INTRODUCTION

Reading is an everyday activity and is a highly complex perceptual and cognitive process. During reading we take in visual information at first, and then transfer this information into words (decoding and word recognition) and finally construct meaning from what is read. Reading involves a series of fixations and saccadic movements across the page (Rayner and Pollatsek, 1989). During fixation, reading contents are kept in the foveal region that is about 2 degrees of visual angle. Perception and comprehension of the reading content occurs during fixations. Saccadic movement is made to bring the fovea into the position where the next fixation target occurs (Robeck and Wallace, 1990). This process calls on many parts of the brain, mainly the parts involved in vision, audition and memory.

Reading a text from the computer screen has become essential in our daily life. We are experiencing a rapid shifting of media: from printed paper to computer screens. This transition is modifying how we read and understand text. The efficiency of reading is dependent on how ergonomically the visual information is presented. Font types and size characteristics have been shown to affect reading. A detailed investigation of the effect of the font type and size on reading on computer screens has been carried out by using subjective, objective and physiological evaluation methods on young adults. A group of young participants volunteered for this study. Two types of fonts were used: Serif fonts (Times New Roman, Georgia, Courier New) and Sans serif fonts (Verdana, Arial, Tahoma). All fonts were presented in 10, 12 and 14 point sizes. This study used a 6 X 3 (font type X size) design matrix. Participants read 18 passages of approximately the same length and reading level on a computer monitor. Reading time, ranking and overall mental workload were measured. Eye movements were recorded by a binocular eye movement recorder.

Reading time was minimum for CourierNew14 point. The participants' ranking was highest and mental workload was least for Verdana14 point. The pupil diameter, fixation duration and gaze duration were least for Courier New 14 point. The present study recommends using 14 point sized fonts for reading on computer screen. Courier New is recommended for fast reading while for on screen presentation Verdana is recommended. The outcome of this study will help as a guideline to all the PC users, software developers, web page designers and computer industry as a whole.

Key words: font type and size; eye movement parameters; onscreen presentation; cognitive workload

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INTRODUCTION

Reading is an everyday activity and is a highly complex perceptual and cognitive process. During reading we take in visual information at first, and then transfer this information into words (decoding and word recognition) and finally construct meaning from what is read. Reading involves a series of fixations and saccadic movements across the page (Rayner and Pollatsek, 1989). During fixation, reading contents are kept in the foveal region that is about 2 degrees of visual angle. Perception and comprehension of the reading content occurs during fixations. Saccadic movement is made to bring the fovea into the position where the next fixation target occurs (Robeck and Wallace, 1990). This process calls on many parts of the brain, mainly the parts involved in vision, audition and memory.

Reading a text from the computer screen has become essential in our daily life. We are experiencing a rapid shifting of media: from the printed paper to the computer screen. This transition is modifying how we read and understand a text. The efficiency of reading is dependent on how ergonomically the visual information is presented. There are many factors that affect the reading ability of a person. These factors include the physical attributes of the characters like size,
shape, colour, brightness, contrast, background, viewing distance, psychophysiological conditions of the viewer, environmental lighting, workplace conditions, types of display, screen resolution, etc. Typography (font type and size characteristics) plays an important role in understanding the complexities of visual information in a man-computer interface.

Typography is a very common issue both in the printed press as well as in the digital media. There are certain rules of typography which are followed by the printed press. But the rules coming from the printed press have limitations for application in the digital media which requires specific rules for this media (Dillon, 1992). When typefaces are digitized for use on computers, the letter forms have to fit within a relatively small pixel grid and this relatively low resolution affects the fine finishing strokes of typefaces on the screen.

There is a rich history of research regarding typography in print. Many sources discuss the layout and selection of typefaces in print, very few studies have experimentally addressed this issue on the computer screen (Waite, 1995).

Fonts themselves have four major qualities, commonly referred to as the ‘elements’ of type. These are line, weight, orientation and size. Every font is created through the use of a distinctive mix of these four elements (Childers and Jass, 2002). A fraction of a millimeter can be the difference between an aesthetically appealing and unappealing letter (Boser, 2003).

The most basic form of typeface classification is simply into Serifs and Sans serifs. A Serif font is one in which lines or curves adorn the ends of each letter, such as Garamond, TNR, Georgia, etc. A Sans serif font, however, as the name suggests, is one which is sans (without) such adornment at the end of each letter, e.g. Arial, Verdana, Tahoma, etc. Typeface sizes are customarily described in points. The modern, standardized system has exactly 12 points in a pica and exactly 6 picas in an inch. As such, there are 72 points in one linear inch (Cavanaugh, 1995; McLean, 1997).

Although there are number of font types used today, the most common font types used on computer screen are Times New Roman (TNR) and Georgia ( Serif) and Arial and Verdana (Sans serif). Times New Roman and Arial were originally developed for print and are the most common fonts of the respective font type used. Georgia and Verdana were developed specifically to be optimized for the computer screen (Boyarski et al., 1998). Tahoma and Courier New are also widely used font types in recent times. The most common font sizes for onscreen presentation are 10 point, 12 point and 14 point.

It is well known that, reading is a highly complex and perceptual cognitive process and font characteristics may affect this cognitive process and thus the reading performance. It has been well documented that different typefaces or fonts carry different connotations and have different influences on the readability, assimilation, interpretation and impact of the words and concepts they represent. Moreover, with the advancement of modern technology and automation industry the human operators have to process a number of visual information (mainly presented in form of reading materials) within a very short period. Moreover, with the educational trend towards internet instruction and interactive multimedia, there seems to be a gap in the visual literacy research. It is possible that certain styles, sizes and presentations of type could affect learning. There always exists the scope to improve the screen designs of interactive multimedia and web-based instruction. Proper presentation of visual information in perfect font type and size interface may reduce the cognitive workload of the operator and facilitate the job.

According to a survey conducted by the Confederation of Indian Industry (2007), the average age of home PC users is around 28 years. There is no specific font type and size till date designated as a standard for use for reading on screen for computer users in the world. The studies carried out on typographic influences on reading in the past on western population are based on subjective responses only. The effect of font type on readability from a computer screen was investigated by Boyarski et al. (1998), Grant and Branch (2000), Bernard and Mills (2002), Bernard et al. (2002), Arditi and Cho (2005) and other researchers by using readability and subjective preference. The observations of these studies differ from each other. It is difficult to decide about the suitability of font types and sizes for onscreen reading based upon the subjective evaluation method only. Considering the limitations of
using self-reported workload ratings as the measures of cognitive workload, researchers have used eye movement parameters that are found to correlate with cognitive workload. Several parameters like blink rate and duration, pupil diameter, saccade, fixation, etc. have been used to estimate the cognitive requirements of different tasks (Brookings et al., 1996; Van Orden et al., 2000; Veltman and Gaillard, 1998; Wilson, 2001; Wilson and Caldwell, 2002).

The benefit of using eye movement activity as a correlate of cognitive workload is that it can measure fluctuations in workload that occur over short time intervals (Ahlstorm and Friedman-Berg, 2006). Beside this the frequency by which researchers collect workload ratings over time has a practical limit. Traditionally, they collect ratings in every 5 min, 2 min (Kuk et al., 1999) or 1 min (Stein, 1985) intervals. Eye movement activity measures can provide more continuous, moment-to-moment measures of workload. It detects differences in workload not reflected in subjective workload rating (Ahlstorm and Friedman-Berg, 2006).

It has been observed that pupil diameter increases (Iqbal et al., 2004, 2005; Lin et al., 2003; Van Orden et al., 2000; Zeghal et al., 2002) blink rate and blink duration decrease (Van Orden et al., 2000; Veltman and Gaillard, 1998; Zeghal et al., 2002) as a function of increased cognitive workload. Increase in workload has also been observed to increase the number of saccades with a simultaneous decrease in saccadic duration (Rognin et al., 2004; Zeghal et al., 2002). There is an increase in the frequency of long fixations with response to increased cognitive workload (Van Orden et al., 2000).

There are some studies (Reichle et al., 2003; Kliegl and Engbert, 2005; Pynte and Kennedy, 2006; Staub et al., 2007; Warren et al., 2008; Pynte et al., 2008) on onscreen reading using eye tracking technology. Reichle et al. (2003) proposed “the E-Z reader model” of eye-movement control in reading; Kliegl and Engbert (2005) resolved a controversy about reading fixations before word-skipping saccades; Kemper et al. (2006) used eye-tracking technology to examine young and older adults’ online performance in the reading in distraction paradigm; Rayner et al. (2006) examined the effect of word frequency, word predictability and font difficulty on the eye movements of young and older readers and Kirkby et al. (2008) in their review article tried to evaluate the literature on binocular coordination during reading and non-reading tasks in adult, child, and dyslexic populations. Recently, few researchers studied various issues of reading by using eye movement recorder. But the eye movement studies on the effect of font type (Yoshioka et al., 2007; Rayner et al., 2006; Banerjee et al., 2010) and size on human cognitive workload during reading are still rare.

Considering the complexity involved in the selection of font type and size, the present study has been designed for evaluating the effect of font type and size on cognitive workload of young adults (who are the major users of computer) during visual information processing in reading and also to optimize the best font type and size for use on computer screen by using subjective (ranking and overall mental workload), objective (reading time) as well as physiological (eye movements) evaluation methods. An attempt has also been taken to find out if there are any differences in the evaluation of human cognitive workload by using objective, subjective and physiological methods during on screen reading in different font type and size interfaces.

**METHODS**

**Participants**

Forty young postgraduate researchers (21 male and 19 female) volunteered for this study and their mean age (SEM) was 27.5 (0.31). All were tested to have 20/20 or better unaided or corrected vision as measured by a Snellen near acuity test for 20/20 vision at a distance of 20 inches. All the participants reported to have regularly read documents on computer screen for several spell of time in a 24 h period. All of them read English fluently and were postgraduate in science subjects. They gave informed consent before the start of the experiment. The study protocol was approved by the Institute’s ethics committee and this experiment conforms to the principles outlined by the Declaration of Helsinki protocol, 1964.
Apparatus
1) Objective and Subjective study
   1. A 17 inch TFT-LCD monitor (M/s HP, model no.HPW1707, 2008) with a 440 mm diagonal screen provided an active viewing area of 339 mm horizontally and 271 mm vertically. The screen resolution was 1280 by 1024 pixels. The brightness and contrast of the screen were set at 69% and 84%, respectively. The screen images were refreshed at a rate of 60 Hz.
   2. A digital stop watch (Racer).
   3. A measuring tape for the measurement of viewing distance.

2) Eye movement study
   1. Binocular eye movement recorder: Eye movements of both eyes were recorded by using binocular eye movement recorder (M/s Applied Science Laboratory, USA, model no-BS-BN6, Head mounted Optics). The sampling rate was adjusted at 120 Hz.
   2. Magnetic head tracker: A magnetic head tracker (Ascension _flock) was used in order to minimize head movements from eye movements.

Workplace conditions
The TFT-LCD was positioned on a table 700 mm in height with an inclination angle of 105° (Burgess-Limerick et al., 2000; Horikawa, 2001) with respect to the vertical axis. Participants were positioned to sit on a chair at a distance of about 600 mm from the computer screen. A headrest restrained the participant’s head 250 mm above the table and kept their viewing distance at 600 mm during the experiment. The ambient illumination was produced by fluorescent lamps and was about 450 lux. No glare appeared on the TFT-LCD screen.

Font type and size combination
Two types of fonts were used; the Serif fonts and the Sans serif fonts. Serif fonts include Times new Roman (TNR), Georgia and Courier New and Sans serif fonts include Arial, Verdana and Tahoma because of their frequent usage. All of these fonts were presented in three different sizes, i.e. 10 point, 12 point and 14 point with visual angles of 0.32 degree, 0.39 degree and 0.45 degree, respectively. Hence, a 6 x 3 (font type x size) design matrix was used to investigate differences in preference for reading text in the objective, subjective as well as in the eye movement study. The different font type and size combinations are shown in Table 1.

Task design
Participants were asked to read eighteen passages. The text of each passage comprised of a font from one of the eighteen type and size font conditions. The passages came from Microsoft’s electronic library, Encarta (Microsoft Encarta Online Encyclopedia, 2000). The passages were written at approximately the same reading level and discussed similar material (all dealt with religion related topics). The passages were also adjusted to have approximately the same length. The amount of words per line varied as a result of the width of the fonts within the different type and size combinations. The colour of the font in all passages was black on a white background.

Experimental procedure
One or two days before the experiment the participants were informed about the entire experimental procedures in detail and a number of dummy trials were carried out to accustom the participants with the experimental procedures. They were asked not to overstrain and have good sleep at night on the previous day of the experiment. On the day of the experiment when the participants reported the laboratory, he/she was examined by a qualified medical doctor for his/her physical and mental fitness. Once the participant was found fit he/she was subjected to experimental procedure. Participants were requested to concentrate the experiment per se and not to divert his/her attention elsewhere.
1) Objective and subjective measures

For carrying out the experiment, participants were positioned at a fixed distance of approximately 600 mm from the computer screen. Participants were asked to orally read at a time one of the texts comprising of eighteen font type and size combinations as quickly and as accurately as possible. The passages were presented randomly to counterbalance the order effects and font type and size combination for each passage was also selected in random order to counterbalance 18 passages across the conditions. They were allowed to take rest for about 10-15 minutes between each trial. Some simple comprehension questions were given to the participants after a certain percentage of experimental trials to ensure that participants read and fully understood the stimuli.

Reading time was recorded by using a digital stopwatch. Accuracy of reading (in terms of “omission” and “misreading”) were noted. Accuracy of about 80% was the consideration point for participant selection for further analysis. Immediately after reading all passages they were shown all of the font type and size combinations and at that moment were asked to rank different font type/size interface for general preference on a seven-point scale (-3 = Difficult to read, -2 = very poor, -1 = poor, 0 = average, 1 = good, 2 = very good, 3 = excellent). Overall mental workload of different font type/size interface during reading was measured by NASA-TLX questionnaire (Hart and Staveland, 1988) immediately after reading of each passage. Out of the six dimensions, the weighted mean of only four (mental demand, performance, effort and frustration) dimensions of this questionnaire were used to evaluate mental workload, since the two dimensions (physical demand and temporal demand) are not related to the reading task.

2) Eye movement study

Eye movement recording was conducted during the same period of the objective and subjective study. Calibration of the eye movement recorder was carried out before the experiment according to the standard nine point calibration method. The calibration method was repeated between each experiment. Once the calibration procedure is over the participants were asked to read passages one after another from eighteen font type and size combinations which has been explained earlier. Eye
movements of each participant were recorded during the period of reading of each passage.

The raw data were analyzed by Eyenal software (M/s ASL, USA). Although a binocular system has been used for data recording, the data of the left eye has been presented here. The following parameters were measured in both the experiments:
- Pupil diameter: the average diameter (in mm) of pupillary aperture.
- Blink rate: the number of blinks occurred in one minute period.
- Mean fixation duration: It is the average time during which the eye remains fix at a single fixation.
- Total gaze duration: entire time period when the eyes remain fixed during reading of a particular passage (No. of fixation X Mean fixation duration).
- Saccadic duration: the time required to complete a saccade (saccades are quick, simultaneous movements of both eyes in the same direction).
- Saccadic amplitude: the angular distance that the eye needs to travel during the movement.

Statistical analysis

Results were presented as the mean (SEM). Statistical analysis of reading time and eye movement data were carried out by two way factorial analysis of variance (ANOVA) with repeated measures using SPSS version 10.05. This analysis was been used to evaluate the effects of font types and sizes on reading time, pupil diameter, blink rate, mean fixation duration, total gaze duration, saccadic duration and saccadic amplitude and also to see the interaction between font type and size. When significant differences were found, Bonferonni multiple comparison tests were performed as a post hoc analysis to compare the pairwise differences between different font types and sizes and changes were considered as significant when p values <0.05 were reported.

The data for ranking of different font type/size interface and overall mental workload were analyzed by using Friedman’s chi square ($\chi^2$) test. A Wilcoxon signed rank test taking into account a Bonferonni correction was used as post hoc test for pairwise comparison between different font types and sizes for these two parameters and changes were considered as significant when p values < 0.05 were reported.

The data of reading time for Serif and Sans serif fonts were analyzed separately, combining all three Serif fonts together and all three Sans serif fonts together of all the participants. Their average values were taken. Statistical comparison between Serif vs. Sans serif fonts have been performed by using paired Student’s t test.

RESULTS

Objective and subjective study

1) Reading time

Figure 1 shows that average reading time was minimum for Courier New 14 point (278.46 ± 12.63) and was significantly less (p<0.01) compared to any other font type/size interface studied here. It was followed by Arial 14 point font (293.73 ± 11.97).

While comparing the readability between different font sizes it was observed that reading time was significantly less for 14 point font size compared to 10 and 12 point font size for font type Courier New (p<0.001) (327.77 ± 14.54, 311.88 ± 12.79) and Arial (326.81 ± 12.59, 329.96 ± 13.94) (p<0.001) only. A significant interaction was found between font type and font size on reading time [F (10, 120) = 5.122, p <0.001).

Average reading time was less for Serif font type/size interface than Sans serif font type/size interface (Fig. 2) and the changes were significant in the case of font size 10 point (p<0.01) and 14 point (p<0.05).
2) Ranking of different font type/size Interfaces  
Participant’s ranking of different font type/size interfaces has been presented in Fig. 2. There was an overall significance in ranking data between different font type and size combinations ($p<0.001$). Participants ranked Verdana 14 point ($2.19 \pm 0.25$) as the most preferred font type/size interface and it was significantly different in comparison to any ($p<0.01$) other font variation (Fig. 3). Arial 14 point ($1.88 \pm 0.16$) was ranked as the second most preferred font type/size interface. Significant difference was observed between Verdana and Arial at 14 point size ($p<0.05$).

3) Overall Mental Workload  
Overall mental workload for each font type/size interface was calculated by averaging the four dimensions of NASA TLX with the same weight. There was an overall significance in mental workload between different font type and size combinations ($p<0.001$). It was observed that the overall mental workload was least for Verdana 14 point ($20.63 \pm 2.70$), followed by Arial ($21.59 \pm 2.62$) and Tahoma ($23.22 \pm 2.68$) of the same font size. There was significant ($p<0.01$) change in this parameter for these three combinations compared to others (Fig. 3). However, no significant change was observed between Arial 14 and Verdana 14 font conditions. Tahoma 14 differed significantly from Arial 14 point ($p<0.05$) and Verdana 14 point ($p<0.01$) fonts.
Eye movement study

1) Pupil diameter

The average pupil diameter for reading of text in different font types and sizes was found to be within the normal range (2 to 8 mm) in this study. Pupil diameter was maximum for font type TNR in all three font sizes and was largest for font size 10 (4.18 ± 0.11 mm.). Minimum pupil diameter was observed for font type Courier New in all three font sizes (4.06 ± 0.10 mm, 4.01 ± 0.11 mm. and 4.01 ± 0.10 mm respectively, for 10, 12 and 14 point font sizes) (Figure 1). The effect of font type and size on pupil diameter was significant [F (2.23, 55.71) = 21.26, p<0.001 and F (1.45, 36.15) = 3.80, p<0.05 respectively], but their interaction was not (p>0.05). Post hoc test showed that in 10 and 12 point size the values of pupil diameter for font type TNR were significantly (p<0.05) different from all other font types except Arial, and in 14 point size it was significantly different from all other font types.

2) Blink rate

In the present study blink rate was within the normal range (3.3 to 14 minute). Effect of font type on blink rate was significant, [F (5, 125) = 5.87, p<0.001], but the effect of font size and the interaction between font type and size were not (p>0.05).

3) Mean fixation duration

Mean fixation duration is the average time (sec) during which eye remains fixed at a particular fixation. In the present study, this was less for larger font sizes for all font types. It was minimum
for Courier new, followed by font type Verdana (Figure 3). The effect of font type on mean fixation duration was significant \( [F (3.62, 90.48) = 71.50, p<0.001] \) as was the effect of font size \( [F (1.45, 36.15) = 3.80, p<0.05] \), and their interaction effect was also significant \( (p<0.001) \).

Post hoc analysis revealed significant difference between Courier New with all other font types, except Verdana in 12 point size and Arial in 14 point size. Times New Roman required maximum fixation duration in all three font sizes \( (0.50 \pm 0.03, 0.41 \pm 0.02 \text{ and } 0.36 \pm 0.01 \text{ for 10, 12 and 14 point fonts, respectively}) \).

4) Total gaze duration

Total gaze duration represents the entire time period when eyes remain fixated during reading. There was a significant effect of font type \( [F (1.83, 45.73) = 14.40, p < 0.001] \) and size \( [F (1.47, 36.66) = 9.71, p < 0.01] \) on gaze duration and their interaction was also significant \( (p<0.001) \).

In this study a reciprocal relationship was observed between gaze duration and font sizes. The values were less for larger font sizes i.e. for 14 point font size followed by 12 and 10 point font sizes (Fig. 4). Post hoc test revealed significant difference in gaze duration between various font sizes of TNR, Georgia, Verdana and Arial. Total gaze duration was least for Courier New \( (38.16 \pm 1.52 \text{ for 10 point}, 37.96 \pm 1.45 \text{ for 12 point and 36.81 \pm 1.63 \text{ for 14 point fonts}}) \) followed by Verdana \( (38.88 \pm 1.46 \text{ for 10 point}, 37.96 \pm 1.60 \text{ for 12 point and 37.28 \pm 1.66 \text{ for 14 point fonts}}) \). However, there
were no significant differences between these two font types in any of the font sizes. Gaze duration was maximum for font type TNR (47.69 ± 2.26 for 10 point, 44.12 ± 1.85 for 12 point and 41.60 ± 1.35 for 14 point font sizes) in all three font sizes and the values were significantly different from all other font types in the 10 and 12 point font sizes.

Fig. 7. Total gaze duration during reading in different font type/size interfaces.

5) **Saccadic duration**

Saccadic duration was within normal range (15-40 msec) during reading in all the fonts. It was minimum for TNR (23.82 ± 2.06) in 14 point size and was maximum for Georgia (28.93 ± 4.33) in 10 point size. There was no significant effect of font type, size and their interaction (p>0.05) on saccadic duration.

6) **Saccadic amplitude**

The amplitude of a saccade is the angular distance that the eye needs to travel during the movement. In the present study, saccadic amplitude did not show any significant variation between different font type and size conditions. It was minimum for TNR (2.16 ± 0.05) and was maximum for Arial (2.28 ± 0.05) in 10 point size of the font.

**DISCUSSION**

The main aim of the present study was to evaluate cognitive workload in different font type/size interface during reading and to select a perfect font type/size interface for presentation of text on computer screen that can reduce the cognitive workload during visual information processing in reading. The experiment was carried out on a particular age group population who are the major user of computer (27.5 ± 0.31 of age) with the almost equal merit level (the subjects were post graduate researchers).

From the results of the present study it has been observed that average reading time was less for Serif fonts compared to Sans serif fonts. It supports the work of Grant and Branch (2000), who found a large, meaningful and statistically significant difference in means of reading time of different font types. They observed that, Serif faces were read faster than Sans serif. The observations of Ling and Schaik (2006), Arditi and Cho (2005), Weisenmiller (1999) and Tinker and Paterson (1943) are different from ours, who found no significant differences for speed of reading with regard to font selection. Bernard et al. (2002) in their paper directly contradicts our findings though they used a very similar methodology for measuring reading speed. Times and Arial were read faster than Courier, Schoolbook, and Georgia. Bernard et al. (2001) revealed that font types that were perceived as being
most legible were Courier, Comic, Verdana, Georgia, and Times.

There are some explanations about the increased readability of Serif fonts than Sans serif. According to De Lange et al. (1993) serifs are used to guide the horizontal “flow” of the eyes; the lack of serifs is said to contribute to a vertical stress as in Sans serifs, which is supposed to compete with the horizontal flow of reading. Serifs are used to increase contrast (and irregularity) between different letters to improve identification. Rubinstein (1988) stated that Serifs might enhance legibility of individual letters by providing an additional cue to the location of stroke ends and that this may help the reader read faster and avoid fatigue. Reynolds (1979) showed that whole words written in Serif font can be recognized just as quickly as letters during an eye fixation and that single letters can be identified quicker when embedded in a word. Tinker (1963) commented that perceived legibility of Serif font is due to familiarity of subjects with this font type. The present study offers evidence that legibility as indicated by speed of reading is a delicate indicator of font type and that Serif font is better in terms of readability compared with Sans serif fonts. The present study also showed that for reading continuous text at a distance of about 600 mm, average reading time was minimum for font type Courier New 14 point among all other font type/size interfaces.

In the present study, participants ranked Verdana 14 font type/size interface as the best one as participant's satisfaction was highest for this combination. It was followed by another Sans serif font type/size interface, i.e. Arial 14 point. Similarly the overall mental workload during reading was significantly least for Verdana 14 point, followed by Arial 14 point. Participants felt more relaxed during reading Verdana or Arial at 14 point size compared to others.

The result of the on screen study conducted by Bernard and Mills (2002) reported that Arial font was the most preferred and it had a slight advantage over the TNR font for the best font choice. In another study Bernard et al. (2002) reported that older people greatly preferred Sans serif fonts (i.e. Verdana and Arial) to Serif font (i.e. Georgia and TNR). Bernard et al. (2003) compared the readability and legibility of TNR (Serif) and Arial (Sans serif) fonts by studying readability with relation to typeface, size, and format on thirty five young volunteers. The study showed that the participants gave their preference for Arial, though there was no difference in terms of readability between Arial and TNR. Ling and Schaik (2006) did two experiments that explored the influence of font type and line length on a range of performance and subjective measures. They designed the experiments with two types of font, e.g. TNR and Arial. The participants of the experiments expressed a preference for Arial, a Sans serif font.

Participant’s preference for Sans serif fonts compared with Serif fonts can be explained with the phenomenon that when font types are digitized on computers, the letter forms have to fit within a relatively small pixel grid with a resultant loss of resolution. This relatively low resolution cannot render effectively enough the fine finishing strokes of Serifs. On the other hand Sans serif fonts tend themselves more naturally to being digitized on computer screen and come out cleaner and thus more legible (Rubinstein, 1988). Some researches have shown that Serifs may actually become visual noise at very small sizes, detracting from the main body shape of the letter form (Morris et al., 2002). The present study also supports this view as we observed that participants did not like reading Serif fonts at 10 point size at all.

According to Poulton (1972) and Reynolds (1979), other factors such as stroke thickness, counter size and x-height are likely to have a far greater effect in preserving the overall identity of a letter form. Anderson (1987) stated that Serif fonts have variable stroke width. This variability in stroke width has been shown to have lower measures of legibility (Yager et al., 1998). Sans serif fonts Verdana and Arial possess greater x height and stroke thickness and so it is more legible than Serif fonts used in this study. More recent studies have shown that computer users prefer Sans serif font for body text online (Boyarski et al., 1998; Bernard et al., 2001; Tullis et al., 1995; Reynolds, 1979).

On the otherhand, eye movement parameters are considered as important physiological measures for assessment of cognitive workload (Kramer, 1991). In the present study eye movements of the subjects were recorded during aloud reading of a text presented on screen. Line length and letter spacing were same in all the experimental conditions. The text was written at approximately the same
reading level, same word level difficulty and discussed the similar material in all passages. The main variables in the present study were font types and font sizes.

Results of the present study showed that, for reading continuous text on computer screen at a distance of about 60 cm, font type Courier New, a Serif font in 14 point size was better than other. Different eye movement parameters such as average pupil diameter, mean fixation duration and total gaze duration were less for this font type in all three font sizes and it was minimum for Courier New 14 point. However, these findings differ from that of Rayner (1998), who stated that if the text looks fairly normal, typographical variables tend to have a relatively minor influence. The present study indicates that the variation in font type and size influences different eye movement parameters. Similar observation was reported by Rayner et al. (2006).

It is known that pupil diameter is an important indicator of cognitive workload (Peng et al., 2006). Present study indicates that during reading, the text written in font type Courier New requires less pupil diameter though the changes were not significant. Text written in TNR font requires more pupil dilatation. The eye is innervated by both sympathetic and parasympathetic nerve fibers. During increased cognitive processing the sympathetic nervous system becomes activated and stimulates dilator pupillae muscle and causes pupillary dilatation (Guyton, 2006) which has probably occurred during reading of texts written in TNR font type in the present study.

The sensitivity of eye blink as measures of visual demand task has been reported by Wilson et al. (1994) and Wilson and Fisher (1991). Reports from previous studies have shown that blink rate decreases with an increase in cognitive workload (Van Orden et al., 2000; Veltman and Gillard, 1998; Zehgal et al., 2002). A decrease in blink rate was observed during mental arithmetic task (Peng et al., 2006) and playing video games (Yamada, 1998). However, Alhstorm and Friedman-Berg (2006) did not find any change in the blink rate during reading video display on screen in aircraft simulator. Similarly, in the present study the blink rate was found to be within the normal range and there was no significant difference in blink rate between various font types and between various font sizes.

According to Jacobson and Dodwell (1979), Rayner and Pollatsek (1989) eye movements are influenced by textual and typographical variables. As text becomes conceptually more difficult, fixation duration increases. Rayner (1998) stated that during reading, words are sometimes fixated more than once, and that some times they are skipped and thus affect the mean fixation duration. Therefore, the uses of only mean fixation duration do not evaluate the cognitive workload appropriately. To solve this problem two most frequently used measures are first fixation duration and gaze duration. In the present study we used total gaze duration as a measure of visual demand. Pynte et al. (2008) observed that gaze duration affected with word level constraint. According to Rayner (1998) mean fixation duration and total gaze duration are important indicators of cognitive workload.

The results of our study revealed that during reading text with font type Courier New, mean fixation duration and total gaze duration were less than those for other font types in all three font sizes. These findings indicate that for reading text with Courier new font type participants required less visual processing load to perceive this font compared with other font types. The favourable results for font type Courier New may be explained due to its bold/fine contrast, equal thickness of all strokes (also serifs) and the rectangular uniform (geometric) appearance of striking serifs which helps to guide the horizontal “flow” of the eye during continuous reading of texts (De Lange et al., 1993).

On the other hand, font type TNR seems to be worst from the observations of the eye movement study as all the eye movement parameters for this font type indicates greater cognitive workload and more visual information processing. Although TNR also belongs to Serif family it showed opposite findings compared to the Serif font Courier New. This may be because of the ununiform stroke width, smaller x height present in font type TNR that made its serifs as visual noise when they had to fit within a relatively small pixel grid on computer screen (Morris et al., 2002). After Courier New, the Sans serif font Verdana was found to evoke better responses in terms of different eye movement parameters.

In this study 14 point font size was found to be best than any other font sizes. Responses of different eye movement parameters were in favour of this font size and worst for 10 point font size.
In 10 point size average pupil diameter was larger than other font sizes. It can be said that during reading text with smaller font size i.e. 10 point font size eye required more pupil dilatation in order to process the text in comparison to 12 and 14 point font sizes.

The mean fixation duration and total gaze duration, the indicators of cognitive workload, showed a decreased value for reading text in 14 point font size in the present experiment. This indicates less requirement of visual information processing and less cognitive involvement during reading text with 14 point font size compared to other font sizes. The size of the visual field where the sharpest image of an object is obtained is a 1° area right around the center of fixation, in the fovea (Boff et al., 1986). Eye movements ensure that a critical visual target always is focused within this region. There are a predetermined number of rods and cones in the human eye to interpret visual symbols such as type glyphs. Moderately larger type, such as that used in the present experiment, will result in more optical receptors being used for reading an onscreen glyph. It is well documented that larger text is more legible and during reading of moderately larger font size it requires less eye accommodation (Chandler, 2001).

During the process of reading, a person usually makes several saccadic movements of the eyes for each line. According to Rayner and McConkie (1976), in reading, there is no correlation between fixation and saccade length. But in nonreading situations, there is a correlation between these two parameters. The longer the saccade, the longer will be the next fixation (Kapoula, 1983). On the otherhand, Jacobson and Dodgewell (1979) and Rayner and Pollastek (1989) stated that saccade length decreases with the increase in text difficulty (influenced by both textual and typographical variables). In the present study, the saccadic parameters did not show any significant variation between different font type and size conditions.

From the present study it is clear that the subjective parameters, readability and the eye movement parameters dissociate from each other in some conditions and associate with each other in other conditions during on screen reading in different font type and size interfaces. From the detailed analysis of the results of the present study it has been observed that there is a direct relationship between reading time and different eye movement parameters in some cases and opposite in others. It was noticed that the average reading time, pupil diameter, mean fixation duration and gaze duration were least for Courier New 14 point in comparison to any other font type/size interface.

The observations of readability and subjective measurements dissociate from each other in most of the conditions in our study. Readability was better for Serif fonts, mainly for font type Courier New compared to Sans serif fonts, ranking and subjective satisfaction levels were less for Serif font type/size interface than the Sans serif font type/size interface. Overall mental workload was least but reading time was high for Verdana 14 point in comparison to others. Similarly, overall mental workload was less for Sans serif font type/size interface than Serif font type/size interface.

Subjective measurements and eye movement parameters dissociate with each other also in some experimental conditions. It was observed that subjective preference and satisfaction level were highest and overall mental workload and ranking were least for Verdana 14 point which is a Sans serif font typeface and size combination. Different eye movement parameters were in favour of Courier New 14 point that is a Serif font type/size interface for the reading of similar text material having similar content and word difficulty.

One important observation in this study is that the subjective parameters evaluated Verdana and Arial as most preferred fonts. On the otherhand, Tahoma which is a common Sans serif font in use on screen was least preferred. Subjects ranked it in negative scale. Similarly, eye movement parameters favoured font type Courier New as the best, but indicated Times New Roman as worst. However, TNR is used normally as a default font on screen in most parts of the world. Therefore, it is impractical to generalize that one category of font (Serif or Sans serif) is more legible than others. The legibility of each font needs to be determined separately depending on the nature of work/task demand. Similar has been observed by Sheedy et al. (2005).

For selection of appropriate fonts dependence on only the subjective evaluation method can not help to choose the perfect one. Beside subjective evaluation, readability test and eye movement study
is very important and essential to choose the perfect fonts for on-screen presentation of text. Beside this, knowledge about the purpose of text presentation is also mandatory.

Thus based on all the above observations and discussion, some general conclusions have been drawn. For font size selection it can be recommended to use 14 point font size for presenting text for reading on computer screen, where page number is not a limiting factor. For continuous and fast reading of on-screen texts Courier New is recommended based on reading time and eye movement responses while for making onscreen presentation more attractive font type Verdana is recommended based on the subject’s ranking and mental workload scoring (Table 2). In conclusion it can be said that regarding choice of font type and size interface, subjective measures and eye movement parameters considered Verdana 14 point and Courier New 14 point as the best combinations, respectively. However, the eye movement parameters evaluated Verdana 14 point as the second best option after Courier New 14 point.

Table 2. Recommended font type and size for different parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Serif</th>
<th>Sans serif</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readability</td>
<td>Courier New 14</td>
<td></td>
</tr>
<tr>
<td>Ranking</td>
<td></td>
<td>Verdana 14</td>
</tr>
<tr>
<td>Overall mental workload</td>
<td></td>
<td>Verdana 14</td>
</tr>
<tr>
<td>Pupil diameter</td>
<td>Courier New 14</td>
<td></td>
</tr>
<tr>
<td>Mean fixation duration</td>
<td>Courier New 14</td>
<td></td>
</tr>
<tr>
<td>Total gaze duration</td>
<td>Courier New 14</td>
<td></td>
</tr>
</tbody>
</table>

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