Using Space: Effect of Display Size on Users' Search Performance

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Abstract
Due to advances in technology large displays with very high resolution started to become affordable for daily work. Today it is possible to build display walls with a pixel density that is comparable to standard office screens. Previous work indicates that physical navigation enables a deeper engagement with the data set. In particular, visibility of detailed data subsets on large screens supports users' work and understanding of large data. In contrast to previous work we explore how users' performance scales with an increasing amount of large display space when working with text documents. In a controlled experiment, we determine participants' performance when searching for titles and images in large text documents using one to six 50" 4K monitors. Our results show that the users' visual search performance does not linearly increase with an increasing amount of display space.

Author Keywords
wall-sized displays, large displays, search task

ACM Classification Keywords
H.5.2 [User Interfaces]: Graphical user interfaces (GUI).

Background

The advent of large high-resolution screens enables fundamentally new possibilities to explore all kinds of data sets. A substantial body of work showed positive effects of large high-resolution screens on exploring large data sets. Most previous work focused on visual analysis of complex data sets. Andrews et al., for example, compared a regular desktop setup with a 17" monitor with a large high-resolution display consisting of 8 30" LCD-panels for sense-making [1]. They showed that participants use the larger display space to arrange information spatially, while users tend to maximize windows when using a 17" display. These findings are supported by Kirsh [4]. He argues that humans use (physical) space to group, to classify, and to order artifacts for keeping an overview of the information displayed and for supporting its recall.

Beside the spatial information arrangements, also the position, orientation, and movement of the users can improve the process of data exploration. Jakobsen et al. considered proxemics for information visualization on large screens, and found that users perceive data navigation by moving their own body to be natural and fast [3]. The authors conducted two user studies on a 3 m $\times$ 1.3 m, 24 megapixel screen. The qualitative results presented by Jakobsen et al. are supported by quantitative results of Ball et al. [2]. They compared search tasks on a map using large screens of different sizes. In the experiment they used a monitor matrix with 8 $\times$ 3 monitors. Each with an resolution of 1280 px $\times$ 1024 px. The results show that users find content faster on larger screens when physically moving themselves in front of the large display than if using the mouse to move the content closer to them. Similarly, Yost et al. compared users' performance on visual search. As different conditions the authors used three different screen sizes. They showed that users perform the tasks faster and more precise when using large screens [6]. For this experiment the authors also used a matrix of 8 $\times$ 3 monitors (17") each with a resolution of 1280 px $\times$ 1024 px.

Our work is mainly motivated by the work of Liu et al. who found that the mental load as well as the user's frustration are lower when performing a sorting task on a wall sized display (5.5 m $\times$ 1.8 m, 20480 px $\times$ 6400 px) than when performing the same task using a desktop setup (30", 2560 px $\times$ 1600 px) [5]. In contrast to previous work, we are interested in investigating the effect of display size on searching in large text documents. Interaction with text documents is a very frequent task in office environments. Therefore, it is an important question if we can support office workers with displaying all pages of a large document at once.

In this paper we investigate if the perceived effort as well as the time needed for searching for titles and images in large text documents depends on the size of large displays. In a controlled experiment we vary the display size by using one to six 50" 4K monitors. We measure participants' task completion time as well as their perceived task load. Thereby, we complement previous work through an analysis of participants' objective performance and subjective perception while searching in large textual data using different sized large screens.

Experiment

To explore the effect of display size on users' visual search performance and perceived effort, we conducted an experiment with a repeated measures design. Our only independent variable was the display width. We used a large high-resolution display consisting out of six single monitors. This allowed us to vary the display width by

switching off single monitors. The six monitors were mounted next to each other in portrait orientation (see Fig. 1). During the study, we used six 67.3 cm $\times$ 113.1 cm 50" 4K Panasonic TX-50AXW804 monitors, which result in one 4.04 m $\times$ 1.13 m display for the condition where we used all six monitors. Each individual monitor has a resolution of 2160 px $\times$ 3840 px resulting in a pixel density of 88 PPI.

Our dependent variables were users' item search time or task completion time (TCT) and perceived task load recorded with the NASA Task Load Index (NASA-TLX). The search task concerned title and image search within text documents. Thus, we presented research papers from the CHI'13 and CHI'14 proceedings on the display and asked participants for retrieving the position of titles and images in the documents through mid-air pointing at the search items.

Figure 1: Setup of the six 50" screens used during the study. Only four screens are used in the shown condition.

To present text documents on the screen, we implemented a custom PDF viewer that shows an adjustable number of pages on the display. During the study we showed 12 pages on each of the used monitors. In each condition, 150 US letter format PDF pages (that are 15 full CHI papers) were presented in total, while the number of immediately visible documents varied per condition according to the number of monitors used. For example, during the condition when all six monitors were used, 72 US letter format PDF pages were displayed at the same time (see Fig. 1). The pages were ordered from left to right across the monitors over the whole display.

Participants could navigate back and forth through all documents (to scroll to those that were not visible on the display) using the arrow keys on a regular wireless keyboard.

We recruited 6 male and 6 female participants through the university's mailing lists. Their effort was compensated with 10 EUR. Participants' average age was 21.17 years ($SD = 2.67$). All participants spoke English fluently.

After welcoming a participant, we introduced the research context and asked the participant to fill in a demographic form. Afterwards, we asked our participants to solve two tasks. In the first task, participants had to search for a specific paper title. The instructor read the title out loud and showed the participant the title printed without any formatting. In the second task, we asked participants to search for an image. The instructor showed the image without caption as a printout.

For every new task a new set of 15 CHI full papers was presented. Hence, no participant saw a paper more than once. We repeated each task three times per condition. Thus, in total the participants performed 36 tasks (6 conditions $\times$ 2 task $\times$ 3 repeats). After performing six tasks of one condition, we asked the participants to fill in a NASA-TLX. We counterbalance the order of the

conditions. We also counterbalanced the position of the search targets. One third of the targets were placed in the first third of the 150 pages, one third in the second third and one third in the last third of the pages. After all tasks had been completed, we asked the participants how many monitors they would like to use, if they could freely choose.

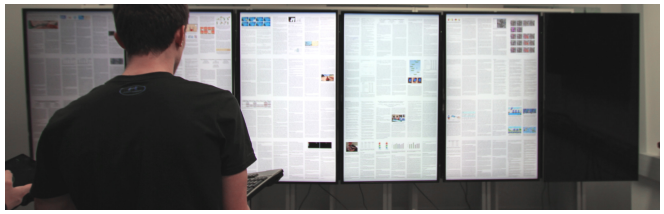

Figure 2: Participant during the condition with 5 monitors.

Results

During the experiment, we recorded task load for each condition and items' search time for each item that had to be searched. We used the item's position in the overall document as an additional factor when analyzing search time assuming that the item position had a substantial effect on required search time.

For the image as well as for the title search, the descriptive statistics (see Table 1) led us to suggest that the number of monitors effects TCT and NASA-TLX just to a certain extend.

Title search. While the average TCT for finding a title in the first third is decreasing from using one up to three monitors, increasing from three up to six monitors results in an increase of TCT (see Fig. 3, line A). TCT for finding a title within the second third of the document is slightly decreasing with more display space. However, again the participants were slightly slower with six monitors in comparison to using only five (see Fig. 3, line B). Only when the item was placed in the last third of the document, TCT was smallest for the condition with six monitors (see Fig. 3, line C).

Image search. The TCT for searching an image shows a similar trend. If searching for an item in the first third of the document, there is no positive effect of having more than one or two monitors (see Fig. 3, line A). For searching items in the middle of the document, three monitors seems to be most suitable (see Fig. 3, line B). The largest decrease of TCT occurred if the search item was in the last third of the document.

The results of the NASA-TLX do not vary much over all conditions (see Fig. 3). Only the physical demand is clearly increasing for the conditions with five and six monitors. The question, how many monitors are desirable indicated that nobody was interested in using more than four screens for daily work. Five (out of 12) participants would like to use three monitors at most.

Number of monitors	TLX	TCT title	TCT image
1	39.24 (11.09)	13.46s (6.91)	11.79s (8.51)
2	34.24 (17.97)	11.40s (7.74)	9.29s (6.62)
3	37.15 (13.40)	10.30s (7.61)	9.54s (6.92)
4	34.17 (14.47)	11.77s (8.60)	9.97s (8.06)
5	38.96 (14.80)	10.99s (8.94)	8.85s (6.14)
6	41.81 (12.38)	12.04s (8.01)	9.53s (6.48)

Table 1: The overall NASA-TLX and TCT for the two tasks. Numbers in parenthesis show the standard deviation.

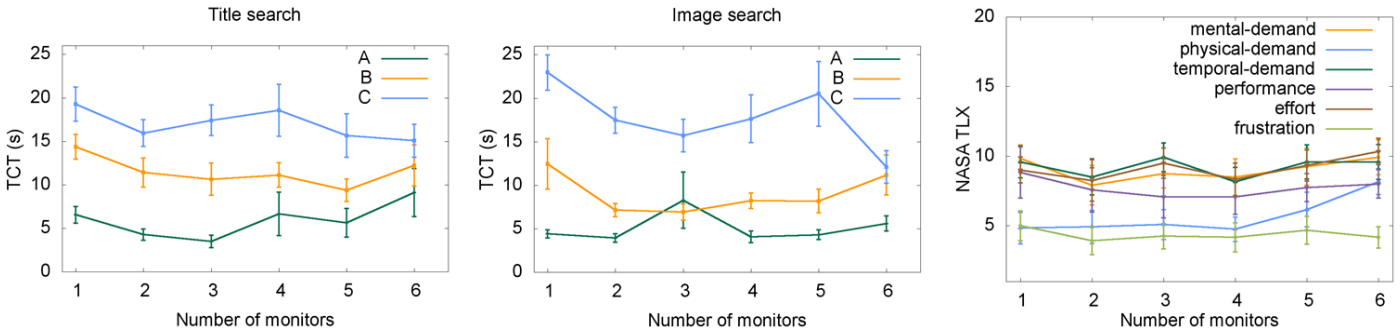

Figure 3: The left and the center chart show task completion time for finding a title (left) and an image (center) in a document using 1 to 6 monitors: (A) The item is in the first third of the document, (B) the item is in the second third of the document, and (C) the item is in the last third of the document. The right chart shows the NASA Task Load Index for finding an item in a document.

Conclusion and Future work

We conducted a study to investigate the effect of display size on item search performance and task load. As search context, we used papers from the CHI'13 and CHI'14 proceedings displayed on a large high-resolution screen. We asked the participants to search for titles and images in the documents. For both search tasks we found only a small effect of the screen size on TCT and on perceived task load. Our results show that screen sizes up to four monitors (269.2 cm $\times$ 67.3 cm) are beneficial. We found that larger screens can support the work with very large data sets, if the search item is at the end of the document.

Accordingly, our results show that TCT is only decreasing with an increase of display size when the search item is not in the beginning of the document. This might have different reasons. All participants started their searches at the beginning of the documents and continued towards the end, which corresponds to searching from left to right. Thus, for items in the first third only four monitors are needed to display the item without a need to scroll within the content. With a high probability then the item was already displayed on one of the first three monitors. Therefore, search results of having three monitors by great change were as difficult as if having four, five or six monitors, which decreased to find clear correlations between display size and search performance.

If the target is at the beginning of the document more screen space has a negative effect on TCT. The reason might be that the user is overwhelmed by closeness of large visible content. We know from searching on great maps that taking a step backwards helps to cognitively capture many information visible at the same time.

According to participants' physical demand and their subjective feedback, three monitors, with a size of 269.2 cm $\times$ 67.3 cm seems to be optimal when searching for titles and images in text documents, which has also been confirmed by subjective comments. With more display space the user has to start to move physically. While previous work showed that physical movements can

be beneficial [2], our participants perceived walking around as additional work load that was perceived to be annoying.

In this work we did not prescribe a particular position of the participant. However, this might influence the performance and the work load. In future studies we will compare different body postures for browsing large documents. In general the feedback from our participants indicates that the use of large and high-resolution displays is more beneficial to discover similarities and trends in large data sets than for browsing through large documents to search for a title or an image. Thus, in our future work we aim to shift our focus towards an analysis of the effect of screen size on tasks that involve comparing and classifying large data sets.

To conclude, this work shows first results about how much screen space is useful for browsing through large amounts of traditionally structured text documents. We learnt that there is a need for a deeper understanding of the influence of users' position, body posture and movement to guide the design of large and high-resolution screens for future work places. Moreover, we suggest to explore alternative ways of content structuring when using large sized displays.

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