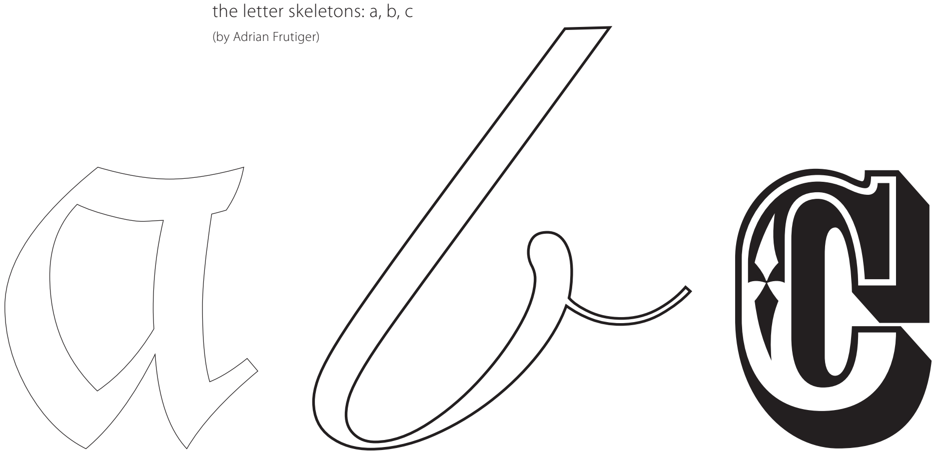
the letter skeletons: a, b, c
(by Adrian Frutiger)



embellished display letterforms that depart from the letter skeletons: a, b, c

Legibility Implications of Embellished Display Typefaces

Sofie Beier

Katrine Sand

Randi Starrfelt

By subjecting participants to brief exposure of single letters in the peripheral visual field, we investigated 1) hemispheric differences in reading of embellished display typefaces, and 2) the legibility difference between different kinds of embellished display typefaces. The test typefaces are designed for the purpose of controlling for the variables of swashes, stroke contrast and drop shadow.

The results show that all fonts are processed more accurately in the right visual field (corresponding to initial processing in the left hemisphere), and this is mainly evident when exposure is very brief (Experiment 1). This is contrary to the expectation that embellished typefaces should have an advantage when presented to the right hemisphere /left hemifield. There was also a clear difference in overall performance between the different embellished typeface styles, suggesting that legibility is more affected by swashed features than by a reversed letter stroke, or by a drop shadow.

When choosing between different styles of embellished display typefaces, it is therefore recommended to choose typefaces where the letter skeleton is not too complicated to decode.

Keywords

legibility

readability

type design

fonts

perception

typeface style

Introduction

Designers will often choose embellished display typefaces for advertisement and for the design of corporate identities. This in contrast to typefaces selected for body text where the style most often is less notable. In this paper, we define an embellished display typeface as one which has additional graphics added to the basic letterform skeleton, as measured by perimetric complexity. An unadorned typeface is one adhering closely to the basic letterform skeleton without adding such embellishments. In spite of the legibility levels varying highly between the embellished display typefaces and the more unadorned body text typefaces, literature of psychophysics and typeface legibility rarely makes this distinction (Tracy 1986). The aim of the majority of legibility studies have been to identify the most legible typeface by comparing several different typefaces (see Dobres et al 2016; Bessemans 2016 for recent examples), or to identity the letter features that results in optimal identification (see Larsen & Carson 2016; Beier & Dyson 2014; Beier & Larson 2010 for recent examples:).Yet none of the studies have focused on the difference between typefaces for display and typefaces for body text, and none of the studies have focused on the legibility matters that specifically relate to display typefaces.

Embellished typefaces are more difficult to visually process than unadorned styles: Pelli and colleagues (2006) have found that the extended number of features in complex typefaces results in a 'bottleneck' in visual perception. This is additionally confirmed in a multidisciplinary collaboration between typographers and cognitive neuroscientists, who explored the discrimination processing of a number of different typeface styles using Electroencephalography (EEG) technology, and found that the brain works harder when exposed to the embellished typefaces Lucida Blackletter and Edwardian Script, compared to the unadorned typefaces Arial and Times New Roman (Thiessen et al. 2015). Bernard and Chung (2013) further found that – up to a certain value – the more complex the typeface the more difficult it is to identify a target letter within a letter string.

We are, however, yet to understand how the different features of embellished typefaces influences legibility.

The present paper presents experimental investigations on 1) whether it is possible to isolate specific character features that affect processing in the two hemifields / heimpsheres differently, and 2) on the legibility implications that can follow with embellished typefaces.

Our understanding of the term 'legibility' follows the description of typographer writer Walter Tracy, who stated that: "…legibility is the term to use when discussing the clarity of single characters (Tracy, 1986, p.31)."

Brain mechanisms in perception of unadorned and embellished typefaces

There is evidence that somewhat different brain processes may be involved in reading of unadorned typeface styles than in reading embellished, more complex, display typefaces, such that unadorned typefaces would mainly draw on left hemisphere processing and some embellished typefaces would need additional processing in the right hemisphere (Wagner & Harris 1994; Bryden & Allard 1976).

It is well-documented that reading is predominantly subserved by the left hemisphere (e.g., Dehaene & Cohen, 2011), which is also the case in the reading of Urdu, Hebrew and Arabic that traditionally are read from right to left (Adamson & Hellige 2006; Eviatar & Ibrahim 2004). Visual areas in the right hemisphere, however, also contribute, and have been suggested to be particularly involved in processing of typefaces (Barton et al., 2010; Susilo et al., 2015).

Because visual areas in the left cerebral hemisphere receives the primary input from the right visual field, and the right hemisphere visual areas receives the primary input from the left visual field, this can be investigated in divided visual field paradigms. Bryden and Allard (1976) used such a paradigm to investigate how the two hemispheres of the brain contribute to the identification of different typographical material in a short exposure experiments (Figure 1), and found that, in general, letters were more accurately identified when presented to the left hemisphere (the right visual field), and that this was most evident in the more unadorned type styles tested. Interestingly, when some of the embellished typeface styles like Palace Script and Profile were presented, recognition was superior for letters presented to the right hemisphere (left visual field). The researchers suggested that in cases where the typeface requires considerable processing, the right hemisphere serves to isolate the relevant features in the letter shapes and at the same time, disregard the irrelevant ones. The results have later been supported by Wagner and Harris (1994) who applied a similar study design and also found a right hemisphere advantage for complex typefaces styles (figure 2). Testing the typeface Helvetica and two handwritten script styles, Hellige and Adamson (2007) found a general left hemisphere advantage in all styles, yet the left hemisphere advantage was significantly smaller with the handwritten script styles than with Helvetica. This division of labour between the two cerebral hemispheres is further demonstrated in studies of brain-injured patients (Barton et al., 2010). For instance, Barton and colleagues (2010) have found, that while patients with damage to posterior areas in the left hemisphere have deficits in reading letters and words, they may be unimpaired in categorizing samples of handwriting and different

Figure 1

The typefaces tested by Bryden & Allard (1976). The two typefaces marked by a star, both demonstrated right hemisphere advantage.

typefaces. Patients with damage to posterior areas in the right hemisphere show the opposite pattern, they are impaired in sorting typefaces and handwriting, but have no problems reading words (Hills et al., 2015; Susilo et al., 2015).

To detect the characteristics that causes a right hemisphere advantage, Bryden and Allard had participants rate the 10 typefaces on the dimensions of 'familiar/unfamiliar', 'high/low internal confusability', and 'script like/print like' features. In addition, the researchers looked into typeface difficulty, by measuring the mean time from presentation to articulation of the letter name.

They demonstrated a correlation between the right/left hemisphere advantage determined in the short exposure experiment, and all of the dimensions except for 'familiar/unfamiliar'. In other words, the typefaces that were judged to be most script like, with high internal letter confusability, and most difficult to read, were also the typefaces that showed a right

Figure 2

Wagner and Harris (1994) tested 8 different typeface styles, and found the typefaces Murrey Hill and Shotgun to demonstrated a right hemisphere advantage.

hemisphere advantage in the short exposure study.

However, a number of the typefaces received high ratings in several of the rated dimensions. As an example, the typefaces Palace Script and Old English were both rated as having high internal letter confusability and as being script like, while it was only Palace Script that showed significant right hemisphere advantage. It is therefore difficult to say whether it was the script style or the internal letter confusability that caused right hemisphere advantage.

By identifying the specific features within a given typeface design that causes a right hemisphere advantage, and by identifying the internal legibility relation between these typefaces, this investigation aims at a better understanding of how the brain processes different styles of typefaces.

Experimental investigation

A visual examination of the four typefaces known to result in right hemisphere advantage, demonstrates two major trends. One is related to the swash style and the uncommon skeletons of the typefaces Palace Script and Murray Hill, and the other is related to the excessive details and heavy weights of the otherwise relative common skeleton of the typefaces Profil and Shot Gun (figures 1 and 2). In this study we will investigate the effect of swash style and the effect of excessive added details. In addition to this, we study the effect of unfamiliar letter strokes. We have worked with two separate hypotheses: The first is related to hemisphere processing. We expect that the more complex and the more illegible typefaces will be better processed in the left visual field (right hemisphere). The second hypothesis is related to legibility, understood as the clarity of the single letter. As complex typefaces are more difficult to visually process than unadorned typefaces (Thiessen et al. 2015; Pelli et al 2006), and as embellished typefaces often have complex letter features, the embellished typefaces are expected to be less legible than the unadorned typeface. The focus is on whether the effect of swash style, the effect of excessive added details, or the effect of unfamiliar letter strokes, will influence legibility the most.

The two hypotheses are investigated through a method of short exposure in the parafoveal field of vision. By exposing participants to the stimuli in left and right parafoveal fields, the study can both provide data on the left/right hemisphere processing, and shed light on more classic legibility related matters. Through a series of investigations carried out in the 1970s, Keith Rayner and colleagues have demonstrated that readers make great use of the parafoveal vision in reading (see Rayner & Pollatsek 1989 for an overview). They found that the easier it is to identify the letters in right parafoveal vision, the easier it is to locate where on the line of text, the eye should fixate next, which results in a more effortless reading experience. Following this, letters that demonstrate high legibility in parafoveal vision will result in better clarity, and hence less troubled reading. Based on these findings, the present study investigates legibility in parafoveal vision at 4.5 degrees.

Test typefaces

Most comparative studies of unadorned and embellished typefaces (Bryden & Allard 1976; Wagner & Harris 1994; Thiessen et al. 2015) include typefaces that vary on many dimensions. As an example, Palace Script and Old English are different in weight, letter slant, stroke contrast, letter skeleton, and in vertical and horizontal proportions. It is therefore difficult to identify which features of Palace Script that caused a right hemisphere advantage in the Bryden and Allard study. The test typefaces of the present study are designed for this experiment. By so doing, it is possible to control the variables that make two random typefaces different from each other. By ensuring that only one visual feature is altered at a time, it is possible to identify the one typeface-feature that causes a given difference in performance.

The test typefaces of the present study are divided into three categories of complexity (figure 3).

Figure 3

Designed for the experiments and with an outset in the Master typeface (NeutralTestRegular), the four expressive typefaces are designed to isolate specific features for investigation.

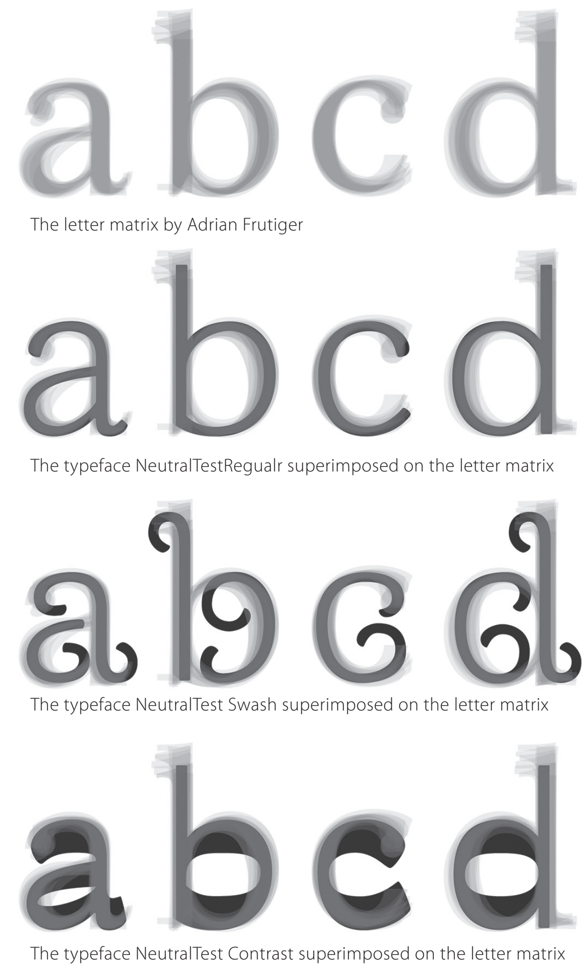
Level 1. An unadorned typeface

Master Typeface.

The typeface NeutralTestRegular (from here on identified as the Master) is developed for experimental investigations by Beier (Beier 2013) (Figure 4. second row). It is based on type designer Adrian Frutiger's idea of the letter matrix (1998; 2008) (Figure 4. top row). Frutiger argued that all readers have a letter matrix in their mind, and that this matrix is based on all the different representation of the letters that the reader has encountered during reading. Following this, Frutiger theorized that the optimal letter skeleton constitutes a neutral letter shape, and that this can be found in the surface area where the characters of the most popular common typefaces overlap. Each letter of the Master is designed based on the darkest overlapping areas of the most common typefaces superimposed. The resulting 'neutral letter shapes' hence follows the requirements for an unadorned typeface.

Figure 4

As suggested by type designer Adrian Frutiger (1998; 2008), the typefaces Garamond, Baskerville, Bodoni, Excelsior, Times, Palatino, Optima, and Helvetica, are superimposed (top row). The dark part where most letters overlap shows the basic letter skeleton.



Level 2. Reversed Swash and Contrast typeface

NeutralTest Swash.
The only difference between the Master typeface and the Swash typeface is the added swashes to the letter skeleton, all other parameters such as stroke thickness, contrast, and letter proportions, remain identical between the two (Figure 4. third row). This is done to isolate the swash effect from the uncommon letter skeletons identified in the typefaces Palace Script and Murray Hill. The swashes do, however, dissolve the basic letter skeleton of the Master typeface.

NeutralTest Contrast.
The only difference between the Contrast style and the Master typeface is the unfamiliar added weight to the horizontal strokes, also called reversed stroke contrast. The tradition of Latin typefaces is that the vertical strokes are heavier than the horizontal strokes. The feature consequently also adds more weight to the letter (Figure 4. fourth row).

It is expected that the Swash and the Contrast typefaces are less legible than the Master typeface.

Level 3. Drop Shadow

NeutralTest SwashShadow and NeutralTest ContrastShadow.
The drop shadow of this category adds excessive details to the letter. It is expected that these typefaces, are less legible, and demonstrate greater right hemisphere activity than the typefaces of level 1 and 2.

Experimental paradigm and data analysis

We tested the two hypotheses using a psychophysical paradigm, a single item report task, analysed within the framework of Bundesen's (1990) Theory of Visual Attention (TVA). Based on TVA, methods for investigating visual attention, as well as visual perceptual processes have been developed, enabling us to quantify aspects of perception like visual processing speed and the threshold for perception for different stimuli. Single item experiments within this framework use unspeeded, accuracy-based tasks, which are unconfounded by motor components. This means that response times are not measured. Rather, the exposure time of the stimulus is varied, and the increase in accuracy with increased exposure duration is measured. The method has previously been used to investigate visual perception of letters, numbers, and words both in normal (e.g. Starrfelt et al. 2013) and brain injured subjects, and also in studies comparing processing of such stimuli in the right and left visual fields (Sand, Habekost, Petersen, & Starrfelt, in press).

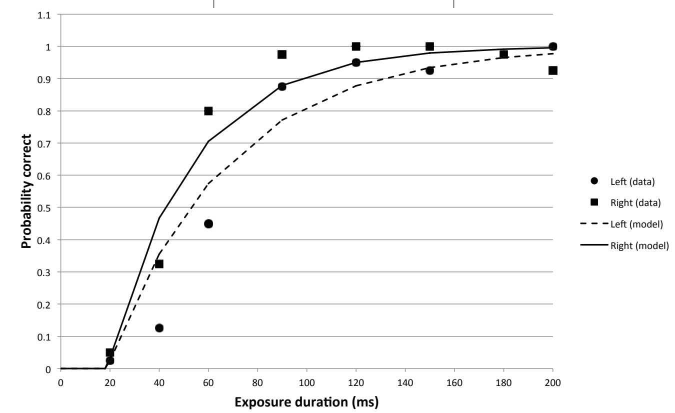


Figure 5

Performance for left and right visual fields of the Master typeface for a representative subject in experiment 2. The curve shows the probability of correct report as a function of stimulus duration. t_0 is the threshold of conscious perception and shows the longest ineffective exposure duration for the subject. *v* is the slope of the curve and reflects the perceptual processing speed.

Here, we use a single item report task to investigate differences in how different typefaces are perceived in the right and left visual fields. We focus on two parameters derived from the TVA: the temporal threshold of conscious perception (t_0), and the perceptual processing speed (*v*) (see Bundesen & Habekost, 2008; Habekost, 2015 for details).

In both experiment 1 and 2, the individual data were fitted to a maximum likelihood procedure using the LibTVA toolbox for MatLab (Dyrholm et al. 2011). Based on the assumption that there would be no laterality difference in t_0 for each typeface, we estimated a single t_0-parameter and two v-parameters (the processing speed for the left and right side respectively). The parameters are illustrated in figure 5. We also report the overall proportion of correct responses across all exposure durations for each typeface, both in total and for each visual field. The overall correct scores, threshold, and visual processing speed across the participants were compared with paired-samples t-tests (two-tailed). Multiple t-tests were not corrected for, due to the exploratory nature of the study. Effect sizes are reported as Cohen's *d*.

Experiment 1

Participants

19 subjects participated in the experiment (11 males, mean age: 23.9, SD: 2.51, range: 21-30). The following inclusion criteria were used: the participants were right-handed, had normal or corrected-to-normal vision, no dyslexia, or psychiatric or neuropsychological condition. We only included subjects who had learned to read in a language using Latin letters. All provided written informed consent. All participants were given a product key for a product sponsored by Microsoft after participation in the experiment.

Materials

All experiments were conducted in a semi-darkened room. Subjects were seated with their head in a chin rest, 80 cm from a 20" CRT-monitor running at 150 Hz with a resolution of 800 x 600 pixels.

Figure 6

Trial outline for Experiments 1 and 2. The only difference between the experiments was the exposure durations used.

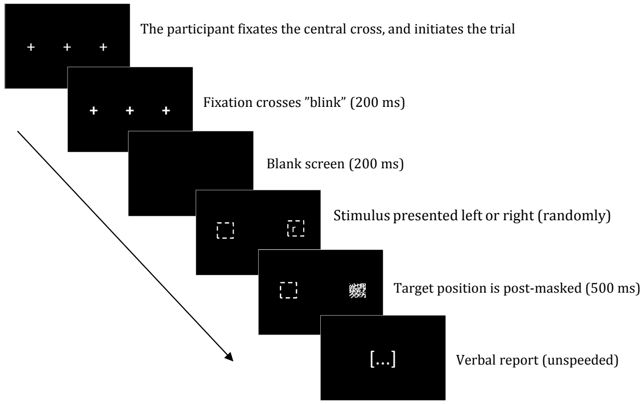


Table 1

Stimulus sizes for the five different typefaces in visual degrees

	Width		Height	
	Mean	Range	Mean	Range
Master	0.67	0.29 - 1.1	0.9	0.72 - 1.43
Swash	0.85	0.57 - 1.3	0.9	0.72 - 1.43
Contrast	0.79	0.57 - 1.1	0.9	0.72 - 1.43
SwashShadow	1.04	0.72 - 1.43	1.04	0.86 - 1.43
ContrastShadow	0.84	0.57 - 1.23	1	0.79 - 1.58

Stimuli and masks

To minimize the backlight from the screen, the stimuli were presented in lower-case, point size 30 in white on a black background. The mean stimulus sizes for each typeface are presented in visual degrees in table 1. Eight different exposure durations (13, 27, 40, 53, 73, 93, 113, and 133 ms), and 16 letters of the alphabet were used (a, b, e, f, g, j, k, m, o, q, r, s, t, x, y, z). Each individual letter was shown the same number of times for each typeface. Stimuli were post-masked for 500 ms with rectangular pattern masks (2.51° x 1.93°), which were constructed of letter fragments, in order to erase the visual afterimage (figure 6).

The participant initiated each trial by pressing the space button when they fixated on a centrally placed fixation cross. When a trial started, the fixation crosses became bold for 200 ms (fixation flash), which was followed by a blank screen for 100 ms before the stimulus appeared on the screen. The stimuli were presented randomly at 4,5° of visual angle to the left or right of fixation. Participants were instructed to make a non-speeded report of the stimulus, and only to report a letter if they were "fairly certain" of what they had seen, in order to refrain from pure guessing but still use all the information available about the stimulus. Participants were informed of their accuracy after each block, and instructed to aim for an accuracy of 80-90% (correct responses of responses given). This is the standard instructions used in experimental paradigms based on TVA (see Habekost, 2015). Subjects completed 40 blocks of 80 trials, with breaks for every ten blocks. Each block consisted all 16 letters shown one time in each of the five fonts. Each font was shown one time randomly without replacement for each exposure duration in each visual field. The entire experiment took between 2.5 - 3 hours to complete.

Table 2

A comparison of visual processing speed (v) and overall correct scores between the left and right visual field in Experiment 1, showing higher processing speed and overall correct score in the right visual field for all typefaces.

	Left visual field		Right visual field		Statistics		
	Mean	SD	Mean	SD	*t*	*p*	*d*
v **- perceptual processing speed**							
Master	23.54	(10.23)	32.1	(10.05)	-4.39	< .001	-0.84
Swash	7.03	(2.71)	8.78	(3.84)	-2.62	.017	-0.53
Contrast	13.03	(5.14)	18.24	(6.61)	-3.38	.003	-0.89
SwashShadow	6.26	(2.31)	8.39	(3.93)	-3.21	.005	-0.68
ContrastShadow	9.68	(3.02)	14.21	(5.94)	-3.21	.005	-1.49
Overall correct score							
Master	0.44	(0.11)	0.52	(0.1)	-5.10	< .001	-0.76
Swash	0.23	(0.08)	0.27	(0.11)	-2.69	.015	-0.42
Contrast	0.32	(0.1)	0.39	(0.1)	-3.77	< .001	-0.7
SwashShadow	0.2	(0.06)	0.25	(0.09)	-3.55	.002	-0.67
ContrastShadow	0.28	(0.08)	0.37	(0.12)	-3.52	.002	-0.9

Table 3

Overall proportion correct reports across all exposure durations for each typeface in Experiment 1. Comparing the Master typeface to the four test-typefaces shows that the Master is perceived significantly better than all four test-typefaces.

	Overall correct score	SD	Master vs.		
Master	0.48	(0.1)	*t*	*p*	*d*
Swash	0.25	(0.09)	17.62	< .001	2.42
Contrast	0.36	(0.09)	13.44	< .001	1.26
SwashShadow	0.23	(0.07)	17.34	< .001	2.94
ContrastShadow	0.32	(0.08)	13.07	< .001	1.78

Results: Experiment 1

The results show that, in general, stimuli presented in the right visual field were reported more correctly than stimuli in the left visual field. Multiple t-tests showed significant left/right differences for all typefaces, which is reflected in both overall correct scores (proportion correct across all exposure durations) and perceptual processing speed (see table 2).

In order to test the overall difference between the typefaces, a mean of the left and right score was calculated, and each of the embellished typefaces was compared to the Master typeface. All tests showed that the Master typeface was reported significantly more correct than each of the embellished typefaces. Of the embellished typefaces, the participants scored highest when stimuli were shown with the Contrast typeface. This was followed by the ContrastShadow typeface (mean: .32, SD: 0.08) and the Swash typeface (mean: .25, SD: 0.09). Participants scored lowest on stimuli shown with the SwashShadow typeface (mean: .23, SD: 0.07). Table 3 shows the overall correct score for each typeface and how each of the embellished typefaces compare to the Master typeface. Comparisons of t_0 (the threshold of conscious perception) for each specially designed typeface with the Master typeface as baseline, showed no significant differences (all *p*s > .159). The mean scores of the Swash and SwashShadow typefaces showed that participants scored significantly higher when the Swash typeface was shown

	Left visual field		Right visual field		Statistics		
	Mean	SD	Mean	SD	*t*	*p*	*d*
***v* - perceptual processing speed**							
Master	28.89	(9.25)	32.86	(13.16)	-1.38	.184	-0.35
Swash	7.02	(2.14)	7.66	(2.56)	-1.44	.168	-0.27
Contrast	13.77	(2.91)	16.23	(4.57)	-2.68	.015	-0.66
SwashShadow	6.42	(2.30)	7.52	(3.27)	-1.71	.105	-0.39
ContrastShadow	8.62	(2.20)	10.61	(3.39)	-2.40	.028	-0.71
Overall correct score							
Master	0.64	(0.06)	0.66	(0.07)	-1.34	.197	-0.31
Swash	0.36	(0.08)	0.38	(0.11)	-1.23	.235	-0.23
Contrast	0.51	(0.05)	0.55	(0.08)	-2.40	.027	-0.54
SwashShadow	0.33	(0.09)	0.36	(0.12)	-1.60	.127	-0.31
ContrastShadow	0.42	(0.08)	0.46	(0.10)	-2.20	.041	-0.54

Table 4

A comparison of visual processing speed (v) and overall correct scores between the left and right visual field in Experiment 2.

without shadow: $t(18) = 3.40$, $p = .003$, $d = 0.25$. This was also found when comparing the Contrast typeface with the ContrastShadow typeface: $t(18) = 4.31$, $p < .001$, $d = 0.47$.

Experiment 2

Due to the low overall correct scores for each typeface in Experiment 1, we set up a new experiment with longer exposure durations, in order to establish whether the results of the previous experiment, showing no left visual field superiority with any of the tested typefaces, could be explained by the difficulty of the experiment.

The setup of the experiment is the same as in experiment 1, however the refresh rate was 100 Hz, and the exposure durations were 20, 40, 60, 90, 120, 150, 180, and 200 ms.

Participants

19 subjects participated in the experiment. (2 males, mean age: 23.95, SD: 2.34, range: 21-30). 9 subjects participated for course credit, and 10 subjects received a gift card of 300 DKK after participation. All participants provided written, informed consent.

Results: Experiment 2

In this experiment, we found a significant difference in the overall correct score and the processing speed between the left and right visual field for the Contrast typeface and the ContrastShadow typeface. As shown in table 4, both typefaces had the highest overall correct score and the highest processing speed when shown in the right visual field, with the highest effect sizes for the processing speed

			Statistics for master vs.:		
	Mean	SD	*t*	*p*	*d*
***t0* - threshold of perceptual processing**					
Master	34.8	(8.33)	-	-	-
Swash	32.11	(11.27)	1.27	.219	0.27
Contrast	34.30	(9.35)	0.26	.801	0.06
SwashShadow	35.24	(11.37)	-0.25	.807	-0.04
ContrastShadow	31.62	(9.37)	2.19	.042	0.36
Overall correct score					
Master	0.65	(0.05)	-	-	-
Swash	0.37	(0.09)	19.83	<.001	4
Contrast	0.53	(0.06)	16.15	<.001	2.18
SwashShadow	0.34	(0.1)	19.04	<.001	4.13
ContrastShadow	0.44	(0.08)	17.89	<.001	3.23
***v* - visual processing speed (mean of both visual fields)**					
Master	30.87	9.49	-	-	-
Swash	7.34	2.15	10.90	<.001	4.04
Contrast	15.00	3.27	7.91	<.001	2.49
SwashShadow	6.97	2.46	11.01	<.001	4
ContrastShadow	9.62	2.21	10.22	<.001	3.63

Table 5

Threshold (t0), visual processing speed (v), and overall correct scores for each typeface in Experiment 2. Comparing the Master typeface to the four test-typefaces shows that the Master is perceived significantly better than all four test-typefaces, and that this is reflected in both visual processing speed and overall correct scores.

The only difference between the Master typeface and each of the embellished typefaces for t_0 is found in the ContrastShadow typeface, which is significantly lower than the Master typeface ($t(18) = 2.19$, $p = .042$, $d = 0.36$, the rest of the *p*s > .219). The p-value for the *t*-statistic is however close to the critical value at .05, and the effect size is small. This may therefore be a random finding, as the ContrastShadow typeface does not stand out in any other way; it does not have an advantage in neither overall correct score nor the mean processing speed compared to the Master typeface. Just like in the first experiment, participants had a significantly lower overall correct score for the embellished typefaces compared to the Master typeface (see table 5).

The t-tests between pairwise typefaces showed significant differences in overall correct scores between shadowed and non-shadowed typefaces. Thus, participants performed significantly worse with SwashShadow compared to Swash: $t(18) = 3.43$, $p = .003$, $d = 0.32$, and ContrastShadow was worse than Contrast: $t(18) = 9.76$, $p < .001$, $d = 1.29$.

Overall, we find that compared to the Master typeface, all the other typefaces degrade the visual perception of each letter. The Swash typeface degrades the visual input more than the Contrast typeface, and the shadow effect degrades the visual input for both SwashShadow and ContrastShadow, compared to no shadow-effect. Furthermore, the only typeface that shows a lateral difference is the Contrast typeface and the ContrastShadow typeface, which are perceived better in the right visual field compared to the left visual field.

Discussion

If a typographical layout is to communicate certain moods or associations, choosing a headline typeface of a more embellished nature can support this approach (Juni & Gross 2008; Brumberger 2003; Tantillo et al. 1995; Walker et al. 1986). Understanding how the brain processes these embellished typefaces, will provide the designer with usable tools when choosing typefaces for a given assignment.

Within psychophysical research, the theory of feature detection finds that at the initial first steps of identification, letters are not identified as wholes but are identified through the individual features (Pelli et al. 2006; Rayner and Pollatset 1989), and that the relevant features that distinguish one letter from the others are the main features important for visual processing (Fiset et al. 2008). It is generally agreed that word reading is a cascaded, interactive process; feature detection and letter recognition feeds into lexical operations which in turn constrains the interpretation of the input via feedback loops (e.g., Dehaene & Cohen 2005; Coltheart et al. 2001; McClelland & Rumelhart 1981). Following this, when reading a complex typeface of letters that are difficult to decode, the reader will have to draw heavily on top down processes of lexical operations. The feature detection theory hence confirms the findings by others (Thiessen et al. 2015; Pelli et al 2006) that typefaces with features that are difficult to identify are more difficult to process –and hence less legible – than typefaces with easily identifiable features.

Bryden and Allard suggested a two stage perceptual process related to feature detection. The theory is that there is an initial stage of right hemisphere activity of a global focus aiming at identifying relevant features, which is proceeded by a second stage of left hemisphere activity of identification and naming of the target. Following this, for successful processing of complex typefaces, the two stages will need to cooperate. However, when processing more unadorned typefaces, the initial stage of identifying relevant features might not be equally essential, as it comes as no surprise where to locate the individual features needed for letter identification.

An interesting finding from Experiment 2 is that there is a significant difference in threshold of perception between the Master typeface and ContrastShadow, whilst there were no significant differences for the rest of the typefaces in threshold of perception. This shows that not only does it take significantly longer to process the ContrastShadow typeface compared to the Master typeface, it also takes a significantly longer time before the

Figure 7

Adrian Frutiger's idea of a basic letter matrix superimposed on the four typefaces that previously have demonstrated right hemisphere advantage (Bryden & Allard 1976; Wagner & Harris 1994).

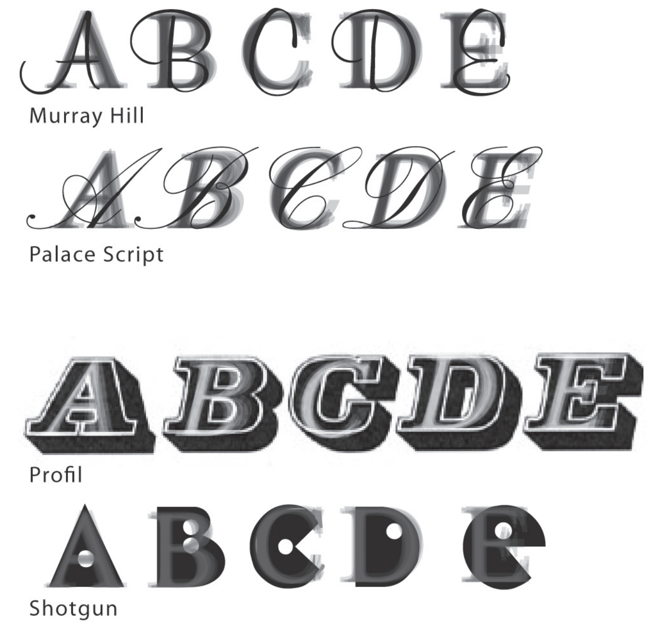


Figure 8

The legibility ranking of the tested typefaces.

participants reach the threshold at which they can consciously perceive this typeface.

A closer look at the script typefaces that previously have shown right hemisphere advantages (figure 7, top) demonstrates that the letter skeleton differs more from the basic letter matrix than in the typefaces of the Neutral Test family (figure 4). A further look at the heavy bold typefaces that previously have shown right hemisphere advantages (figure 7, bottom) demonstrates that the boldness produces tiny inner counters that in some letters are almost non existing, a feature also not seen in the typefaces of the Neutral Test family.

The hypothesis that the most embellished typefaces would have an advantage when presented to the left hemifield / right hemisphere was not supported in the present study. Following the observations above, this result indicates that the visibility level of the letter skeleton might be the key to producing either right or left hemisphere advantages. It is possible that the placement of the essential features in the embellished typefaces of the NeutralTest family was both more predictable and visible, and hence the initial process of a global feature identification did not have to draw significantly on right hemisphere processing.

If the shape of the letter skeleton is the reason why the NeutralTest Swash typefaces did not produce right hemisphere advantage, the higher visibility of the skeleton compared to Palace Script and Murray Hill, was however, not sufficient for the NeutralTest Swash typefaces to be highly legible. The hypothesis that the embellished typefaces are less legible than typefaces of unadorned style, was hence confirmed, as the Master typeface was the most legible of them all. What is interesting is the internal legibility ranking between the three features of swashes, reversed stroke contrast and shadow.

The typeface Contrast Shadow turned out more legible than Swash, which does not have a shadow effect (Figure 8), and so it indicates that the swash effect degrades the visual input more than both reversed contrast and shadow effects. Furthermore, the shadow effect generally degrades the visual input.

As the ornamentation of the Swash typefaces have the same stroke thickness as the letter skeleton, skeletons and ornaments could be difficult to separate, and so have a larger negative impact on the letter legibility than typefaces which manage to maintain a common letter skeleton as in the two Contrast typefaces. The negative effect of the Swash typefaces is even stronger than the added drop shadow on ContrastShadow.

In short, the letter skeleton of the NeutralTest Swash typefaces is too visible to induce a right hemisphere advantage, but not sufficiently visible to result in high legibility.

Conclusion

The data suggests that the style of typefaces, which facilitate additional right hemisphere processing, must be highly script like or heavy weight with small counters. This is concluded, as the tested versions in the present investigation were not sufficiently extreme to show an effect.

The findings further indicate that embellished typefaces with script like features are less legible than embellished typefaces of reversed stroke contrast and of embellished typefaces that both have reversed stroke contrast and a drop shadow.

To maximize legibility of embellished typefaces, type designers will benefit from creating typefaces that maintain a more common letter skeleton. Instead the designer can play with the typeface's expression in other ways, such as in the treatment of the letter stroke, or by added additional effects like a drop shadow. As long as the letter skeleton is maintained, typefaces can carry a range of additional features, and still be relatively legible to the reader.

References

Adamson & Hellige (2006). Hemispheric Differences for Identification of Words and Nonwords in Urdu–English Bilinguals, *Neuropsychology*, 20(2), 232-248.

Barton, J.J., Fox, C.J., Sekunova, A., & Iaria ,G. (2010). Encodingin the VisualWord Form Area:An fMRIA daptation Study of Words versus Handwriting. *Journal of Cognitive Neuroscience*, 22, 1649–1661.

Beier, S. (2013) 'Legibility Investigations: Controlling Typeface Variables', *Praxis and Poetics: Research Through Design*, Conference Proceedings, 92-95.

Beier. S., & Dyson, M. (2014). 'The influence of serifs on 'h' and 'i': useful knowledge from design-led scientific research', *Visible Language,* 47(3), 74-95.

Beier, S. & Larson, K. (2010). 'Design Improvements for Frequently Misrecognized Letters', *Information Design Journal*, 18(2), 118-137.

Bernard, J.-B., & Chung, S. T. (2013). The dependence of crowding on flanker complexity and target–flanker similarity. *J Vis, 11*(8), 1-1.

Bessemans, A. (2016). Matilda: a typeface for children with low vision, *Digital Fonts and Reading*, 19-36.

Brumberger, E.R. (2003). The Rhetoric of Typography: The persona of typeface and text, *Technical communication*, 50(2), 206-223.

Bryden, M.P., & Allard, F. (1976).Visual hemifield differences depend on Typeface. *Brain and Language*, 3(2), 191–200.

Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, *97*(4), 523–547.

Bundesen, C., & Habekost, T. (2008). *Principles of visual attention: Linking mind and brain*. Oxford University Press.

Bundesen, C., Habekost, T., & Kyllingsbæk, S. (2011). A neural theory of visual attention and short-term memory (NTVA). *Neuropsychologia*, *49*, 1446–1457.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108(1)*, 204-256.

Dehaene, S. & Cohen, L. (2011). The unique role of the visual word form area in reading. *Trends in Cognitive Sciences*, 15(6), 254-62.

Dobres,J., Chahine, N., Reimer,B, Gould,D., Mehler, B. & Coughlin, J.F., (2016). Utilising psychophysical techniques to investigate the effects of age, typeface design, size and display polarity on glance legibility, *Ergonomics*, Mar 4, 1-15.

Dyrholm, M., Kyllingsbæk, S., Espeseth, T., & Bundesen, C. (2011). Generalizing parametric models by introducing trial-by-trial parameter variability: The case of TVA. *Journal of Mathematical Psychology*, *55*(6), 416–429.

Evictor, Z. & Ibrahim, R. (2004). Morphological and orthographic effects on hemispheric processing of nonwords: A cross-linguistic comparison. Reading and Writing: An Interdisciplinary Journal, 17, 691-705.

Fiset, D., Blais, C., Éthier-Majcher, Arguin, M, Bub, D., & Gosselin, F. (2008) 'Features for Identification of Uppercase and Lowercase Letters', Psychological Science', 19(11), 1161-1168

Frutiger, A. (1998). *Signs and Symbols: Their Design and Meaning*, London: Ebury Press

Frutiger, A. (2008). *Adrian Frutiger Typefaces: The Complete Works*, H. Osterer & P. Stamm, Basel: Birkhauser.

Habekost, T. (2015). Clinical TVA-based studies: a general review. *Frontiers in Psychology, 6*, 290.

Habekost, T., Petersen, A., Behrmann, M., & Starrfelt, R. (2014). From word superiority to word inferiority: visual processing of letters and words in pure alexia. *Cognitive Neuropsychology, 31(5-6)*, 413-436.

Hellige, J.B., & Adamson, M.M. (2007). Hemispheric differences in processing hand- written cursive. Brain and Language, 102(3), 215–227.

Hills, C. S., Pancaroglu, R., Duchaine, B., & Barton, J. J. S. (2015). Word and text processing in acquired prosopagnosia. *Annals of Neurology, 78*(2), 258-271.

Hunziker, H.J. (1998) 'Typographic work of Adrian Frutiger', Serif: the magazine of type & typography, 6, 32-43

Juni, S. & Gross, J. (2008). Emotional and persuasive perception of fonts. P*erception and Motor skills*, 106, 35-42.

Larson, K. & Carter, M. (2016). Sitka: a collaboration between type design and science. *Digital Fonts and Reading*. 37-53.

McClelland, J.L., & Rumelhart, D.E. (1981). An interactive activation model of context effects in letter perception: part 1. An account of basic findings. *Psychological Review, 88*, 375-407.

Pelli, D.G., Burns, C.W., Farell, B., Moore-Page, D.C. (2006) 'Feature detection and letter identification', Vision Research, 46, 4646-4674

Rayner, K. & Pollatsek, A. (1989). *The Psychology of Reading*. Englewood Cliffs, NJ:Prentice-Hall International.

Susilo, T., Wright, V., Tree, J. J., & Duchaine, B. (2015). Acquired prosopagnosia without word recognition deficits. *Cognitive Neuropsychoogyl, 32*(6), 321-339.

Tantillo, J., DiLorenzo-Aiss, J., & Mathisen, R.E. (1995). Quantifying Perceived Differences in Type Styles: An Exploratory Study, *Psychology& Marketing*, 12 (5), 447-57.

Thiessen, M., Kohler, M., Churches, O., Coussens, S. & Keage, H. (2015) 'Brainy Type: a look at how the brain processes typographic information', Visible Language, 49.1-2, 174-189

Tracy, W. (1986). *Letters of Credit: a view of type Design*, London: Gordon Fraser.

Vangkilde, S., Coull, J. T., & Bundesen, C. (2012). Great expectations: Temporal expectation modulates perceptual processing speed. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(5), 1183–1191.

Wagner, N.M., & Harris, L.J.(1994). Effects of typeface characteristics on visual field asymmetries for letter identification in children and adults. *Brain and Language*, 46(1), 41–58.

Walker, P., Smith, S., & Livingston, A. (1986). Predicting the appropriateness of a typeface on the basis of its multi-modal features. *Information Design Journal*, 5(1), 29-42.

Authors

Sofie Beier is a type designer and associate professor at the School of Design under The Royal Danish Academy of Fine Arts, where she is the head of the MA program in Type & Wayfinding. She holds a PhD from the Royal College of Art in London and is the author of the book "Reading Letters: designing for legibility". Her current research is focused on improving the reading experience by achieving a better understanding of how different typefaces and letter shapes can influence the way we read. Several of her typefaces have been published through Gestalten Fonts, among these the Karlo and the Ovink families. The typeface Karlo received a Creative Circle Bronze Award in 2015.

Katrine Sand is a master's student of psychology at the Department of Psychology at University of Copenhagen. Her studies have mainly been focused on neuropsychology and cognitive psychology. She has conducted research within the field of visual word recognition, with particular focus on psychophysical methods for studying letter and word recognition.

Randi Starrfelt is associate professor in neuropsychology at the Department of Psychology at University of Copenhagen. She conducted her Ph.D. and a post doc at the Center for Visual Cognition at this Department. She also has certification as a specialist in clinical neuropsychology. Her research is concerned with visual recognition in various groups of neuropsychological patients, as well as normal subjects. In particular, she has focused on understanding the cognitive and cerebral processes underlying visual word recognition by combining psychophysical methods and traditional experimental (neuro)psychology. Recently she has extended her research to the area of face recognition, in particular focusing on people suffering from developmental prosopagnosia, or "face blindness".