Lack of regularity between letters impacts word recognition

performance

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19 Abstract

20 Physical inter-letter dissimilarity has been suggested as a solution to increase perceptual
 21 differences between letter shapes and hence a solution to improve reading performance.
 22 However, the deleterious effects of font tuning suggest that low inter-letter regularity (due to
 23 the enhancement of specific letter features to make them more differentiable) may impair
 24 word recognition performance. The aim of the present investigation was 1) to validate our
 25 hypothesis that reducing inter-letter regularity impairs reading performance, as suggested by
 26 font tuning, and 2) to test whether some forms of non-regularities could impair visual word
 27 recognition more. To do so, we designed four new fonts. For each font we induced one type of
 28 increased perceptual difference: for the first font, the letters have longer extender length; for
 29 the second font, the letters have different slants; and for the third font, the letters have
 30 different font cases. We also designed a fourth font where letters differ on all three aspects
 31 (worst regularity across letters). Word recognition performance was measured for each of
 32 the four fonts in comparison to a traditional sans serif font (best regularity across letters)
 33 through a lexical decision task. Results showed a significant decrease in word recognition
 34 performance only for the fonts with mixed-case letters, suggesting that fonts with low
 35 regularity, such as mixed-case letters, should be avoided in the definition of new “optimal”
 36 fonts. Letter recognition performance measured for the five different fonts through a trigram
 37 recognition task showed that this effect is not consistently due to poor letter identification.

38

39 Keywords

40 Peripheral vision, word recognition, letter recognition, reading, font tuning

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1. Introduction

The often repeated saying among typographers that “type is a beautiful group of letters, not a group of beautiful letters” (1), suggests that it is only when letters work as a group that they become type, a visual characteristic that we name “inter-letter regularity”. To achieve this, a basic principles of sign painting and font design dictates that fonts and lettering shall be based on a repetition of shapes with the aim of ensuring harmony and balance between the letters (2, 3) (Fig 1). This means that all lower- and uppercase letters originate in two different modular systems that put together constitute the alphabet (one for lowercase letters and one for uppercase letters) (4). Such an approach naturally leads to letters of relatively similar shapes (and high regularity). By contrast, it has often been proposed that greater letter distinctiveness, where new features are added to selected letters, could facilitate reading, as it minimizes the risk of letter confusion (5-7). However, greater letter distinctiveness also decreases inter-letter regularity.

57

Fig 1. The rule of repetition of shapes in font design, here demonstrated with lowercase letters.

59

To investigate whether high letter differentiation could improve peripheral reading, Bernard et al. (7) created a new font, referred to as Eido (Fig 2). They found that while participants familiarized themselves with the font, their reading performance improved for

63 both letter and word recognition, although sentence reading speed was not significantly
 64 improved. Xiong et al. (8) further found that Eido outperformed both Helvetica and Times
 65 Roman for reading acuity performance, while maximum reading speed was not significantly
 66 improved. Also interested in letter differentiation, Beier and Larson (9) measured letter
 67 recognition of variations within the same font family and found certain letter shapes of
 68 greater dissimilarity to facilitate better single letter recognition than others.

69

70 **Fig 2. The fonts DejaVu Sans Mono and Eido as tested by Bernard et al (7). Eido is based on DejaVu and contains letter groups**
 71 **of mixed upper- and lowercase letters; slant to left and right; and longer ascenders and descenders.**

72

73 The absence of regularity in the Eido font (Fig 2), makes it a very unusual font as a whole
 74 when letters are put together to make words, even if readers are familiar with each of the
 75 individual letter templates. Eido letters look as if they belong to different fonts mixed
 76 together, as typographic nonsense. This is also important, since previous research has showed
 77 that although readers may improve their performance by reading fonts with uncommon letter
 78 shapes, they do not like to do so (10). It also suggests that without prior practice and
 79 familiarization with the font style, the lack of font tuning would have a negative effect on
 80 reading text set in Eido. In multiple cases, font tuning has been demonstrated in central vision
 81 (11-13). This phenomenon occurs when readers recognize a sequence of letters presented in
 82 the same font faster than when presented with a mix of fonts. The effect has been shown in
 83 search tasks when readers recognize a target letter among letters of the same font compared
 84 to a mix of font styles (13), or when lexical decision is positively affected by successively
 85 presented words being set in the same font compared to switching between fonts (Cooper
 86 Black and Palatino Italic) (14) and switching between fonts of the same font family (Regular

and Bold) (15). The results are interpreted as an indication that the perceptual system processes text representation by identifying the specific structures of a font and then tunes into these features (16).

This notion of feature tuning has parallels with findings on words set in miXeD cAsE. The negative effect on recognition of mixed-cased words has been shown in multiple experiments investigating lexical decision (17) and sentence reading (18, 19). By employing a lexical decision paradigm with central visual presentation, recent research has demonstrated that this mixed-case effect is unrelated to the availability of lexico-semantic information and is instead due to a lack of visual familiarity (20). The findings on font tuning (mixed-fonts) and the findings on visual familiarity (mixed-case) all suggest that as a reader is presented with a word, the perceptual system relies on prior exposure to specific visual rule sets concerning how components within a word relate to each other.

In this paper we were interested in the effect of fonts of varying inter-letter regularity styles on word recognition performance. We tested the hypothesis that low inter-letter regularity can have a negative effect on peripheral word recognition performance and tested whether some specific forms of lacking inter-letter regularity are more deleterious than others.

2. Font design

We designed four new fonts that are all based on the traditional font DejaVu Sans. We took great care in developing versions where the letter shapes were of familiar structures. In other words, it was essential not to reinvent the alphabet in the aim for a high degree of letter differentiation. The categories were as follows: A) The Extended category has exceptionally long ascenders and descenders, the longer extenders increasing the dissimilarity between letters such as 'n' > 'h', and 'o' > 'p'. While so doing, we maintain the important modular

110 system that typographers find essential for fluent reading (2). The modular system of the
 111 Extended font results in good inter-letter regularity. B) The Slant category is made by rotating
 112 letters to the left and right, while the letters maintain their internal relation. This rotation
 113 breaks with the inter-letter regularity, as letter pairs such as 'h' and 'b' no longer have
 114 common paths when superimposed. The lack of a modular system for the Slant font results in
 115 poor inter-letter regularity. C) The MixedCase category, defined as a mix of lower- and
 116 uppercase letters, is based on findings that mixed-case text has low visual familiarity (20), as
 117 it breaks with all typographical rules concerning the repetition of shapes (in contrast to fonts
 118 of good inter-letter regularity, 'b' and 'p' share no modules). The lack of a modular system for
 119 the MixedCase font results in poor inter-letter regularity. Three of the fonts contain only one
 120 visual category, while one contains all three categories (Fig 3).

121 All fonts were tested with the same x-height. The two fonts with long extenders (Collect
 122 and Extend) were therefore presented in a larger total vertical size than the fonts with
 123 regular-length extenders (Fig 4).

124

125 Fig 3. The fonts are based on the DejaVu Sans Mono font (a) and are all designed for the present investigation. The font family
 126 includes the three categories: b) Extend with exceptionally long ascenders and descender, c) MixedCase with uppercase letter
 127 shapes as x-height characters and (d) Slant with a mix of letter slant and a letter rotation of +/- 12 degrees. The fourth font (e)
 128 incorporates all three categories.

129

130 Fig 4. All fonts have the same x-height. Due to the long extenders, c) Extended and d) Collect take up more vertical space than
 131 the other fonts.

132

3. Experiment 1. Word recognition

We tested word recognition performance for each of the newly designed fonts and compared it to a master font in a traditional design (DejaVu Sans).

2.1 Subjects

The six subjects who participated in the experiments all had self-reported normal or corrected-to-normal vision. The subjects were aged 20 to 25 years (mean age 23 years), three were females, and they were recruited through the website forsoegsperson.dk. Written informed consent was obtained from the subjects after the nature of the study had been explained to them. The research complied with the Declaration of Helsinki and The Danish Code of Conduct for Research Integrity. All subjects received a gift card of DKK 300 upon completion of the experiment.

2.2 Apparatus

Stimuli were displayed on a 17-inch IBM/Sony CRT monitor (refresh rate = 85hz, resolution = 1024 x 768) connected to an ASUS laptop PC. Experiments were written using the software OpenSesame (21).

The experiments were carried out in a darkened room with dim lighting. Subjects were placed at a viewing distance of 50 cm from the screen. The stimuli were presented as white text on a black background.

153

154 2.4 Words and pseudowords

155 The 500 Danish words were Danish lemmas of four to six characters with a lexical frequency
156 of 0.00002 to 0.03 percent of occurrences. The pseudowords were generated by changing one
157 letter of existing words; care was taken so the change resulted in a pseudoword and not a
158 new, actual word.

159

160 2.5 Procedure

161 We compared word recognition performance for the different fonts through a lexical decision
162 task. Details of the experiment are shown in Fig 5.

163 The subject was asked to fixate on a central dot while words or pseudowords were
164 randomly presented at 10° in the lower visual field. The experimenter kept a close watch on
165 the subject to control for steady fixation on the target dot. Trials that involved eye movements
166 were discarded. When the subject was ready for a trial, he or she pressed the down arrow on
167 the keyboard, after which the exposure occurred. To carry out the task, the subject had to
168 press the left or right arrow when he or she identified a word or a pseudoword. The session
169 lasted about two hours and consisted of nine blocks of 100 trials for each font. The blocks
170 were presented in random order. A total of 450 words and 450 pseudowords were presented.

171

172 Fig 5. Description of the experimental protocol for the lexical decision task.

173

174 2.6 Results, Experiment 1

175 The results of the lexical decision task are shown in Fig 6. The DejaVu font shows the best
176 lexical decision performance on average across subjects (lexical decision time: 0.14 ± 0.01 log
177 ms – average $\pm$ standard error). Collect had the worst lexical decision performance on average
178 (lexical decision time: 0.22 ± 0.02 log ms).

179

180 Fig 6. Average and standard error log response time (s) for the different fonts. P-values: *** <0.001 , ** <0.01 , * <0.05 .

181

182 The visible separation between the two groups of fonts (DejaVu, Extended and Slant vs.
183 MixedCase and Collect is significant, as shown by a linear mixed effect with log reaction time
184 as the dependant variable, font style as the fixed variable, and subject identity as the random
185 variable. P-values that correspond to the differences between the different fonts are shown in
186 Table 1.

	DejaVu	Collect	Extended	Mixedcase	Slant
DejaVu		0.0020**	0.4669	0.0055**	0.8654
Collect	0.0020**		0.0002***	0.7184	0.0014**
Extended	0.4669	0.0002***		0.0008***	0.5832
MixedCase	0.0055***	0.7184	0.0008***		0.0042**
Slant	0.8654	0.0014**	0.5832	0.0042**	

187 Table 1. P-values for the differences between lexical task durations based on our mixed-effect model: *** <0.001 , ** <0.01 ,

188 * <0.05

189

190 2.7 Discussion, Experiment 1

191 The font styles Extended and Slant both resulted in similar performances to that for DejaVu,
 192 with no statistical differences observed between the different fonts. While Extended has
 193 similar inter-letter regularity to DejaVu (both have well-functioning modular systems
 194 between letter groups, such as e-c-o, p-b-q-d and u-n-m-h), the Slant font can be considered
 195 less regular because its oblique features with multiple orientations are features that are rarely
 196 present in typical letters. The findings suggest that a poorer inter-letter regularity, which is
 197 the result from slanting letters to the left and right, does not impede word recognition
 198 performance. The same is not the case for the mixed-case fonts (MixedCase and Collect),
 199 which exhibited large and significant negative difference from the others with regard to word
 200 recognition performance. Mixed-case fonts are considered fonts with poor inter-letter
 201 regularity, as they mix two different kinds of modular systems (lower- and uppercase
 202 systems).

203 Based on our initial findings, we were interested in investigating letter recognition
 204 performance for the same test fonts. We wanted to ensure that our results were due to
 205 differences in inter-letter regularity, not lower-level factors, such as inter-letter confusability.

206 4. Experiment 2. Peripheral letter identification

207 With the same fonts and apparatus as in Experiment 1 we tested letter recognition when the
 208 stimuli were presented to subjects in trigrams (three-letter strings).

209

210 3.1 Subjects

211 Eight new subjects participated in the experiment, all self-reporting normal or corrected-to-
 212 normal vision. The subjects were aged 21 to 29 years (mean age 25 years), seven were

213 females. As in Experiment 1, written informed consent was obtained from the subjects after
214 the nature of the study had been explained to them. The research followed the tenets of the
215 Declaration of Helsinki and The Danish Code of Conduct for Research Integrity. All subjects
216 received a gift card of DKK 150 upon completion of the experiment.

217

218 3.2 Procedure

219 The task was to recognize all the letters of a trigram that was briefly presented at 10° in the
220 lower visual field. Print size was chosen so that the recognition rate of the central letter was
221 about 50% during a pre-trial training session of 10 trials per font. The presentation time was
222 200 ms. Subjects were asked to fixate on a dot centred on the screen. The experimenter kept a
223 close watch on the eyes of the subject to control for steady fixation on the target dot.
224 Approximately 5% of the trials were discarded because of eye movements. The principles of
225 the experiment are shown in Fig 7. When the subject was ready for a trial, he or she pressed
226 the space bar on a computer keyboard, after which the stimulus exposure occurred. Following
227 the presentation, the subject was asked to select the three stimuli letters displayed during the
228 trial from left to right. No feedback was given to the subject. The session lasted about one
229 hour and consisted of six blocks of 100 trials each. To avoid participants becoming familiar
230 with the letter shapes of the fonts, each block consisted of 20 consecutive trials for each font.
231 The font order was random for each block. For each trigram, three letters were randomly
232 selected among the 26 letters of the alphabet.

233

234

235 **Fig 7. Description of the experimental protocol of trigram recognition based on a presentation time of 200 ms.**

236

3.3 Results, Experiment 2

Fig 8 shows the average letter recognition rates per trigram presentation for each font. Standard errors across subjects are indicated in the figure. The traditional DejaVu font has a high recognition score (1.93 ± 0.03 letters per trigram) and on average is only inferior to the Extended font (1.97 ± 0.03 letters per trigram). By contrast, the fonts with the poorest recognition rates are the Collect, MixedCase and Slant fonts, which have an average recognition rate between 1.79 and 1.89 letters per trigram, with the Slant font resulting in the poorest performance.

Fig 8. Average number of identified letters and standard error values across subjects. P-values: *** <0.001 , ** <0.01 , * <0.05 .

We ran a mixed-effect model to test whether the differences observed between the fonts were significant. The dependant variable was the number of letters correctly identified, the fixed variables were the font types, and the random variable was the subject identity. P-values that correspond to the differences between the different fonts are shown in Table 2.

	DejaVu	Collect	Extended	MixedCase	Slant
DejaVu		0.35	0.37	0.049*	0.0006***
Collect	0.35		0.0678+	0.3002	0.0131*
Extended	0.37	0.0664+		0.0040**	0.0000***
MixedCase	0.049*	0.3002	0.0042**		0.1485
Slant	0.0006***	0.0131*	0.0000***	0.1485	

Table 2. P-values corresponding to the differences between the different fonts and based on the linear mixed-effect model:

*** <0.001 , ** <0.01 , * <0.05 .

255

256 The p-values confirm that the DejaVu and the Extended fonts offer a significant advantage
257 in our peripheral letter recognition task. Statistically, Extended shows significantly better
258 performance than the three other fonts. DejaVu is superior to two fonts, and Collect is
259 superior to the Slant font.

260 Overall, the findings demonstrate that the results for letter recognition performance are
261 very different compared to word recognition performance. More generally, the correlation
262 between word and letter recognition performance is very poor ($R^2 = 0.06$).

263

264 [3.4 Discussion, Experiment 2](#)

265 The Extended, DejaVu and Collect fonts had significantly higher scores with regard to letter
266 recognition performance, meaning that they had the lowest inter-letter confusability. The
267 Slant font had the poorest letter recognition performance followed by the MixedCase font.
268 When we compare this with the results of Experiment 1, it suggests that what we observed in
269 Experiment 1 (poorest performance for both fonts with mixed-case letters) cannot be due to a
270 poor inter-letter confusability but is directly linked to the lack of regularity between the
271 different letters.

272 [4. General discussion](#)

273 Our first hypothesis was that poor inter-letter regularity would impair reading performance.
274 Our results suggest that, indeed, lack of inter-letter regularity can significantly impair
275 peripheral word recognition performance. We showed this negative effect for two fonts
276 (MixedCase and Collect), both mixing lowercase and uppercase letters. These fonts with the
277 smallest inter-letter regularity (due to being a mix of lower- and uppercase modular systems)

278 were also the fonts that significantly resulted in the poorest performances, while the fonts
279 that had a better inter-letter regularity (DejaVu and Extended) resulted in the best
280 performances. Interestingly, intermediary irregularity caused by tilted letters (Slant) did not
281 significantly affect word recognition performance.

282 The findings of the word recognition experiment cannot be explained by letter recognition
283 performances, as results were inconsistent between the two experiments. In the case of the
284 Slant font, the findings show opposite results between letter and word recognition. The Slant
285 font was the poorest-performing font with regard to letter recognition, while for word
286 recognition it showed a similar recognition rate to the two best-performing fonts and did
287 significantly better than the two mixed-case fonts. Our findings thus show an important
288 limitation of the usually accepted theory that links peripheral letter and word recognition
289 performance (22, 23). It is also possible that the lack of regularity between letters causes the
290 disruption of word uniformity, and a consecutive decrease in word recognition performance
291 (24).

292 The letters in the slant conditions were either rotated to the right or to the left or had no
293 rotation. It appears that for letter recognition, this rotation is confusing, as it is difficult to
294 predict the nature of the rotation for each single letter. While for word recognition, the
295 rhythm produced by the rotations of the Slant font condition leads to greater predictability of
296 the word components and thus makes it easier for the subjects to tune into the font structure.
297 Our results differ from findings by Gauthier et al. (13), who compared recognition of letter
298 trigrams where the letters were slanted to one side to the recognition of trigrams where the
299 letters were mixed between slants to the left and right (similar to our Slant font) and found no
300 difference in performance between the two font conditions. Since our experiment did not

301 compare the Slant font with a font condition that only had a slant to one side, this may be the
302 cause of the different results.

303 The fact that the mixed-case fonts (Collect and MixedCase) are the poorest-performing in
304 the word recognition experiment confirms previous studies of the mixed-cased effect on
305 foveal recognition (17-20). In the present study, we extend the findings to include peripheral
306 vision.

307 In our experiment on letter recognition, only one out of the two fonts with mixed-case
308 features was significantly outperformed by DejaVu, which indicates that the negative
309 influence of mixed-case fonts on letter recognition is less pronounced than the impact on to
310 word recognition. If letters within a word become too uncommon in relation to each other,
311 subjects may have to adopt a reading strategy based on serial processing of each single letter,
312 which is much less efficient than parallel processing drawing on orthographic lexical
313 information (25, 26).

314 For both letter and word recognition, the long extenders hold an advantage (Extended). In
315 reading situations involving smaller visual angles, a large x-height (meaning shorter
316 extenders) is known to facilitate reading (27). However, it is possible that if the x-height is
317 kept constant, longer extenders could also benefit reading at small visual angles. Our findings
318 suggest that for reading situations involving peripheral reading, long ascenders and
319 descenders may be an advantage. This is interesting, since, to our knowledge, this simple
320 change in fonts had never been directly tested, although it seems to be an easy way to modify
321 a font and improve letter recognition performance.

322 Studies into letter recognition suggest that letters are recognized by their features (6, 28-
323 30). Viewing our findings in this perspective, the data on letter recognition suggests that as
324 long as the letter features are identifiable, the level of inter-letter regularity is of less

325 importance. In contrast to this, the data on word recognition suggests that word processing
326 benefits from regularity. It is generally believed that for successful word processing, it is
327 highly essential to be able to recognize the letters and their features (26, 31, 32); our findings
328 add to this by demonstrating that in addition to great inter-letter dissimilarity (7), inter-letter
329 regularity within a word also contributes to successful word recognition.

330

331 Conclusion

332 We found evidence that a new factor, which we have labelled regularity, has a direct effect on
333 word recognition performance, as fonts of great inter-letter regularity outperformed fonts of
334 low inter-letter regularity in a peripheral word recognition task. The effect varied between
335 letter and word recognition, so that rotated familiar letter shapes had a more negative effect
336 on letter recognition than on word recognition, and mixing upper- and lowercase letters –
337 which was generally detrimental – had a more negative effect on word recognition than on
338 letter recognition. Our key finding is that between letter and word recognition, great inter-
339 letter regularity has the most positive effect on word recognition and less on letter
340 recognition, which shows that supplementary features can improve letter recognition, while
341 they have a negative effect on word recognition. Our findings demonstrate that the
342 typographic approach of working with inter-letter regularity is an important factor that needs
343 to be considered in the design of fonts for word processing in peripheral vision.

344

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350

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- 421

hmu b p d e

Fig 1

a s

A S

e o c

E O C

m n u

m n u

q d b p h

q d b p h

t i l f j

T i l f j

a the quick brown fox jumps over a lazy dog

Extend

b the quick brown fox jumps over a lazy dog

MixedCase

c THE quick BROWN FOX jumps over A lazy dog

Slant

d the quick *brown fox jumps* over a lazy dog

Collect

e The quick *brown* FOX jumps over A *lazy* dog

Fig 3

Fig 4

Fig 5

Experiment 1. Lexical decision

Fig 6

Fig 7

Experiment 2. Trigram recognition

Fig 8