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Investigating paper vs. screen in real-life hospital workflows: Performance contradicts perceived superiority of paper in the user experience

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Abstract

Introduction: All hospitals in the province of Styria (Austria) are well equipped with sophisticated Information Technology, which provides all-encompassing on-screen patient information. Previous research made on the theoretical properties, advantages and disadvantages, of reading from paper vs. reading from a screen has resulted in the assumption that reading from a screen is slower, less accurate and more tiring. However, recent flat screen technology, especially on the basis of LCD, is of such high quality that obviously this assumption should now be challenged. As the electronic storage and presentation of information has many advantages in addition to a faster transfer and processing of the information, the usage of electronic screens in clinics should outperform the traditional hardcopy in both execution and preference ratings.

This study took part in a County hospital Styria, Austria, with 111 medical professionals, working in a real-life setting. They were each asked to read original and authentic diagnosis reports, a gynecological report and an internal medical document, on both screen and paper in a randomly assigned order. Reading comprehension was measured by the Chunked Reading Test, and speed and accuracy of reading performance was quantified. In order to get a full understanding of the clinicians' preferences, subjective ratings were also collected.

Results: Wilcoxon Signed Rank Tests showed *no significant differences on reading performance* between paper vs. screen. However, medical professionals showed a significant (90%) *preference* for reading from paper. Despite the high quality and the benefits of electronic media, paper still has some qualities which cannot provided electronically do date.

Keywords: Paper vs. screen; Textual information; Medical reports; Health record; Reading performance; Chunked Reading Test; User experience

1. Introduction and motivation for research

All the hospitals in Styria (Austria) have been equipped with highly sophisticated enterprise Hospital Information Systems. Every medical workplace is outfitted with high-quality visual

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display units. Consequently, now that almost all information is available electronically one would assume that the paper consumption in the hospitals is significantly reduced; instead we have observed an *increase*.

During our observation of the medical workflows, we were able to see that medical professionals preferred to print their findings on paper, expressing a preference to reading from paper rather than from a screen. This observation of practical evidence was the initial motivation for carrying out this study.

The comparison of visual performance of *computer screens* vs. *paper* has been studied since early computers have been used in work places but there is still a considerable need for a critical examination of visual performance from screen in a *real-life work setting*, especially in a *hospital* real-life work setting. In this study, it was undertaken with hospital employees as participants and original and authentic reading material used in medical workflows in hospitals.

At first, we provide an overview of previous screen vs. paper comparison studies (Section 2.1), followed by a description of information presentation on electronic displays (Section 2.2) and the importance of information presentation for real-life workflows (Section 2.3).

2. Background and related work

2.1. Screen vs. paper

As early as the 1980s, studies dealing with the comparison between screen and paper emerged in the scientific community, reacting to the basic change in *methods of displaying information* occasioned by the introduction of the Personal Computer (PC) across office sites (for an overview, see Mills and Weldon, 1987; Dillon, 1992; Schlick et al., 2008, in press). With this electronic shift, a global speeding up of workflows was expected: with the use of electronic data processing, large text and databases can be displayed and edited easily. The flexibility and versatility of computers have removed many of the limitations of data representation and one would have expected paper and ink to disappear with the advent of the so-called *paperless office* (Sellen and Harper, 2001; Thomas, 2006). However, our everyday experience shows that this prediction was off-target or, at least, premature.

There may be many reasons to account for this phenomenon. Gladwell (2002), for example, holds the "*social life of paper*" to be responsible, i.e., as he calls it "the resistance of people's highly trained reading and handling habits withstand changes". In addition, paper is extraordinarily suited for the reading process, i.e., it is tangible (it can be picked up, readers can flip through it), it is spatially flexible (it can be easily moved on the desk and can be suited to individual reading habits as regards size and portability) and it can be tailored to allow readers to make notes, annotations and add bookmarks, without altering the original text. From a cognitive point of view, the reading comfort and the visual quality of paper as a medium of presentation is very high, possibly because it is the result of a long evolutional process. Consequently, paper can be regarded as an outstandingly suitable display with regard to visual ergonomic demands. It provides high contrast and resolution with neither disturbance by glare, screen reflections or flicker (Ziefle, 2009).

On the other hand, all the advantage of digital documents is evident and undisputed (easy storage, search, transmission and access). However, the reading comfort and ease of information intake has been considerably limited by restrictions of visual display quality, a situation which is changing with the tremendous increase in display technology. Today's electronic media can no longer be compared to the screen quality of VDUs produced 30 years ago. The bulky Cathode-Ray-Tubes (CRTs), display technology which represented the cutting edge-technology of the last century, lost ground continuously to the LCD technology.

During the last years, the quality of Liquid Crystal Displays (LCD)-technology has improved continuously (MacDonald and Lowe, 2003; Schlick et al., 2008; Oetjen and Ziefle, 2009) and meanwhile, LCD-technology is the prevailing state-of-the-art display technology in offices and it also comprises the continuously growing sector of mobile small screen devices (mobile phones or personal digital assistants, PDA).

Since the first evaluation studies of different displays were published (Muter et al., 1982; Wright and Lickorish, 1983; Kruk and Muter, 1984; Heppner et al., 1985; Wilkinson and Robinshaw, 1987), a huge number of studies have dealt with, and still deal with, the fundamental question as to which display type assures the highest reading comfort and the best visual performance (Miyao et al., 1989; Dillon, 1992, 1996; Hollands et al., 2002; Oetjen and Ziefle, 2004, 2007, 2009; Holzinger and Errath, 2007).

2.2. Information presentation on electronic displays

There is also a long history of studies concerned specifically with the evaluation of visual display quality (for an overview see Dillon, 1992; Schlick et al., 2008), basically pursuing two prominent research goals.

The first research approach refers to the comparison of displays with respect to effectiveness and efficiency of encoding and processing information. This type of research typically consists of a benchmark of the traditional hardcopy, in comparison to different types of electronic displays, for example CRTs and LCDs (e.g. Creed et al., 1987; Gould et al., 1987; Heppner et al., 1985; Ziefle, 1998; Menozzi et al., 2001). Aspects of readability and legibility in different texts were scrutinized (e.g. Ishihara et al., 1993; Dillon et al., 2006; Holzinger and Errath, 2007).

The second research approach addresses specific factors affecting visual performance. In this context, effects of *luminance contrast* (e.g. Näsänen et al., 2001; van Schaik and Ling, 2001; Sheedy et al., 2003; Ziefle et al., 2003), *display resolution* (e.g. Miyao et al., 1989; Ziefle, 1998; Huang et al., 2009) and *CRT screen flicker* was discernable, considerably affecting visual performance (e.g. Wilkins et al., 1984; Ziefle, 2001b; Schlick et al., 2008).

However, *user characteristics* (e.g. visual acuity abilities or age, Hung et al., 1996; Ziefle, 2001a, 2010; Omori et al., 2002), the *effects of work settings and body postures* (e.g. Jaschinski et al., 1996; Sommerich et al., 2001; Ziefle et al., 2003) and *effects of typography* (Bernard et al., 2002; Dyson, 2004) on performance also received attention. Speed and accuracy of visual performance have been identified as sensitive measurements for the different display quality in different media, but user judgments regarding the reading comfort and the emergence of visual strain (Owens and Wolf-Kelly, 1987; Bergqvist et al., 1995; Best et al., 1996; Hung et al., 1996; Miyao et al., 1998; Ziefle, 1998) should also be included.

2.3. The importance of information representation for real-life workflows

Across studies, different task types were used to assess the effects of visual display quality on performance, making it rather hard to integrate the outcomes and to draw a final conclusion. As such, simple detection tasks and continuous visual search tasks as well as proof reading tasks were used. In order to meet the requirements of the experimental control procedures, the tasks in most of the studies mainly took advantage of specially created artificial, experimental material. The results that were retrieved, even though accurate, might not be meaningful for practitioners in a real work situation, especially in hospital workflows. Yet, only a few studies undertook a media comparison regarding visual performance and strain using "natural" reading or inspection material in an applied, real-life context. In addition, the respective testing situations used cannot be considered as representative to the situations of real work places.

The participants who usually volunteer to take part in these studies are most often only a handful of young students, as it is often the case in experimental studies done in a university setting. Rarely, real employees are asked to volunteer as participants in a real-life setting in which they are confronted with different reading challenges on different media, and, not seldom, under time pressure and high accountability (Berns et al., 2002; Lewin et al., 2001; Holzinger and Leitner, 2005; Holzinger et al., 2008).

Accordingly, a visual performance difference of several hundred milliseconds (ms) between two different reading media might be substantial from a statistical point of view, impacting in favor of the one display medium over the other. However, there are only very few studies contrasting the reading performance in electronic screens and paper in a real-life setting, in which workers of a wide age spectrum have to read for longer periods and under much more serious working conditions than is the case in the laboratory context.

A typical application scenario, for which the described experiments might be representative, is the responsible workflow of medical doctors in hospitals. Clinicians have a tremendous workload, they work under considerable strain and they have to read lots of material quickly and accurately and to comprehend what they read efficiently and precisely because their quick decisions frequently have far-reaching consequences. Aggravating this situation is the altered circumstances in the hospital in recent years resulting in increased pressure of time without any diminishment in the efficiency and accuracy with which patient records must be read and assessed.

Due to the growing number of patients, along with increased information that the medical professionals have to maintain at short intervals and the increasing use of Information Technology, the workflow in hospitals has changed considerably, forcing clinicians to read more and more documents on-screen. The question as to whether clinicians achieve the same level of text comprehension when a medical text is presented on screen as when it is presented on paper is, therefore, of crucial importance. However, in order to truly answer this question, an experimental rationale should be used that meets the requirements of ecological validity.

3. Methods and materials

3.1. Variables

Two independent variables were under study. The first independent variable was the display type: comparing paper and screen. The second independent variable was the subject of the text (gynecological vs. internal medical).

As dependent variables, the search speed (ms) and the accuracy (% correctly detected targets) of visual search were assessed. As subjective measures, preference ratings were assessed.

3.2. Tasks and reading materials

The participants' task was first to read the assigned record and then immediately go through the Chunked Reading Test referring to this text. The same procedure followed using the second record and the other reading environment. The Chunked Reading Test basically requires the volunteer to detect modified text passages. The time used for these steps was checked manually.

The internal medical record is based on a case published in "Der Internist" by Springer 2007, dealing with a young female patient with the diagnosis of a retroperitoneal fibrosis and contained 40 sentences with 432 words. The gynecological text derives from a case, also published by Springer 2007, in "Der Anaesthesist", describing the complex course of a young patient's cesarean section and contained 38 sentences with a total of 420 words.

To extract the text for the Chunked Reading Test a standardized method was developed to meet medical records requirements, which refers to Carver and Darbys specifications for creating a Chunked Reading Test (Carver and Darby, 1971, 1972), along with standards of established tests for a more valid and objective knowledge control (Klauer, 1984).

In the appendix, we provide examples of the Chunked Reading Tests, in order to visualize participants' tasks.

3.3. Participants

In the Austrian province of Styria, overall $N=111$ (out of a total of 2888) clinicians employed at a Hospital were contacted and volunteered to take part in this study. Participants read diagnosis reports from two medical contexts: a gynecological report and an internal medical document. Reading comprehension was measured by the Chunked Reading Test, and the speed and accuracy of reading performance was quantified. In order to obtain a full understanding of the need and demands of clinicians, preference ratings were collected. The preference ratings gathered included two aspects: one was a binary decision: "which of both media would be preferred in the real work setting". Second, participants were requested "to name the most important reason for their choice", in order to learn the specificity of the preference rating.

Among the total of 111 clinicians volunteering for the study 41% were female and 59% male reflecting the real-life distribution among the 2888 clinicians in Styria. Their age ranged from 25 to 63 years, with the average participant 39 years old. Participants had the following educational background and expertise levels: 75 (67.6%) of the clinicians were medical specialists, 20 (18.0%) trainees (branch of study: general practitioners), 14 (12.6%) were general practitioners and 2 clinicians (1.8%) had the status of a "Fachärzte in Ausbildung (clinicians in training)". All medical professionals were accustomed to the work with digital media and paper within their daily work. Independent of the age of the participants, the sample revealed a high technology interest and familiarity technology.

3.4. Experimental setting and procedure

Testing took place in the respective clinicians' work places amongst 10 different hospitals in Styria. Using a randomized assignment for the order of the reading environment (paper vs. screen) determined in advance, each participant underwent the same procedure for the experiment.

Testing started with the verbal instruction of the volunteer about the goal of the test, its procedure and the testing-technique, the Chunked Reading Test. This was delivered by the author and was identical for each participant (Fig. 1). The second step was established by the visualization of the testing-technique using a demonstration-sheet. Immediately after having read the first report, the participant was asked to complete the Chunked Reading Test regarding this first case. After that, the second case was read using the alternative reading environment, followed immediately by the Chunked Reading Test concerning this specific medical case. A questionnaire comprising of demographic data (age, specialization), interest in the presented records, matters of preferences and media consumption and the participant's level of weariness at the time of being tested closed the testing procedure.

3.5. Apparatus and materials

The text on paper was presented on white paper, sized DIN-A4 ($21 \times 29.7\,cm^2$) weight $80\,g/m^2$. The text was printed onto the paper using an HP Color LaserJet 5550, using a resolution of 600 dpi. For displaying the medical report on screen, the Notebook Acer Aspire 5512 WLMI was used, having a 15.4 in. TFT-monitor and a resolution of 1280×800 pixels (WXGA).

4. Results

4.1. Reading speed

No difference in speed was found (see Fig. 2) when comparing the reading environments screen and paper ($p > 0.05$). The average reading speed performed by 111 clinicians reached 110 words per minute.

4.2. Reading accuracy

Analyses were made using the Wilcoxon Signed Rang Test. Comparing all records read on paper vs. all records read on screen (see Fig. 3), no significant difference in text comprehension was found ($V=3436$, $p > 0.05$).

Detailed analyses comparing each report, read on either medical domain separately, (gynecological vs. internal medical record), read on screen vs. paper confirmed these findings (see Fig. 4).

Correlation analyses (Spearman rank analyses) were run to examine whether participants' previous experience with computer usage impacts the reading performance in the two different media (paper vs. screen). No significant relations were detected between reading performance and technical

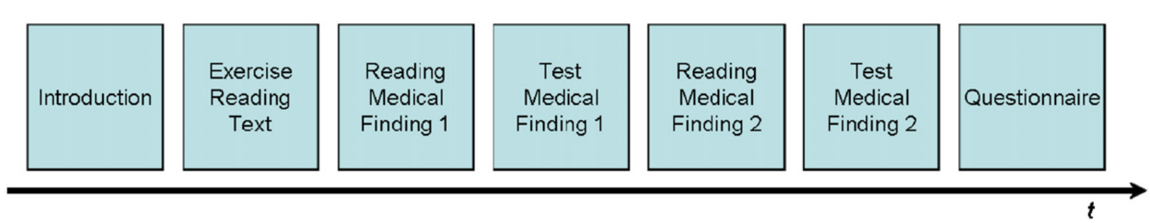

Fig. 1. Procedure Chunked Reading Test.

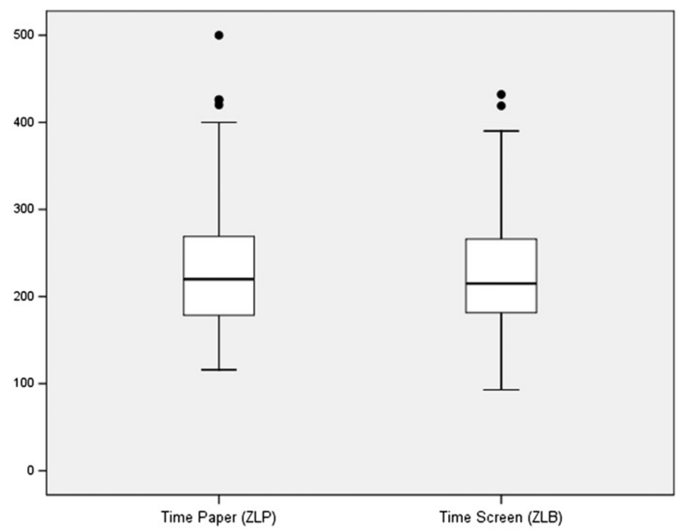

Fig. 2. Time for reading on paper (ZLP) vs. time for reading on screen (ZLB) in seconds.

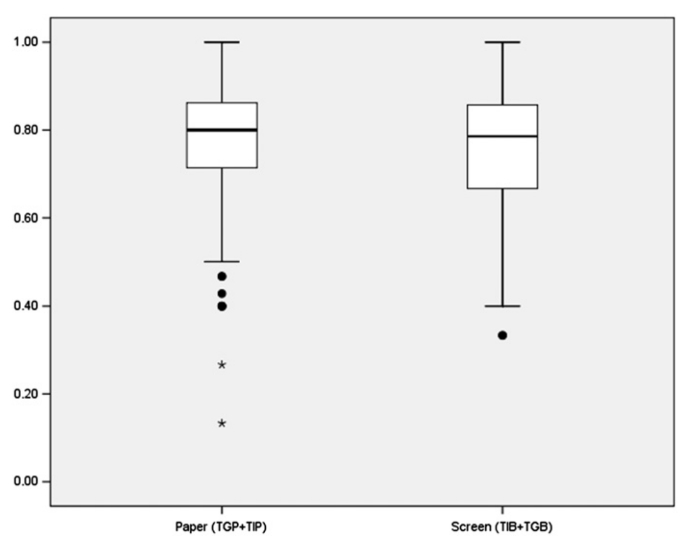

Fig. 3. Text comprehension on paper (TGP+TIP) vs. on screen (TIB+TGB), $N=111$.

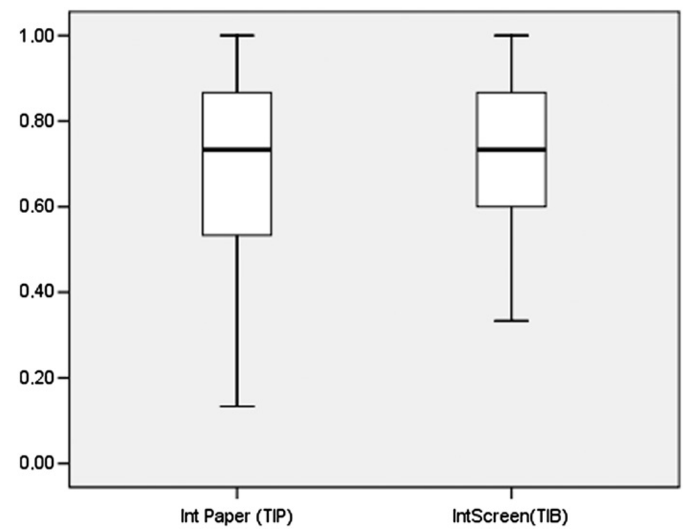

Fig. 4. Text comprehension, internal record on paper (TIP $n=47$) vs. screen (TIB $n=64$).

expertise, neither with respect to the frequency of using computers in a *private context* (screen: $r=.09$; n.s.; paper: $r=.05$; n.s.) nor in a *job-related context* (screen: .09; n.s.; paper: $r=.03$; n.s.). Also, there was no relation between the experience of using computers and the reading performance in the different medical domains (*internal medical reports*: paper: $r=0.042$; n.s.; screen: 0.059; n.s.; *gynecological reports*: paper: $r=0.14$; n.s.; screen: 0.13; n.s.).

4.3. Preference ratings for the different reading media

Even though the outcomes reveal no performance differences between both media, preference ratings show a completely different picture. Asked after the experiment, which of both, screen vs. paper, is the preferred reading medium at work everyday, there was a clear vote of the medical professionals: 100 out of 111 clinicians generally preferred to read on paper (independent of the educational and technical or medical expertise level of the participants as well as independent of the participants' medical field).

Beyond this binary preference rating, we also collected participants' key arguments in order to understand the reasons behind the preference rating ($\chi^2=107.1$; $p=0.000$). Comprising the statements, the perceived benefits of paper can be categorized along five key dimensions: the *flexibility* of the medium, its ubiquitous *availability*, its *mobility* and the possibility of carrying reports from one place to another and sharing them with colleagues as well as the *possibility to make notes* and to scribble information within the document are the key arguments for the preference rating. Also, the participants reported that the orientation within a paper document is much more effective in contrast to an electronically displayed document (*ease of use*).

4.4. Further analyses

So far, the reading performance was analyzed for the whole group. In order to examine whether user characteristics (e.g. age) or text types (difficulty in reading the internal medical record vs. the gynecological record) impact the outcomes, further analyses were run.

4.4.1. Effects of age

To further investigate (Fig. 5), the relation between *time needed to read* the record on paper and the *participant's age* was analyzed. The coefficient of correlation between the two variables was determined (see Figs. 6 and 7), resulting in no relation between the time needed in seconds and the age in years (-0.019). The same coefficient of the variables: time needed to read the record on screen and participant's age, also shows no relation (-0.033).

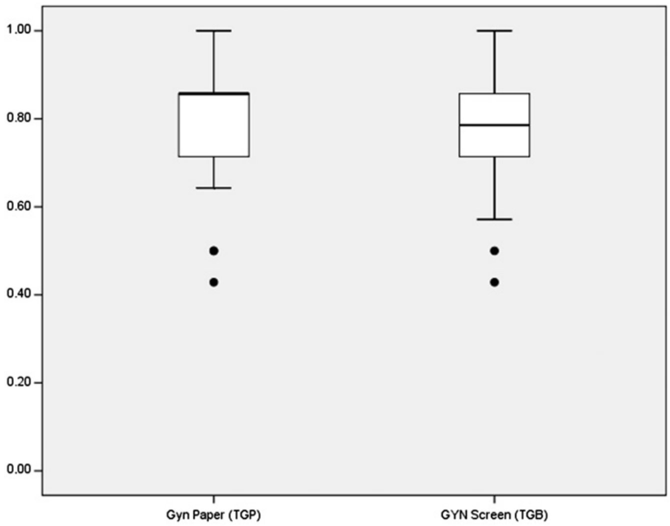

Fig. 5. Text comprehension gynaelogical record on paper (TGP $n=64$) vs. text comprehension gynaelogical record on screen (TGB $n=47$).

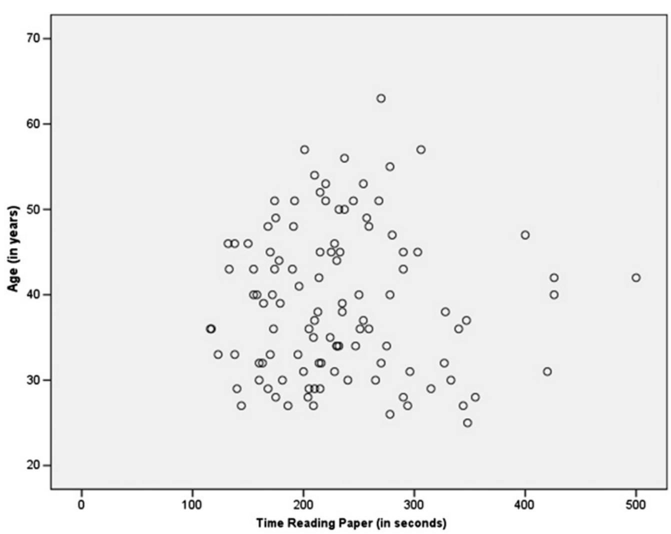

Fig. 6. Left: time needed to read the record on paper (in seconds) vs. reader's age (in years).

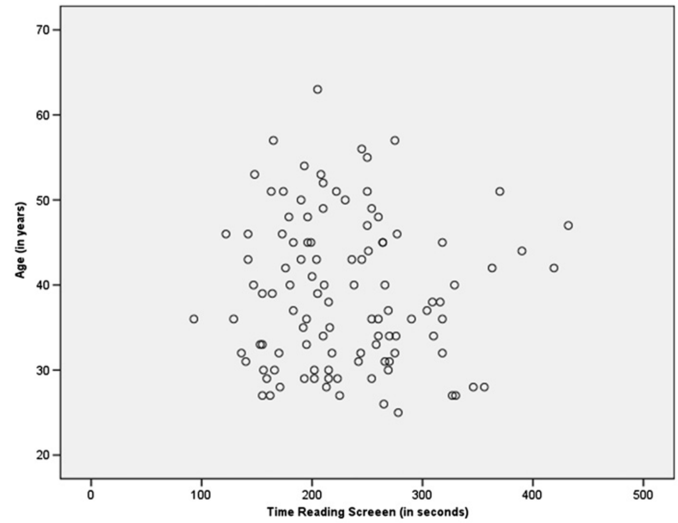

Fig. 7. Right: time needed to read the record on screen (in seconds) vs. reader's age (in years).

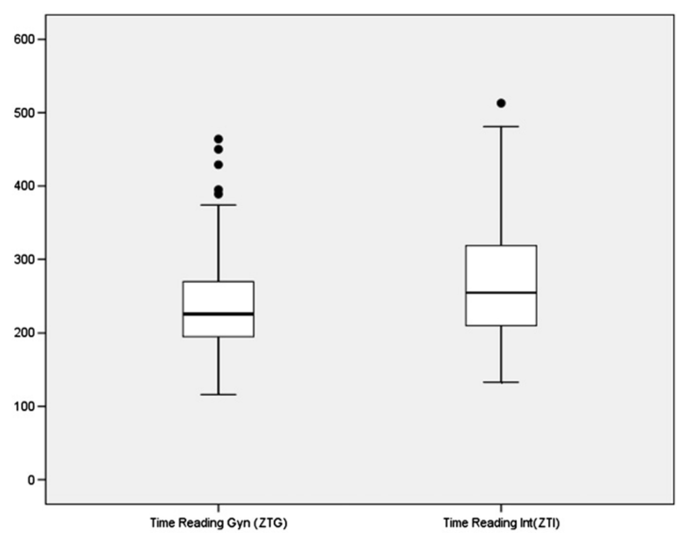

Fig. 8. Time needed to read the 420 word gynecological record (ZTG) vs. 432 word internal medical document (ZTI) in seconds.

4.4.2. Effects of text types

Participants needed significantly more time to read the internal medical record than the gynecological record ($p=0.0004$), see Fig. 8.

5. Discussion

In this section, the outcomes of the present experiments are discussed with respect to the question of whether current reading media – screens and paper – meet visual ergonomic demands regarding a fast, accurate and easy information processing.

Trouble-free usage and user acceptance of any new technology depend substantially on the quality of the visual display as a central communication unit as well as the ease with which the displays allow visual information to be processed. Thus, a careful visual evaluation is indispensable in order to assess the efficiency of visual performance and to identify existing shortcomings of the displays.

In order to classify the observed performance, it is necessary to consider the methodological approach adopted here. In contrast to the majority of visual ergonomic studies considering performance differences in electronic media and hardcopy, it was a deliberate aim of the study to critically scrutinize the visual performance in a *real-life setting*. The rationale behind this procedure is to critically test media differences in a real setting, including natural workflows with realistic and time-critical working conditions. Also, in contrast to visual ergonomic studies, in which often highly artificial detection tasks and visual search tasks without semantic context were applied, real medical reports had to be read and understood by professionals (medical doctors). Thus, the experimental rationale provided a high ecological validity.

Basically, there were two key results. First, no performance differences between paper and electronic screens were detected in speed or in accuracy of reading. This result shows that – at the current technologically high standard of electronic displays – the classical rat race between both media is finished, and the question, whether paper or screen might especially benefit or hamper visual productivity, is not valid any more. However, the second key finding shows that the very same question of media differences did not vanish completely. All professionals distinctly preferred to read on paper, independent of the type of text (medical field), independent of their age, their expertise level and domain knowledge.

Consequently, in contrast to earlier studies in the field (e.g. Heppner et al., 1985; Gould et al., 1987; Dillon, 1992; Ziefle, 1998, 2001b, 2003), visual performance in this study was not correlated with preference and visual comfort ratings. The distinction between performance outcomes (no difference between screen and paper) and preference or acceptance of both media (large difference in favor of paper) shows that the tasks of visual ergonomists might enter a new era of responsibilities.

It is not the global productivity and the prevention of health hazards in terms of visual strain any more, which should be considered in the first place-given that the display quality is off-the-shelf and state of the art. Rather, ergonomists should provide for work place settings, in which workers have the possibility to use the work setting and or the tools they prefer. The professionals clearly stated after the experiment that the advantage of paper for their work in the hospital is much more than the mere visual quality of paper. It is its flexibility, ubiquitous availability and mobility and the possibility of carrying reports from one place to another and sharing them with colleagues. Also, the possibility of skimming through the text and finding various specific references, as well as the fact that spatial and cognitive orientation within the text is much easier compared to a screen page, in which the standard scrolling procedures on electronic screens are neither effective (in terms of search efficiency) nor satisfactory. Medical document searches are perceived as tedious and pesky, especially when considering the immense time pressure of medical workflows, the high responsibility of decisions and the large complexity of the material which has to be read and understood in a given time frame.

In addition, participants expressed that they prefer paper due to its haptic quality and because they simply prefer the medium as such. The latter shows that – also at the given level of technical quality – the hedonic nature or quality of a medium might be also the crucial characteristic of a reading medium, rather than its productivity. This is a good example for what is often subsumed under the terminus user experience (Hassenzahl and Tractinsky, 2006).

6. Conclusion

Concluding, we are able to say that electronic screens match the visual quality of paper, and no differences in visual productivity between both media are to expect in real work settings. However, paper is still the preferred reading medium. Recommendations for reading media therefore should be related to the task and working context they are to be used for and tailored to the preferences of the specific user group using such displays.

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