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Typeface comparison – Does the x-height of lower-case letters increased to the size of upper-case letters speed up recognition?

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ABSTRACT

Daily contents presented on television screen are in most cases equipped with titles, for example the names and surnames of presented people, data about the location, subtitles or different advertisements. It is widely believed that upper-case letters are more useful (compared to lower-case letters) for placing short titles. The aim of the research was to determine the differences in recognition and reproduction times of short titles in various experimental conditions (especially the difference between lower- and upper-case letters when the x-height of lower-case letters is increased to the main size of upper-case letters). We were interested in how lower-case letters are comparable to upper-case letters in recognition and information processing. Five typefaces were included in the experiment, i.e. Calibri, Georgia, Swiss 721, Trebuchet and Verdana. Three-letter words were presented in lower- and upper-case, covering a comparable area in four different positions on the screen. The analysis of variance showed that the Calibri typeface was recognized and processed faster. The Georgia, Trebuchet and Verdana typefaces showed comparable processing times regardless their letter case.

1. Introduction

Our visual attention is drawn to different static and moving objects. While watching television, the main aspect is the moving picture, which gives us the larger part of the information. Apart from the moving picture, static elements can be significant as well. The purpose of these elements, called *titles* in this paper, is to upgrade the video content while providing extra information that can be useful in the holistic view of the situation (data about the presented person, event venue, election- or sports results, subtitles). Static elements, which are presented for a short time, can attract viewers' attention. The question is how to incorporate these elements onto the screen, for them not to be overly disturbing for the viewer, yet still serving as supplementary information to the video.

When titles are presented on the screen for a short period of time, the recognition of letters and words is of great importance. It is not entirely clear yet how different parameters, e.g. size, use of upper- and lower-case letters, position and limited showing time, can affect the attention to and recognition of titles. These can be presented in two different letter cases, i.e. lower- and upper-case. Lower-case letters include different x-height sizes, ascenders and/or descenders, and form clusters of letters, often a whole word (e.g. cat, dog, pig), or the so-called Bouma shape (Larson, 2004). Upper-case letters do not form word shapes since each word written in upper-case letters forms the shape of a horizontal rectangle (e.g. CAT, DOG, PIG). Some researchers (Woodworth, 1938; Smith, 1969; Fisher, 1975; Larson, 2004) have pointed out that the recognition of lower-case letters is easier due to the formation of shapes. Sequences of letters form shapes which can be recognized more quickly and can be remembered better since people tend to remember alternating shapes better than square shapes. Nevertheless, the statement that a word shape has the strongest influence on reading and recalling the text has no solid ground (Hohenstein and Kliegl, 2014). Larson (2004) claims that the word shape is important for word recognition. On the other hand, some researchers (Garrod and Daneman, 2003; Arditi and Cho, 2007) suggest that word shapes do not have the strongest influence on recognition. Some believe that for the recognition of short (three-letter) words, the use of upper-case letters is much more effective (Garrod and Daneman, 2003; Pušnik et al., 2016). The shape of words is less important when determining the recognition of short

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titles (Pelli et al., 2006). Schiepers (1978) and Bock et al. (1993) claim that a series of letters has a stronger impact on the recognition than the word shape. For the recognition of three-letter words, the shape of an individual letter is more important than the shape of the entire word (Bouwhuis and Bouma, 1979).

Research (Lawry, 1980; Nazir et al., 1998) has shown that the design features of letters affect word recognition. In consequence, the research on serif and sans-serif typefaces is important (Lund, 1999; Bernard et al., 2003; Arditi and Cho, 2005) as is the research on the legibility of different groups of typefaces (Sheedy et al., 2005; Moret-Tatay and Perea, 2011). The main characteristics of legible typefaces are increased x-height and stressed counter shape (Weisenmiller, 1999; Wheildon, 2005; Možina et al., 2010). Furthermore, important factors include the form of letters, the thickness of strokes and white spaces (Tinker, 1966; Reynolds, 1988; Lund, 1999; Shaikh et al., 2006).

Legibility is defined as the detection of text with respect to its relative typographic value (Pastoor, 1990) and is measured with the reading speed at which a content can be processed. Typefaces differ according to their usage. Some are more appropriate for printing, others for on-screen use; in both cases, problems can occur if the presented letters are too small in size. This can affect visibility and consequently, recognition and legibility (Weisenmiller, 1999; Nazir et al., 1998; Legge and Bigelow, 2011). At small sizes, the specifics of typefaces which define visibility, recognition and legibility and which are important for reading can be lost (Bouma, 1971; Cosky, 1976). The processing of small upper-case letters is faster than the processing of lower-case letters of the same size since the former cover a wider area. When the x-height of lower-case letters is increased to the main size of upper-case letters, the two cases become more comparable as they are of the same height (Rudnicky and Kolers, 1984; Sanocki, 1991; Bringhurst, 2004). The sizes in the vertical direction become equal, whereas differences appear in the horizontal direction. The rise in letter size increases the white space in lower-case words. A wider word covers a wider visual angle. Consequently, separate letters in the word are more visible (Stevens and Grainger, 2003), which can affect the speed of reading (Yu et al., 2007).

Recognition is not only influenced by the word size but also by its position (Dyson, 2004; Mills and Weldon, 1987; Dyson and Haselgrove, 2001). The titles can be placed in all four corners of the screen; however, in practice, they are mainly placed in the bottom positions of the screen. The positions at the bottom have become almost standard. Therefore, when titles are placed in the top positions, they can represent new, unexpected stimuli, which can attract attention and affect information processing (Nazir et al., 1992; Pušnik et al., 2016).

Other environmental factors, such as noise (Ljung et al., 2009) or vibration if the reading for example takes place in a vehicle (Kumar and Saran, 2014), can also affect the reading performance. In a noiseless environment, a person can focus more easily on reading, which may result in faster and better recognition of letters, higher reading rate and better understanding of the presented text.

The aim of our experiment was to examine how typeface, the size (height) of words, letter case and the positions of a word on the screen affect recognition in an environment free of distractors. We observed the effect of these factors on the recognition threshold, i.e. the minimum time required for the word to be processed to the level of recognition and reproduced correctly.

2. Method

The tested typefaces were Calibri, Georgia, Swiss 721, Trebuchet and Verdana. In television broadcasting, titles are often presented in these five typefaces. The typefaces are representatives of both serif and sans-serif typefaces (Josephson, 2003). Due to their characteristics (higher x-height, distinctive counter shape), they are suitable for on-screen use. The letters were presented in bold. Television broadcasts often use letters in bold for titles. According to Sheedy et al. (2005), a higher number of pixels covered by bold typefaces relates to higher visibility and legibility. The letters were presented on a grey screen, as suggested by White (1996) and Hunt (2004). The x-height of lower-case letters was increased, so that the visual angle in the vertical direction covered the same size as at upper-case letters. This provided a more adequate comparison of the reading performance with the one for upper-case letters since the area coverage (size of presented letters) could affect recognition times. On average, lower-case letters were increased by approx. 36 percent (Table 1). All typefaces were first measured in points (pt) and converted to pixels (px) for a suitable on-screen display.

Each observer participated in 40 experimental conditions – a combination of five typefaces, four positions and two letter cases ($5 \times 4 \times 2$). The high number of experimental conditions forced us to divide the measurements into two parts. The participants took part in 20 experimental conditions at a time (5 typefaces $\times$ 4 positions), first reading the words in lower-, then in upper-case letters, or vice versa. As four positions can be used to present titles on the television screen (bottom left and right or top left and right), we presented words in the four randomly alternating corners of the screen (De Bruijn et al., 1992; Hartley, 1999).

Fig. 1 shows the experimental setup and posture adopted by the participants. Words were presented in the corners of an imaginary square 1280 $\times$ 720 px in size, covering 16.6° of the visual angle vertically and 29.3° of the visual angle horizontally. A black spot with 4 mm in diameter, which represented the starting point (fixation) of each experiment, was placed in the centre of the screen. The distance between the fixation point and the presented word in one of four corners was constant, i.e. 195 mm. The height of the chair was adjusted to each participant so that the participant's eyes were at the height of the fixation point, which enabled them to sit comfortably in front of the screen, with the back supported by the chair backrest. The distance between the viewer and the screen was constant, i.e. 650 mm. TOBII X120 eye tracking device was used to ensure adequate distance from the observer to the screen. If the distance deviated substantially from 650 mm, the person was instructed to move less or not to move at all.

The visual angle of presented words was adjusted to a virtual rectangle (Fig. 2). The presented words (excluding ascenders and descenders) covered the same size in the vertical direction (i.e. the cap height in upper-case words equalled the x-height in lower-case words). The visual area in the horizontal direction was different for each typeface (the smallest with Calibri, followed by Trebuchet, Swiss721, Verdana and Georgia).

The presented words were in black (Hex #000000; RGB (0, 0, 0)) colour on a light grey (Hex #cccccc; RGB (204, 204, 204)) screen (LCD screen, HP ZR24w). The chromaticity of white colour on the monitor was set to D65. The resulting luminance of the LCD screen was between 80 cd/m^2 and 160 cd/m^2 (as suggested by Nooree et al., 2016). The surroundings of the room the experiment took part in were in neutral grey colour. The reflectivity was minimal and in line with the International standard, 2009. The reflectivity of the surroundings was smaller than that of the screen. The screen was calibrated according to the International standard, 2008. The chromaticity of white colour on the screen was set to D65.

Participants were given 10 min to accustom themselves to the lighting conditions of the experiment room. The procedure was explained orally to each participant; however, they also had the possibility to read the instructions. The experiment was divided into two parts to avoid participants' fatigue (separate sessions were carried out for each letter case). The duration of each session was

Table 1
Values of upper-case and increased lower-case letters.

	Upper-case		Lower-case		Increase
	pt	px	pt	px	%
Calibri	31.00	41.33	42.00	56.00	35.48
Trebuchet	27.50	36.67	37.50	50.00	36.36
Swiss 721	27.50	36.67	37.00	49.33	34.55
Verdana	27.00	36.00	36.00	48.00	33.33
Georgia	28.50	38.00	40.00	53.33	40.35
Average					**36.01**

Note: pt – points, px – pixels.

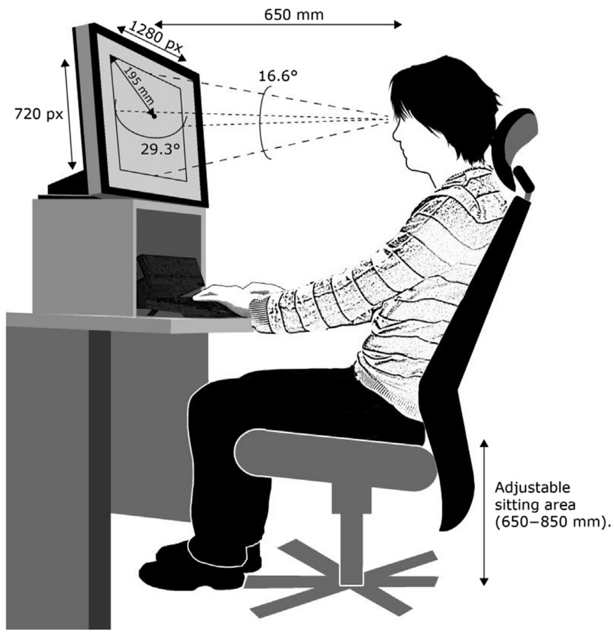

Fig. 1. Experimental setup and posture adopted by the participants.

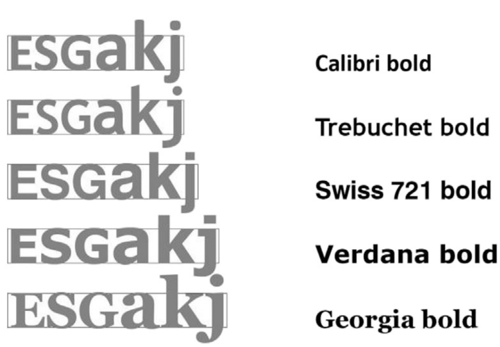

Fig. 2. Lower-case letters covering the same main size (vertically) as capital letters.

from 20 to 30 min. The sessions were taken with the interval of a few days and in mixed order (starting with lower-case letters and continuing with upper-case letters, or vice versa).

For each trial, a three letter word was chosen randomly without replacement out of the pool of 200 meaningful words that were chosen from the Slovenian dictionary. All the words in the pool are daily used in the Slovenian language and are easy to understand. The fixation point was first presented for 1000 ms. Then, the fixation point disappeared and at the same time, the chosen word appeared in one of the four corners of the screen for a certain amount of time. When the word disappeared, an achromatic mask was presented across the entire screen for 500 ms to avoid potential afterimages, which could affect word recognition as suggested by Zhou et al. (2011). When the mask disappeared, a text frame was presented in the centre of the screen, where the participants typed in the word.

To measure the recognition threshold, in each experimental condition, the word presentation interval varied according to the staircase method (Levitt, 1971). A series of time intervals was presented in each experimental condition. The series started with a 150-ms time interval. The presentation time increased by 40 ms if the presented word was not recognized correctly, or decreased by 40 ms if the word was reproduced correctly. The series used in different experimental conditions were interleaved to avoid possible serial errors in measuring recognition thresholds. After the eighth reversal in a certain series, the series ended. At each reversal within a series, the momentary recognition threshold was calculated. In each experimental condition, the first two momentary thresholds were ignored to reduce possible learning effects that may have appeared at the beginning of the experiment and the last six were averaged to obtain the measure of recognition threshold (i.e. the minimum presentation time required for word recognition) in that condition.

Fifty participants were involved in the testing (25 females and 25 males), aged from 20 to 30 years ($M = 24.3$ years, $SD = 5.8$). All participants had normal- or corrected-to-normal vision. The sample size was determined in advance with the power analysis using the G*Power software (Faul et al., 2007), taking into account the expected effect size of $f = 0.14$ (at partial $\eta^2 = 0.02$) for a repeated-measures factor with 5 levels, 5% alpha error rate, 80% power and correlation 0.60 among repeated measures. The participants were students of graphic arts technology and were consequently familiar with the process of typeface design and typeface usability in different media. They voluntarily participated in the experiment and were during that time excused from the study process, which is why we assume their motivation to participate was high. There were no other rewards for their performance.

3. Results and discussion

The heat maps (Fig. 3) we obtained with the eye tracking device show the points of the largest concentration of fixations on the screen during the experiment. As it can be seen, the participants put most focus to the centre of the screen, which was the starting point of each trial, and to the position of the textbox where the words had to be typed in. In the four corners of the screen, a small concentration of gazes can be noticed, which are evenly distributed among the four corners. The dispersion of the results can be attributed to small head and body movements which were allowed during the experimental procedure. Despite the fact that such movements could affect word recognition, they are common in natural situations while watching television, where the observers

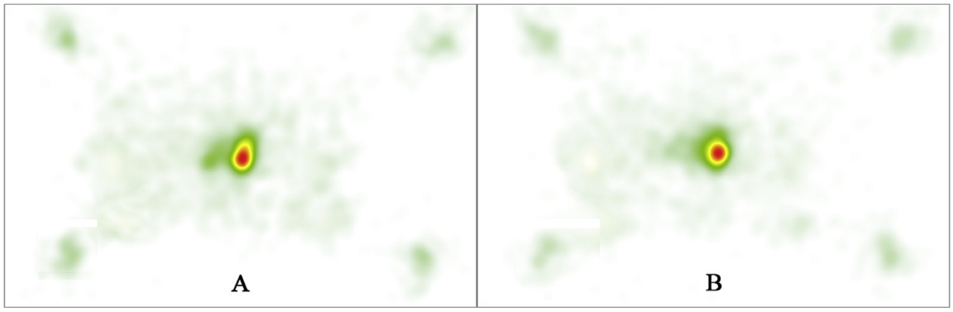

Fig. 3. Heat-maps for trials presenting words with lower-case (panel A) and upper-case (panel B) letters, summed for all participants.

never sit completely still. Our results may hence have higher ecological validity as they would in the case of restraining participants' head and body movements.

The average recognition times were compared in different experimental conditions (Table 2). The lowest recognition threshold was found in Calibri (141.7 ms) and the slowest processing occurred in Swiss 721 (average recognition threshold was 159.9 ms). Calibri, Trebuchet and Verdana are considered humanistic linear typefaces, Swiss 721 a neo-grotesque linear and Georgia a baroque typeface.

A repeated-measures analysis of variance of word recognition thresholds was performed. The hypotheses were tested at the 5% alpha error rate. Table 3 shows the results of ANOVA.

The typeface had the largest effect on the recognition threshold. The tested typefaces, i.e. Calibri, Georgia, Trebuchet, Swiss 721 and Verdana, differed statistically significantly in the recognition thresholds. The results of post-hoc comparisons are seen in the last column of Table 2. Overall, the processing of lower-case compared to upper-case letters showed no statistically significant difference. The average recognition threshold for lower- (148.2 ms) and upper-case (148.0 ms) letters differed by less than 1 ms.

However, there was a statistically significant interaction between the typeface and letter case, which is illustrated in Fig. 4. Whereas in other four typefaces, the recognition thresholds were similar for lower- and upper-case words, a noticeable difference between the two letter cases occurred at the Calibri typeface. In Calibri, the recognition thresholds were much lower for upper-case words than for lower-case words. Based on these results, it can be concluded that, apart from Calibri, the utilisation of increased lower-case letters resulted in similar reading speed as the utilisation of upper-case letters. The increased lower-case letters of Calibri typeface were comparable to the Georgia, Trebuchet and Verdana typefaces. Words in Calibri were processed even faster when in upper-case style. Calibri in bold shows medium thickness of strokes (compared to other tested typefaces), which might have helped when reading Calibri in the upper-case style.

Calibri, Trebuchet and Verdana are representatives of the same stylistic group. Their letters have small differences in stroke thickness; the white space is slightly increased, which results in better legibility when used on screen. The thickness of strokes in the Trebuchet typeface is slightly smaller compared to the Calibri and Verdana typefaces. Consequently, the counter shape is increased and can contribute to better legibility. The Georgia typeface is differentiated by the thickness of strokes and serifs. Words written in Georgia required shorter recognition time. We assume that the design characteristics of typefaces, which are based on humanist typefaces (for example renaissance, baroque, linear humanist) affect word processing favourably. The Swiss 721 typeface requires the longest processing time, possibly due to relatively thick, closed and static forms (in comparison to humanist linear typefaces).

The position of the presented word had a statistically significant effect on the recognition threshold (Table 3). The post-hoc analysis showed shorter recognition threshold for the words presented in the upper part of the screen compared to the lower part of the screen. An additional difference was seen between the bottom-left and bottom-right part of the screen (cf. also Table 4). It is slightly surprising that the words were processed faster when presented in the upper parts of the screen, even though in practice titles are not placed in this position. Previous research (Schomaker and Meeter, 2012; Pušnik et al., 2016) suggested that faster processing of words in the upper half of the screen could be explained with the less expected stimuli attracting attention faster.

4. Conclusion

The aim of the research was to examine if there are differences in legibility among typefaces (as measured with the recognition threshold) when the x-height of lower-case letters is increased to the size of upper-case letters. The average recognition thresholds for the Georgia, Trebuchet and Verdana typefaces were similar when comparing lower- and upper-case letters, while a great improvement in the recognition was noticed at the Calibri typeface when words were presented in upper-case letters (recognition threshold was much lower compared to lower-case letters). The stroke thickness in Calibri is not the biggest (strokes in Swiss 721 and Verdana are thicker); therefore, evident counter size is noticeable. The difference among typefaces is also noticeable in stroke endings. Calibri has rounded endings while other linear tested typefaces have straight ones. Rounded endings appear more organic and letters are more open, which could be a reason for faster processing of words when presented in Calibri and upper-case style. Furthermore, the ratio between the width and height in Calibri shows higher letters compared to the letters in Verdana, for example. Different ratio between the width and height in higher and narrower letters can affect the processing. A comparison to Swiss 721 where the strokes are more closed can also suggest a reason for better legibility and faster processing of Calibri. In Calibri,

Table 2
Means and standard deviations of recognition thresholds (in ms) for typefaces in lower- and upper-case.

	Lower-case		Upper-case		Average	
	M	*SD*	*M*	*SD*	*M*	*SD*
Calibri	144.7	29.5	138.7	31.7	141.7	30.6
Georgia	144.5	30.8	145.2	29.4	144.9	30.1
Trebuchet	145.6	29.8	147.3	30.0	146.5	29.9
Swiss721	159.2	24.8	160.6	22.4	159.9	23.6
Verdana	147.5	29.6	146.6	32.0	147.1	30.8
Average	148.3	36.1	148.0	29.0	148.0	30.2

Table 3
Results of ANOVA of recognition threshold.

Source of variability	*SS*	*df*	*MS*	*F*	*p*	η_p^2	Results of post-hoc comparisons
T	80,481.92	5.00	16,096.39	36.39	0.000	0.43	Calibri < Georgia, Trebuchet < Verdana < Swiss 721
Error (T)	108,359.22	245.00	16,096.39				
LC	956.34	1.00	956.34	0.29	0.596	0.01	
Error (LC)	164,476.47	49.00	3356.66				
P	22,455.69	2.19	10,274.28	6.43	0.002	0.12	Upper right, upper left < lower left < lower right
Error (P)	171,161.49	107.09	1598.21				
T × LC	5325.34	4.76	1119.53	2.57	0.030	0.05	
Error (T × LC)	101,488.72	233.08	435.42				
LC × P	2636.78	2.66	991.03	1.71	0.174	0.03	
Error (LC × P)	75,507.49	130.37	579.17				
T × P	3655.87	15.00	243.72	0.77	0.710	0.02	
Error (T × P)	232,180.07	735.00	315.89				
T × LC × P	5994.78	15.00	399.65	1.26	0.225	0.03	
Error (T × LC × P)	234,001.57	735.00	318.37				

Note: T – Typeface, LC – Letter Case, P – Position.

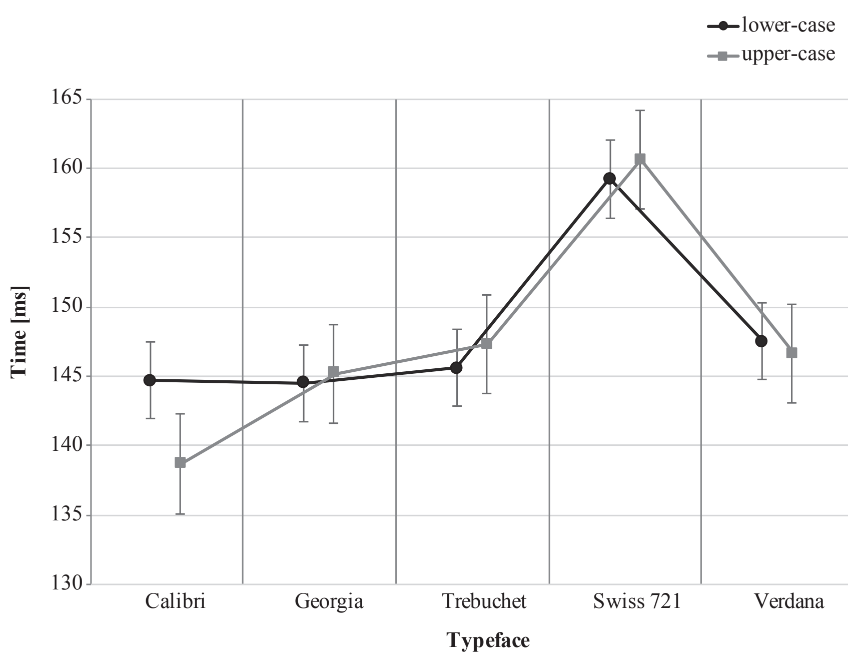

Fig. 4. Recognition thresholds (in ms) for combinations of typefaces and letter cases. Standard errors of mean are shown for each experimental condition.

Table 4
Means and standard deviations of recognition thresholds (in ms) for positions in lower- and upper-case style.

	Lower-case		Upper-case		Average	
	M	*SD*	*M*	*SD*	*M*	*SD*
Top left	145.0	29.0	148.3	26.7	146.7	27.9
Top right	144.7	32.5	143.1	32.4	143.9	32.5
Bottom left	149.4	30.5	147.4	31.4	148.4	31.0
Bottom right	154.1	23.5	151.9	25.9	153.0	24.7
Average	148.3	28.9	147.7	29.1	148.0	29.0

the letters are more open. The Swiss 721 typeface stood out – its average recognition thresholds for both lower- and upper-case letters were significantly longer, which was probably due to the static, closed and thicker strokes.

All of the five tested typefaces were made for screen use. In general, they are also marketed and used particularly for this purpose. However, in our study, Swiss 721 proved less legible. The recognition thresholds for this typeface were by more than 10 ms longer than for other tested typefaces. The reason for this could be found in the form of Swiss 721. Its letters are more closed and static.

When watching television, titles are sometimes presented in a crawl, moving at the top or at the bottom of the screen from the right to the left (information about current events, election results, effects of natural disasters etc). Viewers can have difficulties in following the content if the letters are too small, which might make providing important information pointless. The selection of an appropriate typeface with the design features that increase legibility is of major importance, especially if the speed of crawl is high. In such cases, it is recommendable to use lower-case letters in larger sizes. In this way, observers have the ability to process the crawling titles faster. It is advisable to increase the x-height of lower-case letters for on-screen presentations. An increase in x-height to the size of upper-case letters makes letters by almost twice as large, leading to better legibility and faster word processing.

Words presented in the top parts of the screen were processed faster than in the bottom parts. It might be better to place short titles in the top part of the screen, the same as it is common in the computer usage, where all vital system and program functions are placed in the upper part of the computer screen.

With an appropriate typeface selection, position and increased x-height, information can be processed faster. Future studies should examine if legibility can further increase when colour combinations are carefully combined with the factors we studied in this research.

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