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# Target Expansion as a Means to Facilitate Eye-based Selection

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### Introduction

Complexity of modern software with constantly increasing numbers of UI widgets on display requires a careful approach to screen space management. Recently, research has focused on dynamically expanding targets as a means to facilitate pointing within the region at the user's focus of attention [1, 2]. In other words, iconic targets are expanded to a "pointing-friendly" size only when the user needs to interact with them; otherwise they are displayed considerably reduced in size. Consequently, this can provide an efficient solution to the problem of limited real estate of the screen.

Empirical evidence that dynamic target expansion speeded up performance in a point-select task was first reported in [1]. Furthermore, an improvement was achieved even when the target size changed as late as after 90% of the distance to the target had already been covered. In a subsequent study [2], these findings were validated for the case where target expansion was made unpredictable by presenting expanding targets along with shrinking and static ones in a random sequence.

The problem of limited screen space becomes even more severe in eye gaze driven interfaces. In the applied eye tracking literature, it is commonly agreed that eye gaze cannot be more accurate than one degree of visual angle, which places an eye tracker into the category of low-resolution pointing devices such as touch screens [3]. This limitation is dictated by the size of the fovea – the portion of the retina providing high acuity vision of the object of current interest. As a result, targets are required to subtend at least one degree of visual angle for sufficiently reliable pointing with an eye tracker.

The findings concerning expanding targets acquired by conventional manually operated pointing devices such as puck handles on digitizing tablets encourage investigation whether target expansion can also have a similar impact on target selection. One has to be cautious, however, when undertaking a transfer from the domain of manual control to eye gaze interaction due to fundamental differences.

First, for eye gaze, the benefits of *dynamic* expansion might be arguable due to the jumpy nature of eye movements. An object of interest can only be viewed during a short period of relative stability called a *fixation*. Fixations are connected by *saccades* – sudden motions of the eye – that allow navigation between objects of interest. These motions are ballistic in nature, meaning that each destination must be selected before the onset of movement (see [3] for more details). Since no proper visual feedback is available during a saccade, little advantage could be gained from dynamically expanding targets.

Second, even during a fixation the eye does not stay still. Instead, it constantly makes micro movements to allow visual perception of the scene. Given this jittery behavior, target expansion visible to the user would most likely act as a distraction. Finally, in a gaze-controlled interface, the cursor is redundant, since the gaze acts as the pointer itself.

The implications of the above are that static target expansion seems more reasonable to apply in eye gaze interfaces rather than dynamic. Also, there is a need to separate visual domain and motor space. In other words, the interface should respond to gaze point coordinates within the boundaries of the expanded target area, yet the appearance of the target should remain unchanged at all times.

To test the efficiency of invisible target expansion, we conducted an experiment involving a simple point-select task with movement time and error rate measured as performance indicators.

### Methods

**Participants.** Twelve volunteers (8 male, 4 female) participated in the experiment without compensation. All the participants were students at a local university. All had normal or corrected vision. Four of the participants had prior experience with eye tracking technology.

**Apparatus.** The experiment was conducted on a Pentium III 500 MHz PC with a 17-inch monitor set at the resolution of 1024x768. A head-mounted eye tracking system *EyeLink*™ from SensoMotoric Instruments was used as the input device. The participant PC was connected to another PC (Celeron 466 MHz) used for analysis of the captured eye images.

**Procedure.** Participants were seated at a viewing distance of approximately 70 cm. A simple point-select task was used for the experiment (Fig. 1). At the beginning of each trial, a magenta colored home box appeared on the screen with gray background. It was visible to participants as a square with 20 screen pixels on a side (solid outline in Fig. 1). The actual size of the home box, however, was 120 x 120 pixels (dashed outline). The expansion in motor space facilitated homing through increased tolerance to instabilities in calibration of the eye tracker. On the other hand, making only the central portion of the home box visible ensured bringing the gaze closer to the center of the box.

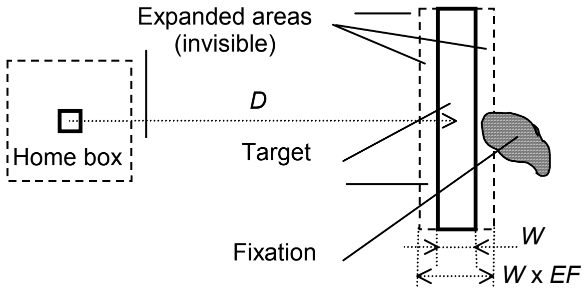

**Fig. 1.** Experimental task

Upon appearance of the home box, participants had to look at it and keep their gaze there for 1 second. If this requirement was met (indicated by the box turning green), a rectangular target appeared right away elsewhere on the screen. Otherwise, the box turned red to indicate that a trial could not start until the eye tracker was recalibrated.

Participants were instructed to look at the target as soon as it appeared in their peripheral field of view (timing started), and fixate upon the target until it was selected (timing ended). A time window of 3 seconds was given to participants for completing a trial. If no selection occurred during this time window, a TNC-type (trial not completed) error was recorded. Then, the next trial followed.

As revealed by our experiences from the experiment preparation phase, selecting targets as narrow as 20 pixels or so was not always straightforward. Quite often, only a small fraction of the gaze points belonging to the same fixation entered the target (see Figure 1 for illustration). As mentioned before, a scatter of the gaze points is inevitable due to the inherent jittery behavior of the eye. To tackle this, we introduced a simple aid called a grab-and-hold algorithm (GHA). The algorithm works as follows.

Upon appearance of the target, there is a settle-down period of 200 ms during which the gaze is expected to be brought into the target area and stay there. Then, the algorithm starts filtering out the gaze points until the first sample with the coordinates inside the expanded target area is logged. Once it succeeds, the target is highlighted, and the selection timer triggered. The timer counts down a specified dwell time (*DT*) interval.

The target is selected irrespective of the actual location of the gaze point at the moment of the *DT* expiry, provided no interruptions (i.e., interspersing saccades) occurred in the fixation throughout the *DT* interval. Thus the gaze is virtually held on the target once it is "grabbed". This way some intelligence is added to the interpretation of the eye tracker data: the gaze point is allowed to deviate from its intended destination as long as this deviation does not extend beyond the boundaries of the current fixation.

In case the eye makes a saccade before the end of the *DT* countdown, however, the target is de-highlighted resetting the selection timer. Then the algorithm starts hunting for the next gaze point that gets into the expanded target area, and the process is repeated.

**`Design.`** The experiment was a 3 x 4 x 3 x 3 x 3 x 3 repeated measures factorial design. The factors and levels were as follows:

| | |
|---|---|
| Dwell time | 750, 1000, 1250 ms |
| Direction | left, right, up, down |
| Distance (*D*) | 128, 256, 512 pixels |
| Width (*W*) | 12, 24, 36 pixels |
| Expansion Factor (*EF*) | 1, 2, 3 |
| Trial | 1, 2, 3 |

Although no learning effects were expected due to the highly intuitive nature of eye-gaze based pointing requiring no training, participants were still randomly assigned to one of three groups. Each group received the dwell time conditions in a different order using a Latin square.

For each *DT* condition, participants performed 12 blocks of trials (3 blocks per movement direction) in one session. The three sessions were run over consecutive days with one session lasting approximately half an hour. Each block consisted of the 27 *D-W-EF* conditions presented in random order. For each *D-W-EF* condition, 3 trials were performed. The trials for any of the conditions, however, were not repeated within the same block, but administered as separate blocks to allow more frequent breaks for resting the eyes. Thus, a block consisted of 27 trials. The conditions above combined with 12 subjects resulted in 11,664 total trials in the experiment.

The 27 *D-W-EF* conditions were chosen to cover a range of task difficulties spanning from 1.13 to 5.45 bits. The index of difficulty was calculated as:

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

The dependent measures were movement time (*MT*) and error rate (*ER*).

## Results

The grand means on the two dependent measures were 1672 ms for *MT* and 9.9% for *ER*. The main effects and interactions on each dependent measure are presented below. As could be expected, the 750-ms *DT* condition was the fastest with a mean *MT* of 1444 ms. The 1000-ms *DT* condition was slower by 17% (1683 ms), and the 1250-ms *DT* condition by 31% (1887 ms). The differences were statistically significant ($F_{2,22} = 191.0$, $p < .0001$). The main effect for *EF* was also significant ($F_{2,22} = 73.4$, $p < .0001$), as was the $DT \times EF$ interaction ($F_{4,44} = 4.2$, $p < .05$). The main effects and interaction are illustrated in Fig. 2.

Fig. 3 shows movement time as a function of movement direction. Vertical movements (with the means of 1714 ms and 1690 ms for the upwards and downwards direction, respectively) were slightly slower than horizontal movements (1653 ms and 1635 ms for the leftwards and rightwards direction, respectively). The differences were not significant ($F_{3,33} = 2.1$, ns).

The relationship between movement time and distance to the target is shown in Fig. 4.

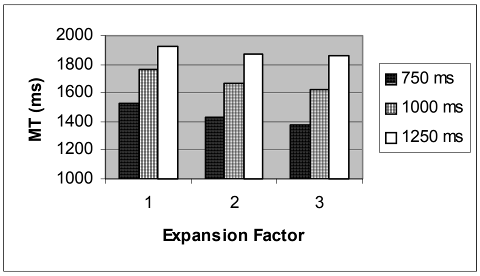

**Fig. 2.** Movement time vs. expansion factor for the three dwell-time conditions

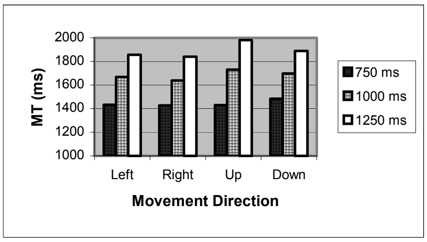

**Fig. 3.** Movement time vs. movement direction for the three dwell-time conditions

As distance increased, *MT* also increased. Averaged across the three *DT* conditions, it took 1641 ms to complete the task for the shortest distance. To cover the distance twice as large, an increase of less than 1% in *MT* was required (1655 ms). For the longest distance, an increase of 5% was observed (1724 ms). The differences were significant ($F_{2,22} = 27.6, p < .0001$).

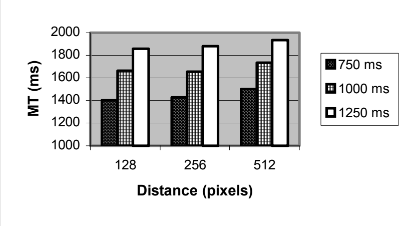

**Fig. 4.** Movement time vs. distance to target for the three dwell-time conditions

The lowest error rate was in the 1000-ms *DT* condition (9%). It was followed by the 750-ms condition at 10% of errors, and the 1250-ms condition at 10.9%. The differences were not significant ($F_{2,22} = 1.8$, ns). The main effect of *EF* on *ER*, however, was significant ($F_{2,22} = 101.0$, $p < .0001$). The $DT \times EF$ interaction was not significant ($F_{4,44} = 1.3$, ns). The main effects and interaction are illustrated in Fig. 5.

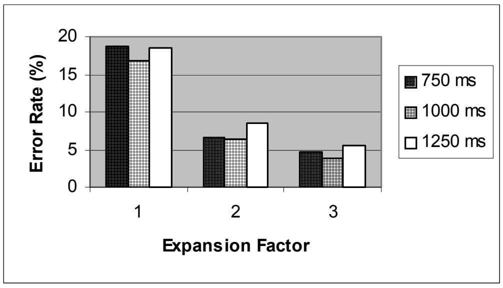

**Fig. 5.** Error rate vs. expansion factor for the three dwell-time conditions

Fig. 6 shows error rate as a function of movement direction. The highest error rates were recorded for the upward movements (17.8%). Movements in other directions were considerably less error-prone. Error rate for the downward movements was 8.6%, followed by movements to the left (7.1%), and finally movements to the right (6.3%). The differences were significant ($F_{3,33} = 85.9, p < .0001$).

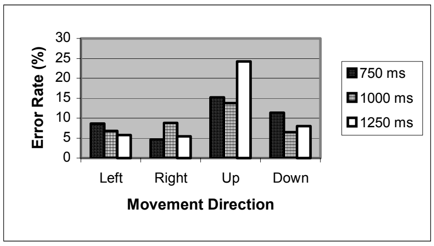

**Fig. 6.** Error rate vs. movement direction for the three dwell-time conditions

Fig. 7 displays the relationship between error rate and distance to the target. As with movement time, there were increments in error rate with increasing distance. Averaged across the three *DT* conditions, 7.8% of the trials were in error for the shortest distance. For the middle-range movements, error rate was 8.6%, whereas 13.4% errors occurred during the performance of the longest movements. The differences were significant ($F_{2,22} = 116.3, p < .0001$).

Regression analyses showed that the data for any of the three *DT* conditions did not fit the Fitts' law equation [4] very well, with $r^2$ values falling just under 0.7. This is in contrast to the finding in [5], where the equation accounted for more than 98% of the variability in the data. In that study, however, the mouse cursor was visible as a feedback of the current gaze point location, whereas no mouse cursor was present in this study. The presence of the cursor might have influenced the strategy of performing pointing movements.

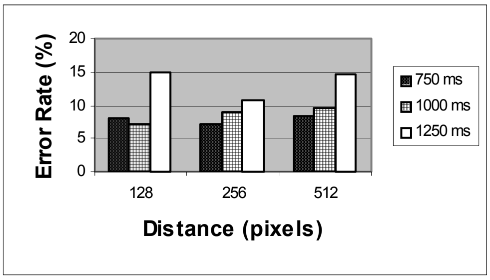

**Fig. 7.** Error rate vs. distance to target for the three dwell-time conditions

Despite the relatively low correlation, however, the slope of the linear regression line (99 ms/bit for the 750-ms *DT* condition) was consistent with the finding of [6] obtained for pointing at expanding targets with a puck on a tablet. This is a clear demonstration that a speed-accuracy tradeoff still takes place during eye gaze interaction, even in the absence of the pointer.

## Conclusions

The results of this study indicate that movement time to an expanding target decreases with increasing expansion factor. Also, movement time increases in quasi-linear proportion to dwell time on the target. Furthermore, there is a steady increase in movement time with increasing distance to the target. Movement time, however, is invariant with respect to approach angle to the target (i.e., movement direction).

As with movement time, there is a similar trend in reduction of target selection errors with expansion factor getting bigger. Moreover, error rate increases with increasing distance to the target. Error rate is affected by movement direction: there is a marked increase for movements in the upward direction, whereas performance in other directions exhibits a similar pattern. In contrast to movement time, error rate is independent of dwell time on the target.

As evidenced by the data, there is a speed-accuracy tradeoff during performance of target selections with eye gaze. In other words, movement time is traded off against error rate to optimize the performance.

Overall, the results of this study clearly demonstrate that target expansion in motor space (i.e., invisible to the user) facilitates pointing both in terms of speed and accuracy. Even though the associated spatial cost is permanent, the space occupied by the expanded areas can still be used for display of non-interactive objects.

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**D. Miniotas, O. Špakov. Ekrano taikinių plėtimasis kaip priemonė jų išrinkimui žvilgsniu palengvinti // Elektronika ir elektrotechnika. - Kaunas: Technologija, 2004. – Nr. 3(52). – P. 13-16.**

Pastarojo meto publikacijose skelbtos išvados, jog besiplečiantys taikiniai pagerina kompiuterio žymeklio pozicionavimo ranka kokybę, kelia provokuojantį klausimą: ar panašaus rezultato galima tikėtis ir valdant žvilgsniu? Šiame darbe aprašomas eksperimentas, kuriuo buvo siekiama ištirti taikinio plėtimosi įtaką jo išrinkimo žvilgsniu tikslumui ir spartai. Eksperimente dalyvavo dvylika tiriamųjų, o įvesčiai buvo naudojama akių judesių registravimo sistema *EyeLink*. Gauti rezultatai rodo, jog tiek judesio link besiplečiančio taikinio laikas, tiek išrinkimo klaidų procentas yra atvirkščiai proporcingi plėtimosi koeficientui ir tiesiog proporcingi atstumui iki taikinio. Judesio laikas yra kvazitiesinė reglamentuotosios taikinio fiksacijos žvilgsniu funkcija, tačiau klaidų procentui šis parametras įtakos neturi. Tuo tarpu judesio kryptis turi įtakos klaidų procentui, bet nedaro poveikio judesio laikui. Taigi rezultatai patvirtina taikinio plėtimosi naudà pozicionavimo kokybei. Todël naudojant besipleèianèius taikinius didëja þvilgsniu vykdomos ávesties praktinio pritaikymo potencialas. Il. 7, bibl. 6 (anglø kalba; santraukos lietuviø, anglø ir rusø k.).

**D. Miniotas, O. Spakov. Target Expansion as a Means to Facilitate Eye-based Selection // Electronics and Electrical Engineering. - Kaunas: Technologija, 2004. – No. 3(52). – P. 13-16.**

Recent evidence about positive impact of expanding targets on user performance during manual pointing raises a provocative question whether a similar effect can be expected for eye gaze interaction. We present an experiment designed to examine the benefits of target expansion during an eye-controlled selection task. The experiment involved twelve participants and a head-mounted eye tracking system *EyeLink*™ used as the input device. Our results suggest that both movement time to an expanding target and selection error rate are reciprocal functions of expansion factor and monotonic functions of distance to the target. Furthermore, movement time is a quasi-linear function of dwell time on the target, whereas error rate is invariant with respect to dwell time. Finally, movement direction has an effect on error rate, but not on movement time. Overall, the results confirm the boosting effect of target expansion both in terms of pointing speed and accuracy. These findings indicate that target expansion has the potential of making eye gaze input more suitable for practical applications. Ill. 7, bibl. 6 (in English; summaries in Lithuanian, English, Russian).

**Д. Миниотас, О. Шпаков. Расширение экранных целей как средство облегчения их выбора взглядом // Электроника и электротехника. – Каунас: Технология, 2004. – № 3(52). – С. 13-16.**

В публикациях последнего времени сделаны выводы о том, что расширяющиеся цели улучшают качество позиционирования рукой компьютерного курсора, задают провоцирующий вопрос: можно ли ожидать подобного результата и в случае управления взглядом? В этой работе описывается эксперимент, целью которого являлось выяснение влияния расширения цели на точность и скорость ее выбора. В эксперименте участвовало 12 испытуемых, а ввод осуществлялся при помощи системы регистрации движения глаз EyeLink. Полученные результаты показывают, что время движения в направлении цели и процент неудач при выборе обратно пропорциональны коэффициенту расширения и прямо пропорциональны расстоянию до цели. Время движения является квазилинейной функцией от регламентируемой для фиксации взглядом, но для процента неудач этот параметр значения не имеет. В то же время направление движения влияет на процент неудач, но не на время выбора. Эти результаты подтверждают выгоду использования расширения цели на качество позиционирования. Ил. 7, библ. 6 (на английском языке; рефераты на литовском, английском и русском яз.).

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