HCI and Cognitive Psychology related Performance Benefits and Disadvantages of Large High-Resolution Displays for Single User Application

Fabian Martinis

Bachelor Thesis

Institute of Psychology

University of Basel

April 2014

UNI BASEL

Thesis Supervisors: Mirjam Seckler, M.Sc., Prof. Dr. Klaus Opwis

Center for Cognitive Psychology and Methodology

Human-Computer Interaction Lab

Missionsstrasse 62a, Institute of Psychology, University of Basel

Author Note: Fabian Martinis, Im Marteli 5, 4102 Binningen

fabian.martinis@stud.unibas.ch

Abstract

This bachelor thesis examines the use of large high-resolution displays, as a single unit or as a total of multiple displays resulting in a large space to visualize information for single user application. The resulting benefits and drawbacks of said display arrays, based on research in HCI and cognitive psychology are considered. A multitude of different aspects of large high-resolution displays are being examined. Physical and technical attributes, such as bezels and pixels are defined. Interaction on large high-resolution displays is investigated. Cognitive theories such as using the human spatial memory for sensemaking, mental workload, change blindness, eccentricity effects and interaction techniques are examined. Ultimately this bachelor thesis is concluded to answer the question whether large displays positively or negatively impact user performance and thus productivity.

Table of Contents

Introduction 5

Physical and Technical Attributes of Large High-Resolution Displays 6

Definition of large high-resolution display 6

Display size 6

Bezels 6

Resolution 7

Interaction 8

Spatial Arrangement of Information Sources 8

Navigation in virtual environments 9

Benefits of Large High-Resolution Displays 9

Proprioception, physical navigation and virtual navigation 9

Making use of the human spatial memory 10

A large amount of pixels offers a large visualization capability 13

Peripheral awareness 14

Disadvantages of Large High-Resolution Displays 14

Arrangement of display arrays 15

Information overflow 15

Change blindness 16

Mental workload 17

Interaction related difficulties 17

Discussion 18

Physical navigation – a key benefit of large high-resolution displays with minor disadvantages 18

Cognitive aspects – enhancements and obstacles 19

Obstacles of current research 20

Future research 20

Conclusion 21

References 23

Introduction

Large high-resolution displays are becoming increasingly common at offices and similar workstations as displays are becoming less expensive (Ball & North, 2005; Ni et al., 2006). Thus, especially multi-display configurations are made use of more frequently (Nacenta, Gutwin, Aliakseyeu & Subramanian, 2009). Due to the larger screen real estate, users are able to view more information at once and in a more detailed view than on a smartphone or tablet (e.g. Andrews, Endert, Yost & North, 2011; Ball & North, 2005).

Large high-resolution displays feature a variety of performance enhancing qualities, such as visualizing a large amount of data simultaneously and in greater detail due to graphical scalability (Andrews et al., 2011), provided the display has an adequate resolution (Sawant & Healey, 2005). Tasks such as professional editing or handling data sheets profit from an increased screen real estate as the physical navigation can replace virtual navigation such as zooming, panning and thrashing through open windows (Andrews et al., 2011).

However, there are drawbacks and challenges to be considered, ranging from compatibility to interaction problems, change blindness, information overflow (Bi & Balakrishnan, 2009; Truemper et al., 2008) and mental workload (Rantanen & Goldberg, 1999; Yost, Haciahmetoglu & North, 2007).

To the author’s knowledge there is no scientific paper comparing the benefits and disadvantages of large high-resolution displays under consideration of cognitive psychology as well as interaction strategies while including the individual advantages and disadvantages of these cognitive psychology and interaction related properties of large high-resolution displays. Therefore, this bachelor thesis examines the use of large high-resolution displays, as a single unit or as a compilation of multiple displays resulting in a large space, to visualize information and answer if the resulting benefits and drawbacks are in favour or against the use of large high-resolution displays for single user application. Single user application refers to the use of large high-resolution displays by a single person. Thus, this bachelor thesis does not address the use of large-high resolution displays for simultaneous use by multiple users.

Physical and Technical Attributes of Large High-Resolution Displays

To facilitate the understanding of how large high-resolution displays influence the cognitive functions and interaction techniques of the user, the following section provides a description of the physical and technical attributes of large high-resolution displays.

Definition of large high-resolution display

The technological definition of a large high-resolution display is subjective. Through the advancements of technology the perception of a large high-resolution display changes (Andrews et al, 2011). Thus, Andrews et al. (2011) define a large high-resolution display as a display which through its resolution and size approximates or exceeds the limits of the user's visual acuity.

Display size

Large display real estate can be achieved by either a single large display or by stacking and/or tiling multiple regular sized displays. Hsieh and Tamura (as cited in Melanson, 2012) found that as of the fourth quarter of 2012, the average display size, measured in the displays' diagonal, for a desktop computer measures 20.7 inches. Most of the research examined here focuses on multiple stacked and/or tiled displays as it is the more common and accessible way for a user to achieve a large high-resolution display (Ni et al., 2006).

Bezels

Bezels are the physical frames surrounding the display panel. While a single large display only has one bezel surrounding it in its entirety, multiple displays have a bezel for each display in the array.

Bezels offer the possibility to partition the total screen real estate into sections and therefore divide the tasks at hand and thus enhance or even promote multi-tasking (Truemper et al., 2008). However, bezels also introduce a visual break in the full picture, due to the fact that there is no actual display underneath the bezel, thereby increasing the distance the user has to travel with the input device. This may be distracting to some users and lead to cursor skipping, and propagating mouse cursor loss (Robertson et al., 2005).

Resolution

The resolution or “amount of pixels” on a display is determined by the amount of pixels in one horizontal line multiplied by the vertical amount of pixels (e.g. 1920x1080 pixels). The resolution of a display determines the amount of information it is capable of visualizing (Andrews et al., 2011). As of January 2014, www.w3schools.com claims that 99% of display resolutions are 1024x768 pixels or higher.

Ware (2000) suggests that the optimal resolution is 4000x4000 pixels, as it was most efficient at matching displayed pixels to “brain pixels” which interpret the signal transmitted from the eye photoreceptors, while Wegman (1999) suggests that approximately 6’500’000 pixels are perceivable at a regular viewing distance.

Most visualization techniques assume that sufficient display resolution is available and the human visual acuity is sufficient to complete the required task, which is not necessarily the case, especially for complex datasets (Sawant & Healey, 2005). This assumption directly affects visual scalability, an important factor that has be taken into consideration when talking about the benefits of large displays. As Eick and Karr (2002) specified: “Visual scalability is the capability of visualization tools effectively to display large datasets, in terms of either the number or the dimension of individual data elements.” (p. 1). An initial measure of how much a specific visualization design profits from being visualized on a large, high-resolution display is graphical scalability. Andrews et al. (2011) define “graphically scalable” as encoding with limitations which can be addressed by adding more pixels. Therefore limitations introduced by the limited number of pixels available, become less of a restriction on large, high-resolution displays, as the amount of pixels available to visualize a dataset is higher than on a standard display (Yost et al., 2007). Hence, the resolution of a display plays a significant role in its ability to visualize data as both visual and graphical scalability have to be considered.

Interaction

Large high-resolution displays tend to change the way users interact with them, or more specifically how they interact with their virtual environment. They offer new ways of arranging the information sources and navigating through them. The following section provides an analysis of interaction techniques used on large high-resolution displays.

Spatial Arrangement of Information Sources

The ability to arrange visualization in a spatially meaningful way is a common interaction technique for virtual environments (Andrews, Endert & North, 2010; Andrews et al, 2011; Bi & Balakrishnan, 2009). Clustering visualizations is not a benefit exclusive to large high-resolution displays. But large high-resolution displays greatly extend clustering by adding the possibility to cluster views and their contents. Spatial interaction enables a deeper analysis by interactively adjusting proximities. Large high-resolution displays boost spatial interaction, such as dragging and dropping, spatial arranging and linking, grouping and clustering of information sources (Andrews et al., 2011).

Bi and Balakrishnan (2009) observed users to simultaneously display an increased amount of windows when working on large high-resolution displays compared to their private single or dual display configuration. They have observed dual display users partitioning the large high-resolution display in a focal and a peripheral region, as they do with their private dual display setup. But also users who usually rely on a single display for their daily work, showed this behaviour. The primary task was usually located in the focal region of the display. Most of the interaction, measured in mouse events, such as clicking and dragging, occurred in the assigned focal region of the display. The peripheral region was mainly used for applications, such as email clients, instant messaging, assisting documents and search pages. The applications placed in the peripheral region of the display served as assistance for the primary task.

Navigation in virtual environments

The use of regular sized displays mostly relies on virtual navigation techniques (Andrews et al., 2011), such as panning and zooming as described by Eick and Karr (2002) to "involve manipulating a logical viewport over a much larger graphical display." (p. 29). Large high-resolution displays on the other hand offer virtual and physical navigation, such as turning the head, as viable options of navigation. Bi and Balakrishnan (2009) have observed an increase in physical navigation as well as virtual navigation techniques, such as resizing and dragging the information source of interest into the focal region of the display.

Benefits of Large High-Resolution Displays

The following section addresses the cognitive psychology and interaction related benefits offered by large high-resolution displays. Specifically the human spatial memory, peripheral awareness and shifts in interaction techniques are examined.

Proprioception, physical navigation and virtual navigation

Switching between open windows and thrashing through information sources using key combinations such as "Alt+Tab" and "CMD+Tab" or using the input device, mouse, touchpad or touchscreen to select open windows and applications from the taskbar, are widely known utilities that can be found in many operating systems (e.g. Windows, Mac OS and GNU/Linux). Those utilities serve to switch information sources into the focus of the display in order to gain a detailed view of their content. This virtual navigation has a negative effect on the time needed to complete a task which requires multiple sources of information, as these techniques, especially the ones relying on cursor or touch input, are not very efficient (Ball, North & Bowman, 2007).

Physical navigation, in contrast to virtual navigation, does not rely on input devices of any sort or switching the display output, but rather uses physical means to navigate between information sources such as moving the head or a flick of the eyes (Ball et al., 2007). Physical navigation is more efficient due to the embodied resources that support it, even if virtual navigation may be faster under certain circumstances (Andrews et al., 2011).

Large high-resolution displays enable the user to go through information at multiple levels of detail through physical navigation while smaller, lower resolution displays do not offer this possibility (Ball et al., 2007). The use of large high-resolution displays also reduces the need to drag and resize windows in order to access the desired level of detail after opening more than one application (Truemper et al., 2008). Thus, large high-resolution displays reduce or even eliminate the need for virtual navigation, depending on the number of applications to display. Increased display size correlates with an increase in physical navigation which again correlates with a lower task completion time (Ball et al., 2007). Ball et al. (2007) observed that physical navigation was preferred and made use of whenever applicable.

Making use of the human spatial memory

In their study Ball and North (2005) found that large high-resolution displays increased the user’s performance in basic visualization tasks of finely detailed data. Their goal was “to explore the fundamental trade-offs between low- and high-resolution displays for basic low level visualization and navigation tasks” (p. 2). They chose a 3x3x2 design, either one, four (2x2) or nine (3x3) tiled displays, each with a resolution of 1280 x 1024. The tasks to be fulfilled were finding a single target and comparing paired targets or finding and comparing targets of identical shapes. The targets were clusters of red pixels in a picture consisting otherwise of grey pixels. Three differently sized targets were chosen. The picture used was specifically designed for this study and had a total resolution of 3840 x 3072 pixels, so it was to entirely fit the largest display condition. For this experiment 36 participants were tested, 36% females and 64% males. All participants completed their tasks on all three display configurations, but only one target size condition per participant had been used.

The data gathered by Ball and North (2005) shows that recognition of small targets was significantly faster in the nine display condition than in the one display condition. Also, there had been a trend showing that larger displays in general facilitate small target detection. The nine displays never negatively impacted the participants' performance. The performance in the four display condition was equal or superior to the one display condition for all participants.

The largest display condition consisting of nine (3x3) displays, made virtual navigation, in this case zooming and panning, superfluous due to the fact, that the picture containing the targets to be found, was shown in its entirety. The targets did not change their relative position on the display and thus enabled the participants to spatially remember their location. This spatial memory was enhanced by the bezels of the displays as they acted as natural borders segmenting the picture. Neither multiple reportings of the same targets nor claiming the targets to be inexistent occurred in the nine display condition. Moreover, all the participants were much less frustrated when using multiple displays (Ball & North, 2005). Ball & North (2005) therefore concluded, that large high-resolution displays are beneficial for basic visualizations of finely detailed information.

Andrews et al. (2010) define “sensemaking” as “the process of building understanding out of a collection of data” (p. 1). They classify the use of space for sensemaking into two categories: memory and semantics. Memory is focused specifically on internal memory, referring to memorizing and recalling information, and external memory, referring to making information accessible through visibility and presence. Semantics is referring to spatially grouping and categorizing documents to create relations between the information sources.

Andrews et al. (2010) suggest that many representations created by individuals are ultimately a form of external memory due to the fact that objects in space are persistent and visible. It is important to consider the space occupied by the visualizations on large displays. An analogy to external memory drawn by Andrews et al. (2010) names the to-do notes which are stuck to the display as an example for external memory as they are as much about content as they are about their placement in space. The notes are spatially persistent meaning they do not shift their location, they remain attached to the display, and are in a location of attention where casual gazes are drawn to and therefore refresh the internal memory.

As with the sticky notes on the bezel of the display, they have observed this behaviour on the display itself as well. Important documents were placed in obvious locations and in full visibility, thereby meaning detailed view, while documents of lesser relevance or importance were overlapping each other. The documents' visual appearance and location provided the users with cues that allowed them to stay conscious of the state of the document. The respective location of the information sources can be considered as crucial to enable easy access to the information itself. Virtual navigation such as zooming and switching focal windows is replaced by physical navigation such as turning the head, flicking the eyes and equal bodily movement (Andrews et al., 2011).

The spatial layout of the information visualizations provides a reduced need for changing the focus away from the current task as information can be gathered by simply looking at another region of the display. If users have to relocate an object of interest they require recall and recognition while in a spatially meaningful layout the perception allows using cues linked to the relative position of the documents to each other and thus reducing the need for recall (Andrews et al., 2011). Jang, Trickett, Schunn and Trafton (2012) found that stacking information sources may reduce task completion time by up to 30% as the users have to memorize the previous information while switching back and forth between windows as compared to being able to view the information sources side by side.

Space also provides a “flexible semantic layer” (Andrews et al., 2010) which introduces meaning to the specific alignment of the visualizations relative to each other. If the spatial layout of the information displayed is used in this way, it reduces the need to construct internal models of the information at hand through replacing memorization and processing by perception. It is more efficient and easier to recognize categories of visualizations than to memorize the relation between the documents and their respective contents.

Andrews et al. (2010) coined the phrase “Unless explicitly specified (…), space imposes no strict interpretation on space.” (p. 63). They suggest that the space available can be used in a multitude of different ways. The users may experiment with possibilities of alignments and context groups on the display area starting off by creating rough categorizations of information and as they get deeper into the subject at hand creating more meaningful patterns that are easy to retrace and thereby result in a better understanding of the data.

A large amount of pixels offers a large visualization capability

The resolution or number of pixels on a large display, either the amount of pixels found in one large display or the total of pixels found across multiple displays, is of great importance to the benefit of utilising a large display area in the first place (Andrews et al., 2011). An increased number of pixels offers the possibility to create an environment in which the visualizations can be linked between their representation and position. While on regular “small” displays with a standard amount of pixels, documents can either be viewed in detail mode, which results in them taking up most of the display’s real estate or in icon view, where details are not visible. On large high-resolution displays, multiple detailed views can be visualized at the same time and still not take up the full available display surface and therefore allow for objects, such as documents, browsers or other programs to be arranged in spatially meaningful patterns (Andrews et al., 2010).

Bi and Balakrishnan (2009) found that users strongly preferred large high-resolution display environments for their daily work. Their results indicate that a large high-resolution display is of great advantage for tasks requiring multiple applications with a fitting or exceeding number of visualizations as the user may perceive multiple detailed information sources at once. Especially information rich tasks including spreadsheets such as Microsoft Excel and virtual maps benefit from large high-resolution displays, as more information can be shown simultaneously and therefore the need for virtual navigation is reduced.

Peripheral awareness

Peripheral awareness is a key benefit for large high-resolution displays. It enables the user to take advantage of the peripheral vision to monitor applications of lower importance than the primary task or applications serving a different purpose, when placing them in the peripheral areas of the display (Bi & Balakrishnan, 2009).

In their study, Bi and Balakrishnan (2009) instructed the participants to complete their daily routine computer work on a large high-resolution display, a setup of multiple projectors, for five hours a day for five consecutive days. The participants found the large high-resolution display to be a more immersive experience than the regular desktop display which helped them focus on attention requiring tasks such as proof reading and coding. The large high-resolution display also provided some ergonomic benefits by not having to gaze at a small area for a long period of time and therefore experiencing less fatigue .

Disadvantages of Large High-Resolution Displays

Large high-resolution displays also have disadvantages. The following section focusses on variety of different factors that may affect the usability and user experience of large high-resolution displays. Those factors include physical aspects as well as cognitive and interaction related disadvantages of large high-resolution monitors.

Arrangement of display arrays

When creating an array of multiple tiled and/or stacked displays the bezels of the displays have to be taken into consideration as they may impact the usability of said array.

Truemper et al. (2008) found that if multiple displays were to be used most efficiently, there is suboptimal display distributions. The 2x2 grid of displays used in their study was considered as not as usable by many of their participants since the centre of the display was blocked by the bezel. Therefore the authors suggest that a 2x2 layout may not be the optimal arrangement for a multi-display configuration.

Robertson et al. (2005) and Ni et al. (2006) found that if visualizations such as windows or pictures are crossing bezels, because they are too large to fit a single display, visual discontinuity is introduced which makes reading text or examining pictures more difficult. Also, when the mouse cursor crosses the bezels, it often seems to be jumping the displays as the physical bezel has no virtual representation on the display itself. This also frequently leads to losing track of the mouse cursor when combined with the usually higher cursor speed and acceleration chosen in large high-resolution display environments.

Information overflow

Windows and applications placed in non-focal regions of the display do not change their default layout, i.e. menus and icons of the windows and applications are displayed regardless of their position on the display. Those menus and icons do not serve a purpose in a shrunken window. Apart from taking up valuable display space that could be used to display more information in the condensed visualization, they also distract the user (Bi & Balakrishnan, 2009).

Truemper et al. (2008) conducted a study examining the usability of multiple monitor displays by analysing the feedback of the participants. They found that using too many displays can cause distraction and leads the participants to attempt to complete multiple tasks at once which ultimately affects their overall performance. Additional evidence, which has been gathered from video recordings made during the experiments, reinforced this statement.

Increased display size also enforces task management problems as more windows are displayed and therefore more information is available at the same time which leads to more complex user multitask behaviour requiring better task management techniques (Robertson et al., 2005).

Change blindness

Change blindness is the missing of information, provided by the difference between two frames (Simons & Levin, 1997). Healey and Enns (2012) suggest that change blindness is not due to limited visual acuity but rather caused by “inappropriate attentional guidance” (p. 1179).

In their discussion about change blindness, Healey and Enns (2012) figure that increasing display size increases change blindness. The limitations of the visual memory are even more important for large high-resolution displays, as more information is visually presented to the user.

Simons (2000) suggested “overwriting”, “first impression”, “nothing is stored”, “everything is stored, nothing is compared” and “feature combination” as the main factors that cause change blindness. (1) Overwriting – means that the information gathered from the current image perceived is being overwritten by the image to follow, unless it has been set into relation with the information gathered from the previous image. They suggest that changes are only detected in the centre of attention in a detailed manner that could serve for comparison and therefore allow the user to detect changes within the two frames. (2) First impression describes that only the initial view of a picture is processed and scanned for changes and if no change is detected, it is not re-encoded. (3) Nothing is stored – means that after a picture has been abstracted, the details are not being represented internally. Should an individual need to access a specific detail the whole scene has to be re-examined in order to detect said detail. (4) Everything is stored, nothing is compared – means that the perceived details are stored internally but cannot be accessed without an external stimulus. Finally (5) feature combination states that perceived details of a past or present frame are merged with a present or future frame to create a combined picture. Thus, the user is unaware of when the detail was added to the mental representation and therefore is unable to detect changes.

Mental workload

The human field of view is influenced by the mental workload an individual is subjected to at a given time. The visual field of view is reduced to 92% under medium mental workload and decreases to 86% under heavy mental work load. The degree of mental workload was determined by an acoustic task in which either one, two or three different sounds had to be counted and a visual task in which either one, two or three different rectangles had to be counted. (Rantanen & Goldberg, 1999). According to Yost et al. (2007) this effect may lead to a decrease in overall performance as the additional data visualized on a large high-resolution display may lead to an increased mental work load and therefore result in a decrease of data visibility due to the narrowed field of view.

Interaction related difficulties

Carrasco, Evert, Chang and Katz (1995) suggest that large high-resolution displays may affect user performance due to interaction related difficulties. The eccentricity effect shows that performance impacts are to be expected as the target moves farther away from the user's point of visual fixation and this effect scales with an increase in display size. Yost et al. (2007) conclude that on a large high-resolution display the visualized details are farther away from the user and the eccentricity effect may negatively impact performance. The increased number of pixels on a large high-resolution display results in an increased amount of simultaneously displayed information enlarging the negative performance gains.

While large high-resolution displays reduce the need for virtual navigation and promote the use of physical navigation which overall is more effective and advantageous for task completion times (Ball et al. 2007), some of the benefits introduced by physical navigation may be partially set off by the mandatory increase of mouse movement distances and target search time (Jakobsen & Hornbæk, 2011). Mouse movement as well as physical navigation can have a negative effect due to applications placed in the peripheral regions of a large high-resolution display that may therefore be hard to see or read due to their size which leads to the effect of increasing unnecessary physical navigation or even virtual navigation (Bi & Balakrishnan, 2009).

Discussion

The goal of this thesis was to analyse the benefits and disadvantages of large high-resolution displays in comparison to standard displays, while specifically focussing on cognitive and interaction related aspects.

Physical navigation – a key benefit of large high-resolution displays with minor disadvantages

Physical navigation as an aspect of large high-resolution displays is well researched (Andrews et al., 2010; Andrews et al., 2011; Ball et al., 2007; Bi & Balakrishnan, 2009; Jang et al., 2012). While most authors consider it to be superior to virtual navigation, it is not unanimously seen as flawless. On the one hand, an increased display size increases the mouse travel distances, which now either can increase the time taken to reach a desired target, or can be less accurate according to Fitts' law (Fitts, 1954). Also physical navigation can be unnecessarily required if peripheral displays are not able to display the content in a readable fashion, for example by being too small or by bad visual angles. On the other hand, the user is prompted to spatial memory through the use of physical navigation which can be used to make sense of the visualizations on large high-resolution displays (Andrews et al., 2010).

Cognitive aspects – enhancements and obstacles

Numerous cognitive factors are influenced by large high-resolution displays. The use of spatial memory to navigate and especially create meaningful patterns on large high-resolution displays is one of its key advantages. Another benefit of using the human spatial memory is the fact that if the information is spread across the display and can be viewed in its detail, the user does not have to change the information at the focal position and therefore is able to easily glance at another source of information without requiring to focus his attention on another window that may have to be moved or resized. This benefit is due to remembering the spatial position of the information – space is used as a form of external memory (Andrews et al., 2010). By maintaining its spatial position it can be compared and used to refresh the internal memory. Ball et al. (2007) also found that using large displays reduces user frustration and increases task accuracy.

While the human spatial memory alongside physical navigation is a great benefit in most scenarios, there are other cognitive factors that affect user performance when a large high-resolution display is being used.

Windows placed in peripheral regions of the display may be distracting thereby affect user performance (Bi & Balakrishnan, 2009) as well as due to their increased number compared to a small, regular display lead to overly frequent multitasking attempts which again negatively impact user performance (Truemper et al., 2008). Another negativity related to the use of large high-resolution displays is change blindness and the larger the display is the more common is this phenomenon (Healey & Enns 2012). As the amount of displayed information increases so does the mental workload, which ultimately narrows the human field of view (Rantanen & Goldberg, 1999) and thereby being more of an issue displays increasing in size. In addition the higher the mental workload is , the narrower the field of view becomes, a fact which some authors regard as a disadvantage when using large displays, as information is stored in the periphery as well as in the focal region (Yost et al., 2007). The eccentricity effect also suggests that large displays are not beneficial as the targets are further away from the point of visual fixation on a large display than they are on a small display (Carrasco et al., 1995).

Obstacles of current research

However, previous research leaves many questions unanswered. High-resolution does not seem to be clearly defined due to the rapid technological advancements as mentioned by Andrews et al. (2011). Thus, relating and comparing the different concepts, studies and finding to each other becomes more difficult. Moreover, many of the studies were performed by having the participants fulfil non-common tasks – e.g. navigation on huge maps as in the study conducted by Jakobsen and Hornbæk (2011) – which may impact their external validity. Of course the results can be applied to large high-resolution displays in general, yet some portions of them may not apply to daily office work such as word processing. There is very little mention of technical aspects such as different panel technologies and how they impact the user performance as they may positively or negatively impact the user depending on what kind of display they are using. Especially panel technology may influence peripheral legibility due to the different viewing angles provided by the different kinds of panels available. Wall-sized displays also were a very favoured approach when measuring the impact of large high-resolution displays, while for a home user wall-sized displays are not feasible due to space and monetary restraints.

Future research

Future research should concentrate on commonly used display arrays in private homes or offices and focus on more recent operating systems (e.g. Windows 8.1, Mac OS X and various GNU/Linux distributions) as these operating systems do not seem to be very well included into the research yet. A standardised resolution for conducting experiments should be agreed on in order to be able to better relate the different studies to each other. As touchscreens alongside a mouse or track pad seem to be a common feature of newly released notebooks in particular, designing an experiment to examine whether the mix of mouse and touch used together on devices with different display sizes offers an interaction benefit on large high-resolution displays, could be of added value.

Conclusion

Large high-resolution displays, either as a single unit or as a total of multiple displays require certain technical specifications. First the operating system has to support it, which nowadays is not that much of an issue as Mac OS X and Windows 7, 8 and 8.1 all fully support the use of multiple displays and most Linux distributions do so as well. In some operating systems there might be compatibility issues or a certain amount of computer knowledge required to set them up properly.

Ultimately, do the benefits of large displays outweigh the disadvantages and therefore improve the user experience and task performance time? Most of the research papers cited are fairly positive that in the long run, large high-resolution displays will improve productivity. Overall the positive aspects of using large, high-resolution displays seem to be of more importance than the negative impacts. While human spatial memory eases the use of multiple datasets, the mental respective workload reduces the performance. While researchers, such as Andrews et al. (2011) and Ball et al. (2007) suggest that physical navigation makes sense of the visualizations of large displays and virtual navigation partially becomes obsolete and thereby keeps attention where it is supposed to be, researchers such as Bi & Balakrishnan (2009) and Truemper et al. (2008) suggest that multiple instances of information distract the user’s attention and lead to increased amounts of multitasking which decreases performance.

Still, further research is needed. Operating systems are changing and so are the challenges and opportunities which each individual iteration of any operating system brings about. A standardised display resolution for further research should be implemented which would enhance the comparison of the different results gained out of the many studies conducted in this field. The external validity of the large high-resolution display research should be considered as well, as many of the apparatus used for conducting the research so far cannot easily be applied to home or office use. Neither are the specific tasks requested easily applicable to home and office use.

In conclusion, high-resolution displays offer a great performance benefit once the user has learned to interact with them. All the counter arguments are outweighed by the advantages.

References

Andrews, C., Endert, A., & North, C. (2010). Space to think: large high-resolution displays for sensemaking. In *Proceedings of the SIGCHI Conference on Human Factors in Computing*, 55–64. Retrieved from http://dl.acm.org/citation.cfm?id=1753336

Andrews, C., Endert, A., Yost, B., & North, C. (2011). Information visualization on large, high-resolution displays: Issues, challenges, and opportunities. *Information Visualization*, *10*(4), 341–355. doi:10.1177/1473871611415997

Ball, R., & North, C. (2005). Effects of tiled high-resolution display on basic visualization and navigation tasks. In *CHI'05 extended abstracts on Human factors in computing systems*, 1196–1199. ACM. Retrieved from http://dl.acm.org/citation.cfm?id=1056875

Ball, R., North, C., & Bowman, D. A. (2007). Move to improve: promoting physical navigation to increase user performance with large displays. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, 191–200. ACM. Retrieved from http://dl.acm.org/citation.cfm?id=1240656

Bi, X., & Balakrishnan, R. (2009). Comparing usage of a large high-resolution display to single or dual desktop displays for daily work. In *Proceedings oft the SIGCHI Conference on Human Factors in Computing Systems*, 1005–1014. Retrieved from http://dl.acm.org/citation.cfm?id=1518855

Carrasco, M., Evert, D. L., Chang, I., & Katz, S. M. (1995). The eccentricity effect: Target eccentricity affects performance on conjunction searches. *Perception & Psychophysics*, *57*(8), 1241–1261. Retrieved from http://download.springer.com/static/pdf/517/art%253A10.3758%252FBF03208380.pdf?auth66=1393685658_44047930bb9bf27d9c0aaa374e770c4f&ext=.pdf

Eick, S. G., & Karr, A. F. (2002). Visual scalability. *Journal of Computational and Graphical Statistics*, *11*(1), 22–43. doi:10.1198/106186002317375604

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. In *Journal of Experimental Psychology*, *6*(47), 381–391.

Healey, C. G., & Enns, J. T. (2012). Attention and visual memory in visualization and computer graphics. *IEEE Transactions on Visualization and Computer Graphics*, *18*(7), 1170–1188. doi:10.1109/TVCG.2011.127

Jakobsen, M. R., & Hornbæk, K. (2011). Sizing up visualizations: effects of display size in focus+ context, overview+ detail, and zooming interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1451–1460. ACM. Retrieved from http://dl.acm.org/citation.cfm?id=1979156

Jang, J., Bell Trickett, S., Schunn, C. D., & Gregory Trafton, J. (2012). Unpacking the temporal advantage of distributing complex visual displays. *International Journal of Human-Computer Studies*, *70*(11), 812–827. doi:10.1016/j.ijhcs.2012.07.003

Melanson, D. (2012, October). NPD study finds average display sizes continuing to rise in all areas but laptops and tablets. *www.engadget.com*. Retrieved April 2nd, 2014, from http://www.engadget.com/2012/10/16/npd-study-finds-average-display-sizes-continuing-to-rise-in-all/

Nacenta, M., Gutwin, C., Aliakseyeu, D., & Subramanian, S. (2009). There and back again: Cross-display object movement in multi-display environments. *Human-Computer Interaction, 24*(1), 170–229. doi:10.1080/07370020902819882

Ni, T., Schmidt, G. S., Staadt, O. G., Livingston, M. A., Ball, R., & May, R. (2006). A survey of large high-resolution display technologies, techniques, and applications. In *Virtual Reality Conference, 2006*, 223–236. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1667648

Rantanen, E. M., & Goldberg, J. H. (1999). The effect of mental workload on the visual field size and shape. *Ergonomics*, *42*(6), 816–834. doi:10.1080/001401399185315

Robertson, G., Czerwinski, M., Baudisch, P., Meyers, B., Robbins, D., Smith, G., & Tan, D. (2005). The large-display user experience. *Computer Graphics and Applications, IEEE*, *25*(4), 44–51.

Sawant, A. P., & Healey, C. G. (2005). A survey of display device properties and visual acuity for visualization. *Department of Computer Science, North Carolina State University*. Retrieved from http://www.csc.ncsu.edu/faculty/healey/download/cstr.05a.pdf

Simons, D. J. (2000). Current approaches to change blindness. *Visual Cognition*, *7*(1-3), 1–15. doi:10.1080/135062800394658

Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in cognitive sciences*, *7*(1), 261–267. Retrieved from http://ac.els-cdn.com/S1364661397010802/1-s2.0-S1364661397010802-main.pdf?_tid=420edc00-c36b-11e3-aaf7-00000aacb360&acdnat=1397435298_2a270d94d5bedf1fe055b36dc17c7478

Truemper, J. M., Sheng, H., Hilgers, M. G., Hall, R. H., Kalliny, M., & Tandon, B. (2008). Usability in multiple monitor displays. *ACM SIGMIS Database*, *39*(4), 74–89.

Ware, C. (2000). Information visualization: Perception for design. *Information Visualization.* Morgan Kaufmann, 2000.

Wegman, E. (1999). Visions: The evolution of statistics. *Research in Official Statistics*, *2*(1), 7-19.

Yost, B., Haciahmetoglu, Y., & North, C. (2007). Beyond visual acuity: the perceptual scalability of information visualizations for large displays. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, 101–110. ACM. Retrieved from http://dl.acm.org/citation.cfm?id=1240639

Author unknown (2014, February). Screen Resolution Statistics. *www.w3schools.com.* Retrieved March 2nd, 2014, from www.w3schools.com/broswers/browsers_display.asp