physical screen dimensions effect target acquisition performance, especially for small screen scales. Target movement also negatively impacted performance, but the difference between stationary and moving target performance was reduced for smaller screen scales.

Future work will include a greater range of screen scales and would focus on comparing finger-based pointing on mobile devices to mouse-based pointing. Since our current study used only mouse pointing, the results may change under such different input conditions. We would also further investigate the effects of target movement speed and pixel density across displays. Finally, a systematic approach to experimenting with screen size is required to facilitate comparisons between studies, especially if considering the interdependency of scale factors.

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