Learning to Read Vertical Text in Peripheral Vision

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Abstract

Purpose

English–language text is almost always written horizontally. Text can be formatted to run vertically, but this is seldom used. Several studies have found that horizontal text can be read faster than vertical text in the central visual field. No studies have investigated the peripheral visual field. Studies have also concluded that training can improve reading speed in the peripheral visual field for horizontal text. We aimed to establish whether the horizontal vertical differences are maintained and if training can improve vertical reading in the peripheral visual field.

Methods

Eight normally sighted young adults participated in the first study. RSVP reading speed was measured for horizontal and vertical text in the central visual field and at 10°eccentricity in the upper or lower (horizontal text), and right or left (vertical text) visual fields. Twenty-one normally sighted young adults split equally between 2 training and 1 control group participated in the second study. Training consisted of RSVP reading either using vertical text in the left visual field or horizontal text in the inferior visual field. Subjects trained daily over 4 days. Pre and post horizontal and vertical RSVP reading speeds were carried out for all groups. For the training groups these measurements were repeated 1 week and 1 month post training.

Results

Prior to training, RSVP reading speeds were faster for horizontal text in the central and peripheral visual fields when compared to vertical text. Training vertical reading improved vertical reading speeds by an average factor of 2.8. There was partial transfer of training to the opposite (right) hemifield. The training effects were retained for up to a month.

Conclusions

RSVP training can improve RSVP vertical text reading in peripheral vision. These findings may have implications for patients with macular degeneration or hemianopic field loss.

Key Words: Reading, Vertical Text, Horizontal text, Rapid Serial Visual Presentation (RSVP), Visual Span, Peripheral Visual Field, Macular Degeneration

1

2

3 **INTRODUCTION**

4 Readers of the English language usually read horizontal text, from left to right although

5 there are occasions where they may need to read horizontal text printed in vertical

6 columns (columnar text) in tables or telephone directories. Text can also be formatted to

7 run vertically, e.g. the title of a book printed vertically along the spine. Vertical text can

8 take three forms: horizontal text which has been rotated clockwise or anticlockwise by

9 90º and marquee text. Marquee text refers to text where upright letters are presented

10 one below the other and may be used when text needs to be written vertically because

11 of limited horizontal space. For example, on buses, "watch your step" signs are often

12 painted in marquee text on the poles next to the doors.

13

14 Several researchers have compared reading speed for horizontal, columnar [1, 2] and

15 vertical text [3,4] in central vision and have found that reading speed is fastest for

16 horizontal text. Byrne[3] used a page of text composed of 30 three–syllable words and

17 found that marquee text had the slowest reading speeds. There were no differences in

18 reading speeds between vertical text rotated clockwise and anticlockwise although

19 horizontal reading speeds were always superior to vertical reading speeds. Byrne's

20 subjects read lines of text requiring saccadic eye movements making it difficult to

21 ascertain whether horizontal-vertical differences were perceptual in origin or due to

22 differences in oculomotor control. Yu et al[4] addressed this issue by studying the

23 contribution of oculomotor factors using two different methods for displaying text: RSVP

24 (Rapid Serial Visual Presentation) which minimizes the need for eye movements, and

25 Flashcard (a four line block of text) which required saccadic eye movements. Although

26 reading speed for RSVP text was always faster than reading speed for flashcard text,

27   reading speed for horizontal text was on average 139% faster than marquee text and

28   81% faster than rotated text. These results confirmed that the horizontal-vertical

29   differences in reading speed are likely to have a perceptual origin. Furthermore, in this

30   study horizontal-vertical differences in reading speed were highly correlated with

31   corresponding differences in the size of the visual span for horizontal and vertical strings

32   of letters. The visual span can be defined as the number of characters that can be

33   recognized reliably without moving the eyes. [5,6]

34

35   Most native English speakers have little experience reading vertical print. Oda et al [7]

36   found that Japanese readers who have experience reading both horizontal and vertical

37   text, read both types of text at approximately similar speeds. This result suggests that

38   there is potential for English speakers to improve vertical reading speeds with practice.

39   In support of this possibility, Tinker[2] had subjects practice reading text formatted into

40   vertical columns of single, upright words. Before the practice, conventional horizontal

41   text was read approximately 50% faster than columnar text. Columnar reading speed

42   improved with practice, but remained slightly slower (about 20%) than horizontal reading

43   speed.

44

45   Previous studies which have investigated vertical reading speeds have all done so for

46   the central visual field only. However, the peripheral visual field plays an important role

47   for people who have age related macular degeneration (AMD). AMD is one of the major

48   causes of visual impairment in the western world (See for e.g. Congdon et al [8]) and

49   causes a loss in central visual function. Many individuals with AMD rely on their

50   peripheral visual field to read. These individuals often choose a peripheral area of the

51   retina that is located near the edge of the central vision loss for reading. This is known

52   as the preferred retinal location (PRL) and can be located either above, below or to the

53 right or left of the central scotoma. There is a potential disadvantage to reading

54 horizontal text using a left or right PRL because the central scotoma would block text on

55 the line being read. Moreover, Peli[9] suggested that reading eye movements are more

56 effective in the vertical direction for PRLs to the right and left of the visual field loss.

57 Together, these observations imply that for certain individuals with AMD it could be

58 advantageous to read vertical text rather than horizontal text. Further evidence of the

59 superiority of vertical text in certain situations comes from a study by Tanaka et al [10] in

60 which, depending on the extent of the field loss and position of the PRL, some Japanese

61 readers read vertical text faster than horizontal text.[10] The first aim of the current study

62 was to compare vertical and horizontal reading speed in the peripheral visual field of

63 subjects with normal vision.

64

65 Given that there may be a potential advantage to reading vertical text for some subjects

66 with AMD, the next question to ask is whether perceptual learning can help improve

67 vertical reading speeds? Perceptual learning has been defined as "any relatively

68 permanent and consistent change in the perception of a stimulus array, following

69 practice or experience with this array."[11] Reading speed improves with perceptual

70 learning in the peripheral visual field of normal subjects using a variety of different

71 training tasks including a trigram letter recognition task [12,13,14], a lexical decision task [13]

72 and an RSVP reading task. [13] The greatest improvement was obtained when the RSVP

73 task was used for training. Subjects with AMD have also shown improvements in reading

74 speed following training with the RSVP task[15,16] and with oculomotor training [16,17]

75 although not all studies agree that training with RSVP reading results in an

76 improvement. [17] These previous studies have investigated the effects of training using a

77 variety of tasks with horizontal text and it is not clear whether these findings also apply to

78 vertical text.

79

80   The second aim of the current study was to establish if practice on an RSVP task using

81   vertical text in the left visual field improves RSVP reading speed. One group of subjects

82   was trained on reading text in the left visual field. To establish if any improvements in

83   reading speed are retinotopically specific or orientation specific, reading speeds were

84   also measured for vertical text in the right visual field and for horizontal text in the lower

85   visual field. We also wanted to investigate whether the previously observed benefits of

86   training using horizontal text in peripheral vision would transfer to vertical reading. To

87   address this issue, a second group of subjects was trained on peripheral reading of

88   horizontal text, with vertical reading tested prior to and after training. A third group of

89   control subjects was tested to determine the outcome if no training was provided.

90

91   **EXPERIMENT 1**: Establishing if there are differences in reading speed for vertical and

92   horizontal text in the peripheral visual field of normal young adults.

93

94   **METHODS**

95   **Subjects**

96   Eight normally sighted young adults (Mean age= 20.75, SD= 1.49) participated in the

97   study. All subjects were recruited from the student population of the University of

98   Minnesota and had best corrected distance visual acuity of 0.0 Log MAR or better. No

99   subjects had prior laboratory experience of reading vertical text or participating in

100   perceptual learning studies involving the peripheral field. All subjects were native English

101   speakers. Subjects received monetary compensation for their participation. Ethical

102   approval for the study was obtained from the Institutional review board of the University

103   of Minnesota and the study adhered to the tenets of the Declaration of Helsinki.

104

105 **Apparatus**

106 All stimuli were generated via MATLAB 5.2.1(MathWorks, Massachusetts, USA) using

107 Psychophysics Toolbox Extensions. [20, 21] Stimuli were presented on a Sony Trinitron

108 Colour Graphic Display monitor (model: GDM-FW900, refresh rate 76 Hz, resolution:

109 1600x1024) (Sony corporation of America, New York USA) controlled by a Power Mac

110 G4 (Apple, California, USA). Experiments were carried out binocularly in a dark room

111 with subjects wearing their best distance correction.

112

113 **Stimuli and experimental design**

114 Reading speed measurements were carried out using the RSVP technique which has

115 been described previously. [18] Words within a sentence were presented sequentially, at

116 the same location on the display. Measurements were made using horizontal text and

117 horizontal text rotated 90° clockwise which will be referred to throughout this paper as

118 vertical text. For horizontal text the words were left justified and for vertical text the words

119 were top justified. Figure 1 illustrates examples of the horizontal and vertical text used in

120 relation to the visual field. All words were displayed as black letters on a white

121 background using lower case Courier, a serif font with fixed width.

122 Sentences were randomly chosen by computer software from a pool of 2658 sentences

123 assembled by Chung et al. [18] The length of a sentence ranged from 7 to 17 words

124 (average 11 words). Words ranged in length from 1 to 14 letters (average 4 letters).

125 None of the participants read any sentence more than once. A letter size of 2.5° (defined

126 as x-height in lowercase) at a working distance of 40 cm was chosen based on a pilot

127 study using vertical text.[a] Measurements were carried out in the central visual field and

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[a] The choice of letter size and working distance was based on pilot studies of 4 subjects using vertical (clockwise) text at 10° eccentricity in the left visual field. Six letter sizes were used (0.55°, 1°, 1.8°, 2.5°, 3.2°, 5°). For sizes 0.55°, 1°, 1.8° and 2.5° a working distance of 40 cm was chosen. For the remaining sizes a working distance of 20 cm was chosen due to limitations

128   at 10° in the superior and inferior peripheral visual fields for horizontal text and the right

129   and left visual fields for vertical text. RSVP reading speeds (horizontal and vertical)[b]

130   were measured in the peripheral visual field on all eight subjects and in the central visual

131   field on four of the eight subjects.

132

133   For measurements involving the peripheral visual field, subjects fixated a line (10° to the

134   right, left, above or below the text depending on the type of print and location being

135   tested) while the words were presented in the periphery. Subjects were allowed to move

136   their eyes along the line and were reminded from time to time to maintain fixation on the

137   line. The subject's head was stabilised using a chin and forehead rest and subjects were

138   instructed not to tilt their head or to alter the working distance in any way.

139

140   Eye movements were monitored using a web camera for four subjects. The camera's

141   image was displayed on a separate dedicated monitor visible to the researcher. If an eye

142   movement away from the fixation line was detected by the researcher, the trial was

143   discarded. This was similar to the method described by Cheong et al., 2007 [19] who

144   stated that the accuracy of detecting eye movements using this method is approximately

145   2°. Trials were also discarded if a subject verbally reported moving their eyes. Typically

146   no more than 5% of trials were discarded. It should be noted that no significant

147   differences were observed between the results for subjects monitored for eye

148   movements and those who were not.

---

imposed by the screen dimensions. A two-line fit was used to fit plots of reading speed versus print size to estimate critical print size (CPS). All 4 subjects had CPS smaller than 2.5° for vertical text. Previous studies [12] indicate that at least for horizontal text this value is larger than the CPS for most subjects at 10° eccentricity.

[b] It should be noted that throughout the methods, results and discussion section we use the term reading speed to refer to reading speed measured using the RSVP text.

149 At the commencement of each new trial a row of crosses appeared, alerting subjects to

150 the location of stimulus words. Subjects initiated a trial when ready by clicking a mouse.

151 At the end of each trial a row of crosses appeared as a post mask. Subjects read each

152 sentence aloud and were permitted to complete their response after the last word had

153 disappeared from the screen.

154

155 For each condition tested, six word exposure durations were used with 6 trials per

156 duration (total 36 trials). These durations were selected so that subjects could read fewer

157 than 30% of words correctly at the shortest duration and more than 80% of words

158 correctly at the longest duration. The condition tested was randomised and subjects

159 were given breaks if required. Reading accuracy was measured as a proportion of words

160 read correctly. The resulting data were fitted with a Weibull function, and reading speed

161 was calculated from the exposure duration yielding 80% of words read correctly. Values

162 obtained were converted to reading speed in words per minute (wpm).

163

164 Visual Span measurements using a trigram letter recognition task [12] were also carried

165 out as part of the experimental procedure during the pre- and post-testing sessions but

166 these results will not be reported in this paper.

167

168 **RESULTS**

169 Mean reading speeds in the central visual fields were 559.20 (SD=193.02) wpm for

170 horizontal text and 308.62 (SD=140.51) wpm for vertical text.

171 A paired sample t-test comparing horizontal and vertical reading speeds in central vision

172 found that mean horizontal reading speed was significantly faster than vertical reading

173 speed (p=0.001). Across the 8 subjects, the ratios of horizontal to vertical reading

174 speeds ranged from 1.17 to 3.39 with a mean of 1.96 (SD = 0.75).

175

176 Mean reading speeds in the peripheral visual fields in units of wpm were: 200.84

177 (SD=77.71) for horizontal text in the superior field, 199.76 (SD=80.41) for horizontal text

178 in the inferior field, 125.94 (SD=27.24) for vertical text in the right visual field and 126.16

179 (SD=26.11) for vertical text in the left visual field. Paired samples t-tests showed no

180 significant differences between mean reading speeds in the superior and inferior visual

181 fields ($p=0.95$) and the right and left visual fields ($p=0.94$). Accordingly, for each subject,

182 a vertical reading speed was based on the average of values from the left and right

183 visual fields, and a horizontal reading speed was based on the average values from the

184 superior and inferior visual fields. Similarly, for peripheral vision the resulting mean

185 peripheral horizontal reading speeds were significantly faster than the peripheral vertical

186 reading speeds (paired samples t-test) ($p<0.05$). Across the 8 subjects, the ratios of

187 horizontal to vertical reading speeds ranged from 1.10 to 2.37 with a mean of 1.69 (SD

188 =0.43).

189

190 Using a paired samples t-test we compared the mean horizontal/vertical reading speed

191 ratios in the central and peripheral visual fields. We found no statistically significant

192 differences between the two measures ($p=0.37$) suggesting that horizontal/vertical ratios

193 are similar in the central and peripheral visual fields.

194

195 **EXPERIMENT 2:** Training to improve reading speed for vertical text in the peripheral

196 visual field.

197 **METHODS**

198 **Subjects**

199 Twenty one normally sighted young adults (Mean age= 21.3, SD= 2.98) participated in

200 the study. Thirteen subjects were recruited from the student population at the University

201   of Minnesota (5 in each of the two training groups and 3 in the control group), and 8

202   subjects were recruited from the student population at City University London (4 in the

203   control group, and 2 in each of the training groups). Subjects were randomly allocated

204   to either a training group or to a control group. There were two training groups and one

205   control group. Each group had 7 participants.

206

207   All subjects had best corrected distance visual acuity of 0.0 Log MAR or better. No

208   subjects had prior laboratory experience of reading vertical text or participating in

209   perceptual learning studies involving the peripheral field. Subjects were ineligible to

210   participate in the training experiment if they had participated in Experiment 1. All subjects

211   were native English speakers. Subjects received monetary compensation for their

212   participation. Ethical approval for the study was obtained from the Institutional review

213   board of the University of Minnesota and the Research and ethics committee at City

214   University London. The study adhered to the tenets of the Declaration of Helsinki.

215

216   **Apparatus**

217   The apparatus used was slightly different for subjects tested at City University London,

218   as follows. Stimuli were generated via MATLAB (2009b) (MathWorks, Massachusetts,

219   USA) using Psychophysics Toolbox Extensions. [20, 21] Stimuli were presented on a Sony

220   display monitor (model: Multiscan E400, refresh rate 75 Hz, resolution: 1600x1200)

221   (Sony corporation of America, New York USA) controlled by MacBook Pro (Apple,

222   California, USA). Similar to Experiment 1 a letter size of 2.5° was used throughout the

223   experiments at both sites. Due to limitations of the screen size at City University London

224   all reading speed measurements with vertical text were carried out at a viewing distance

225   of 30 cm and reading speed measurements with horizontal text were carried out at 40

226 cm. At the University of Minnesota both vertical and horizontal measurements were

227 carried out at 40 cm.

228

229 **Experimental design**

230 There were three groups, each with 7 subjects—a control group and two training groups.

231 Subjects in the control group attended two pre-test and one post-test session. Subjects

232 in the training groups attended two pre-test, one post-test and two retention sessions, in

233 addition to four training sessions which were conducted over four consecutive days. A

234 series of experiments usually commenced on a Thursday (Week 0), when the first pre-

235 test session was held. The second pre-test session was normally held the following day

236 on Friday (Week 0). Training where applicable took place from Monday to Thursday of

237 the following week (Week 1), with the post-test session being held on the Friday of that

238 week (Week 1). The first retention session was held a week later on a Friday (Week 2)

239 and the second retention session was held a month after the test session, usually on a

240 Friday (Week 5).

241

242 The first pre-test session was devoted to preliminaries including informed consent, and

243 introduction to the RSVP test. During the second pre-test visit, baseline measurements

244 were made for reading speeds using horizontal and vertical text at 10° in the peripheral

245 visual field. Vertical text measurements were made in the right and left visual field and

246 horizontal text measurements were made in the inferior visual field. For each RSVP

247 condition tested (for example horizontal text inferior visual field), six word exposure

248 durations were used with 6 trials per duration (total 36 trials). This constituted a block of

249 trials. During the post-test and retention sessions the same measurements carried out in

250 the second pre-test visit were repeated. Field location (inferior, right or left) and the text

251 tested (horizontal or vertical) were randomised at each pre- and post-test visit. Visual

252 spans were also measured in the pre- and post-tests, but the results are not reported in

253 this paper.

254

255 Subjects were either trained on reading vertical or horizontal text at 10º in the left or

256 lower visual field (training groups) or received no training (control group). Each training

257 session consisted of 6 blocks of 36 trials (one sentence per trial), resulting in a total of

258 864 trials across four days. At the start of each training session, subjects completed a

259 'subject alertness questionnaire' to determine their suitability for the training session.

260 The subject alertness questionnaire consisted of all the questions from the Stanford

261 Sleepiness Survey [22] and two questions from the Pittsburgh Sleep Quality Index. [23] All

262 subjects had a score of either 1 or 2 for all training sessions (indicating they were fully

263 awake and able to concentrate) and reported very good sleep quality the previous night.

264 Each training session lasted one hour and subjects were given a break if they desired.

265

266 We chose reading as the training task because a previous study showed that this form of

267 training produced larger improvements than two other related forms of training. [13]

268

269 **RESULTS**

270 Table 1 summarizes group means and standard deviations for reading speeds in the

271 pre- and post-tests for the various conditions. Highlighted cells refer to results when

272 groups were tested with the same conditions used for training. The table also

273 summarizes changes in reading speed from pre-test to post-test. Changes in reading

274 speed are presented as ratios, with values greater than 1.0 meaning that reading speed

275 improved. [c]

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[c] Ratios of reading speeds convey the same information as differences in log reading speeds.

276   Mean reading speeds pre- and post-training for the vertical training group in wpm were

277   85.67 (SD=30.68) and 217.78 (SD=49.09) for vertical text in the left visual field, 101.24

278   (SD= 45.31) and 173.08 (SD= 44.28) for vertical text in the right visual field, and 203.50

279   (SD= 94.52) and 270.14 (SD= 91.17) for horizontal text.

280   Mean reading speeds pre- and post-training for the horizontal training group in wpm

281   were 90.65 (SD= 29.56) and 158.88 (SD= 33.26) for vertical text in the left visual field,

282   106.24 (SD= 47.10) and 168.75 (SD= 64.91) for vertical text in the right visual field, and

283   158.05 (SD= 76.84) wpm and 281.88 (SD= 104.38) for horizontal text.

284   Mean reading speeds pre- and post-training for the control group in wpm were 101.74

285   (SD= 25.25) and126.31 (SD=32.26) for vertical text in the left visual field, 112.11

286   (SD=24.29) and 126.82 (SD=20.35) for vertical text in the right visual field and 157.34

287   (SD= 31.27) and 183.30 (SD= 30.61) for horizontal text.

288

289

290   **Pre-post comparisons for RSVP reading speed**

291   Separate statistical analyses were performed to compare the vertical training group with

292   the control group, and the horizontal training group with the control group. In each case

293   a 2 x 2 repeated measures ANOVA on log reading speed [d] (pre/post-test, vertical

294   training group/control group or horizontal training group/control group) was performed. A

295   significant interaction indicated a training-related difference in performance

296

297   Transfer of training from a trained condition to an untrained condition was also assessed

298   by 2x2 repeated measures ANOVAs (pre/post-test, trained/untrained field location). In

---

[d] Log reading speeds were used to be consistent with other studies. It should however be noted that the same pattern of significant results was found when the analysis was conducted directly on reading speed.

299 these cases significant main effects of the pre/post variable coupled with a significant

300 interaction provided evidence for partial transfer of training. A significant main effect of

301 the pre/post variable without a significant interaction provided evidence for complete

302 transfer of training. We recognize that analysis of transfer effects are based on statistical

303 criteria and that data from additional subjects could reveal a significant interaction in

304 cases where we find "complete transfer."

305

306 Both training groups and the control group had improved log post-test reading speeds

307 (all $p < 0.05$)) in all three conditions: left vertical, right vertical and horizontal text.

308

309 For the group trained with vertical text in the left visual field, there was a greater

310 improvement in log reading speeds than for the control group (significant interaction, $p <$

311 0.0005) providing evidence for the effect of training. The large training effect in the

312 trained left visual field transferred to the untrained right visual field, but this transfer was

313 incomplete (significant interaction, $p = 0.02$), providing evidence for partial transfer of

314 training from the left to the right visual field. This group also showed post-test

315 improvement in horizontal reading speed in the lower visual field, but this improvement

316 did not differ significantly from the improvement exhibited by the control group in the

317 horizontal condition. Therefore, we cannot conclude that there is transfer of training from

318 vertical to horizontal reading in our study.

319

320 For the group trained with horizontal text in the lower visual field, there was a greater

321 improvement in reading speed than for the control group (significant interaction, $p=0.04$)

322 providing evidence for the effect of training. The training effect showed significant and

323 complete transfer to vertical reading in both the left (significant effect of time: pre/post-

324 test, $p = 0.007$, and non significant interaction, $p=0.93$) and right (significant effect of

325   time: pre/post-test, p = 0.005, and non-significant interaction, p=0.39) visual fields.

326   These effects imply that there was complete transfer of training from the horizontal

327   reading to vertical reading.

328

329   To summarize, both training groups showed post-test improvements in reading speed

330   exceeding controls. Training on horizontal text appeared to transfer completely to

331   improved reading on vertical text. Training on vertical text in the left visual field partially

332   transferred to vertical reading in the right visual field, but transfer to horizontal reading

333   was equivocal.

334

335   **Progression Retention and Transfer of learning effects**

336   Figures 2 and 3 indicate that for both training groups there were improvements in the

337   trained reading speed after every training session with maximal improvement occurring

338   after the first session (264 trials) and less improvement occurring thereafter.

339   Improvements normally occurred within the first three sessions with no to minimal

340   improvement at the fourth and final session. For both training groups, improvements in

341   reading speed for left and right vertical and horizontal text were maintained for up to one

342   month post-training. This was substantiated by repeated measures ANOVAs (p> 0.1)

343   using post/pre ratios of post-test, one-week and one-month post-test.

344

345   **Differences between horizontal and vertical reading speeds**

346   One research question was whether training would yield vertical reading speeds that

347   would match or exceed horizontal reading speeds. Following training using vertical text,

348   vertical speed improved on average from 85.67 wpm (SD= 30.68) to 217.78 wpm

349   (SD=49.09). There were no statistically significant differences between the mean

350   vertical reading speeds in the post-test and either the pre-training horizontal reading

351   speeds (Mean=203.50 wpm, SD=94.52) (p=0.657) or the post-training horizontal reading

352   speeds (Mean=270.14 wpm, SD=91.17) (p=0.091). These results indicate that training

353   using vertical text may yield vertical reading speeds that almost match horizontal

354   speeds. From inspection of results of individual subjects in the vertical training group,

355   only one subject's trained vertical reading speed exceeded the post-training horizontal

356   reading speed, with the ratio being 1.36. For the remaining six subjects, horizontal speed

357   was greater than vertical speed by factors of 1.20, 1.21, 1.26, 1.31, 1.39 and 1.59

358   respectively.

359

360   **DISCUSSION**

361   Our goal in Experiment 1 was to ascertain whether the differences in reading speed for

362   horizontal and vertical text previously found in central vision [4] extend to the peripheral

363   visual field. In untrained observers, reading speed with horizontal text was always faster

364   than with vertical text regardless of whether the text was presented in the central or

365   peripheral visual field. The horizontal/vertical reading speed ratios were similar in the

366   central and peripheral visual fields suggesting similar underlying constraints across

367   locations.

368

369   Our goal in Experiment 2 was to determine if vertical reading speed in peripheral vision

370   improves with training. There were three groups of subjects—one trained with vertical

371   text in peripheral vision, one trained with horizontal text in peripheral vision, and a control

372   group who did not receive training.

373

374   Before discussing the training effects, we will briefly comment on left vs. right hemifield

375   effects on reading. There has been a debate regarding whether the hemispheric

376   projections split at the fovea or whether there is a foveal region of bilateral projections,

377   and the potential implications for reading. For a review, see Ellis & Brysbaert. [24]

378   Regardless of the debate, it is certain that the vertical text in our study, located 10º from

379   the fovea, projected to the contralateral hemispheres. Further, there is some evidence

380   for a right visual field (left hemisphere) advantage for word recognition (reviewed by Ellis

381   & Brysbaert). [24] In Experiment 1, there was little difference in the average reading

382   speeds for vertical text in the left and right visual fields. However in Experiment 2,

383   combining data across all three groups, there was a significantly greater mean reading

384   speed for vertical text in the right visual field (mean 106.53 wpm, SD=38.46) than in the

385   left visual field (mean=92.69 wpm, SD=27.98) (p=0.048). This small advantage for the

386   right visual field is consistent with previous findings of a right visual field advantage for

387   word recognition.

388

389   Experiment 2 showed that training improves reading speed for both vertical and

390   horizontal text in peripheral vision. On average vertical reading speeds improve by a

391   factor of 2.8 with individual improvements ranging from a factor of 1.9 to 5.1. This study

392   demonstrated again that training yields increased reading speed in peripheral vision for

393   horizontal text—an increase by a factor of 2.08, compared with the increase of 1.72

394   reported by Yu et al [13] who also trained normal subjects with an RSVP training task

395   using a similar protocol. The greater improvement in our study is primarily due to one

396   subject whose reading speed improved by a factor of 4.1. Excluding this subject from the

397   analysis results in reading speed improving by a factor of 1.74, similar to the average

398   improvement found by Yu et al. [13]

399

400   Several types of learning could contribute to the training-related improvement in vertical

401   and horizontal reading speeds in peripheral vision. We briefly consider task specific,

402   attentional and perceptual possibilities.

403

404   Task Specificity: Subjects may be learning to perform the RSVP task, which differs from

405   conventional eye movement mediated reading. If the learning is solely due to learning

406   how to perform the RSVP task, we would expect complete transfer among all peripheral

407   RSVP conditions in our study, and no transfer to non-RSVP reading tasks in peripheral

408   vision. However, complete transfer of training across RSVP tasks did not occur in

409   Experiment 2. Moreover, Yu et al. [13] showed partial transfer of learning from training with

410   RSVP reading to other tasks in peripheral vision (trigram letter recognition and lexical

411   decision). These observations imply that task specific learning is not the sole explanation

412   for our training effects.

413

414   Attention: Subjects may be learning to deploy attention to peripheral vision while

415   maintaining central fixation. Lee et al [25] investigated whether attention could account for

416   improvements observed in reading speed and visual span through training in the

417   peripheral visual field. Their training protocol was similar to ours but differed in two ways:

418   the study tested only horizontal reading and the training task involved recognition of

419   trigrams (strings of 3 unrelated letters) in peripheral vision. Although training did result in

420   an improvement in their measure of peripheral attention (based on a lexical decision

421   task), the improvement was not correlated with the training related improvements in

422   peripheral reading speed. They concluded that deployment of attention to peripheral

423   vision was not the major factor accounting for training-related benefits in peripheral

424   reading. Although we did not measure attention in the present study, the results from

425   Lee et al. [25] suggest that attention may not account for the improvements in vertical

426   reading speeds observed in our study.

427

428   Perceptual Learning: We consider two types of perceptual changes which may

429   contribute to improved vertical reading speed. First, training may result in a reduction in

430   the effect of crowding between adjacent letters. In support, He et al [26] trained the

431   peripheral vision of subjects using a trigram recognition task. Training resulted in an

432   increase in the size of the visual span and an associated increase in reading speed. He

433   et al used a decomposition analysis to infer that a reduction of crowding accounted for

434   most of the enlargement of the visual span, likely contributing to the improvement in

435   reading speed. Similarly, Yu et al. [27] reported that differences in horizontal and vertical

436   reading speed in central vision were correlated with differences in the size of the visual

437   span, with the visual span being limited by crowding. Pelli et al. [28] have also

438   demonstrated a close relationship between crowding, the size of the visual span and

439   reading speed.

440

441   A second perceptual factor may be learning to transform vertical words with letters

442   rotated by 90° into a representation suitable for lexical access. As shown in previous

443   studies, while recognition time for single letters is largely independent of letter

444   orientation, rotated words take longer to be recognized than upright words [29, 30,31]. It

445   seems plausible that recognition times for rotated words could decrease with practice, as

446   a separate effect from crowding.

447

448   Although we cannot exclude task-specific learning and effects of attention, it seems likely

449   that perceptual factors played the major role in accounting for the training-related

450   improvement in reading speed we observed.

451

452   **Transfer of learning effects**

453   An ancillary aim of our study was to determine whether training with vertical text

454   transfers across location (to the untrained hemifield) and orientation (to horizontal text).

455   Other studies of training with reading-related tasks in peripheral vision have found

456   varying levels of transfer across location and task. For example, Chung et al [12] found

457   that training with a letter recognition task in the peripheral visual field resulted in

458   increased reading speeds and a transfer of training to an untrained retinal location. Yu et

459   al. [14], who used similar RSVP training of horizontal text in the lower visual field, found

460   substantial transfer to reading speed in the upper visual field, to a print size not used in

461   training and to enlargement of the visual span. Our results indicate that training effects

462   can transfer. We found that training horizontal reading in the lower visual field transferred

463   to vertical reading in the left and right visual fields. For vertical training in the left visual

464   field, there was partial transfer of learning to the right hemifield but transfer to horizontal

465   text was not statistically significant. This difference may represent a lack of reciprocity in

466   transfer of learning between horizontal and vertical training, or might be due to our small

467   sample size. The lack of reciprocity in transfer of training effects may also depend on the

468   difficulty of the task involved. Tasks which are harder result in more specific training

469   effects [32]. Given that readers are more familiar with horizontal text it is likely that this is

470   an easier training task and might result in greater generalization than training with

471   vertical text in peripheral vision.

472

473   What might be the cortical site of the training effect? A previous study[13], using a similar

474   paradigm, found partial transfer from the lower visual field to upper visual field. The

475   authors suggested that these results might reflect effects of training at both an early

476   retinotopic site in the visual pathway and also a higher level non-retinotopic site.

477

478   **Retention of learning effects**

479 Since training is time intensive the practical value of training would be questionable if the

480 training effects are short lived. Chung et al [12] found that improvements in reading speed

481 and visual span in the inferior and superior visual field obtained through training could be

482 maintained for at least three months after the training. The current study found similar

483 results, with good retention of horizontal and vertical reading speeds across both training

484 groups up to one month post-training. If patients with visual impairment were to find

485 vertical training useful, it is likely that repeated use would sustain the training gains over

486 a prolonged period.

487

488 **Possible Clinical implications**

489 Our study has demonstrated that it is possible to train vertical reading to achieve speeds

490 that are similar to untrained horizontal speeds. This finding may have clinical implications

491 for people with Macular Degeneration who have a PRL lateral to a central scotoma. In

492 these cases, there may be difficulty reading horizontal text because the scotoma

493 occludes text either to the left or right of fixation. For such individuals, reading vertical

494 text can potentially result in uninterrupted reading. The same would hold true for people

495 with hemianopias. In both instances it may be possible to improve reading performance

496 by simply rotating a page of text 90° to produce vertically oriented text although this will

497 involve vertical eye movements which may also require training.

498

499 Although we did not specifically measure whether training on an RSVP reading task

500 leads to improvements in page reading, previous findings by Nguyen et al [16] are

501 promising. They showed that improvements in reading speed made through RSVP

502 training in subjects with macular disease lead to improvements in normal reading of a

503 page of text.

504

505 Yu et al [15] found that training peripheral vision with trigram stimuli resulted in larger

506 improvements in the visual span and reading speed of young subjects when compared

507 to their older counterparts. Training effects did not transfer to an untrained location for an

508 untrained task in these elderly subjects. It is likely that there will be less transfer of

509 learning effects if we train vertical reading speeds in elderly subjects.

510

511 In our study we used a time intensive training schedule where subjects trained daily for

512 four days. Many individuals who suffer from Age Related Macular Degeneration and

513 hemianopias are elderly and it may be difficult for them to adhere to such a schedule.

514 Chung and Troungs [33] found that reading speed and visual span improve regardless of

515 whether training takes place daily weekly or biweekly. Given these findings it is likely that

516 a flexible training schedule could be used.

517

518 To conclude, our study has established that reading of RSVP vertical text in the

519 peripheral visual field can be improved with training and that the levels of reading speed

520 obtained with vertical text are similar to those obtained with horizontal text.

521

522 **Data Sharing**

523 All data from this study, including the visual-span data, are available from the first author

524 upon request.

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Figure Legends

Figure 1. Examples of (A) vertical and (B) horizontal text in relation to the central fixation line

Figure 2. Horizontal reading speeds for the horizontal training group in the pre- test post-test and training sessions.

Figure 3. Left Vertical reading speeds for the vertical training group in the pre-test, post-test, and training sessions.
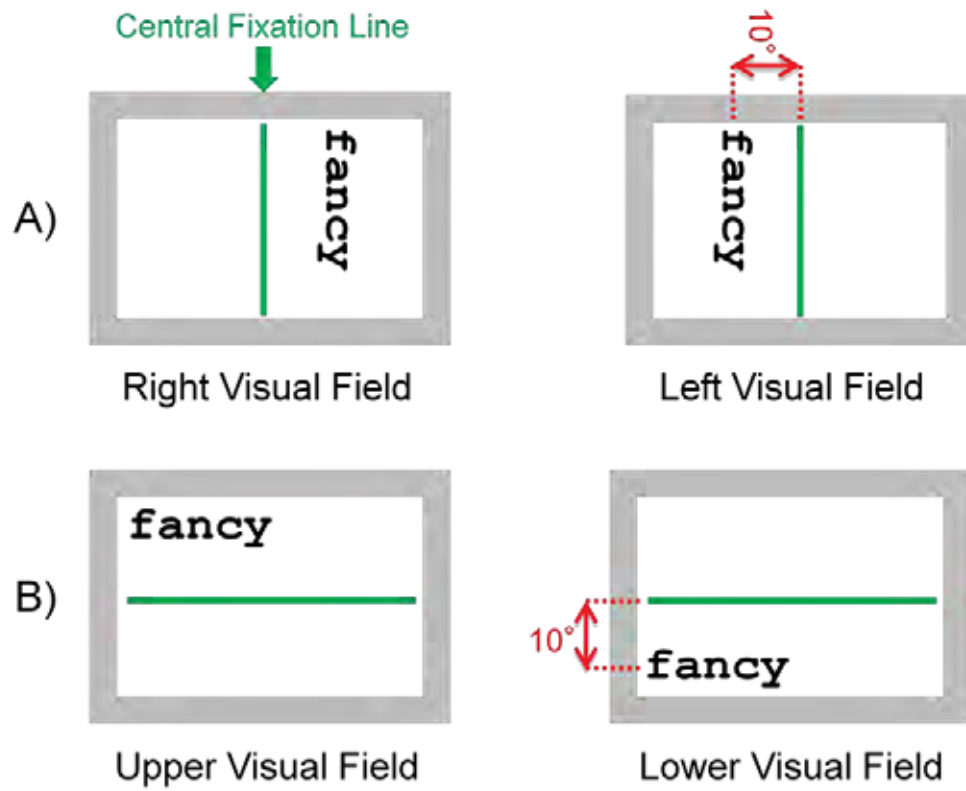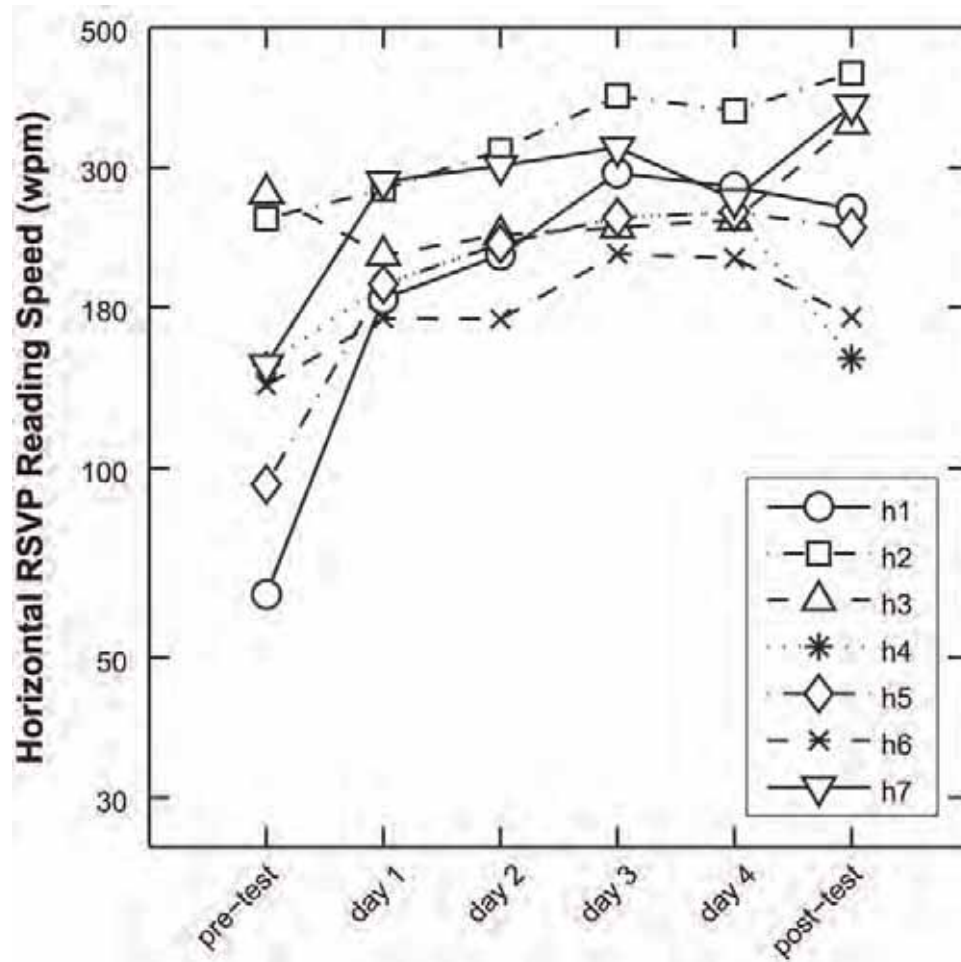
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A)

Central Fixation Line

fancy

Right Visual Field

10°

fancy

Left Visual Field
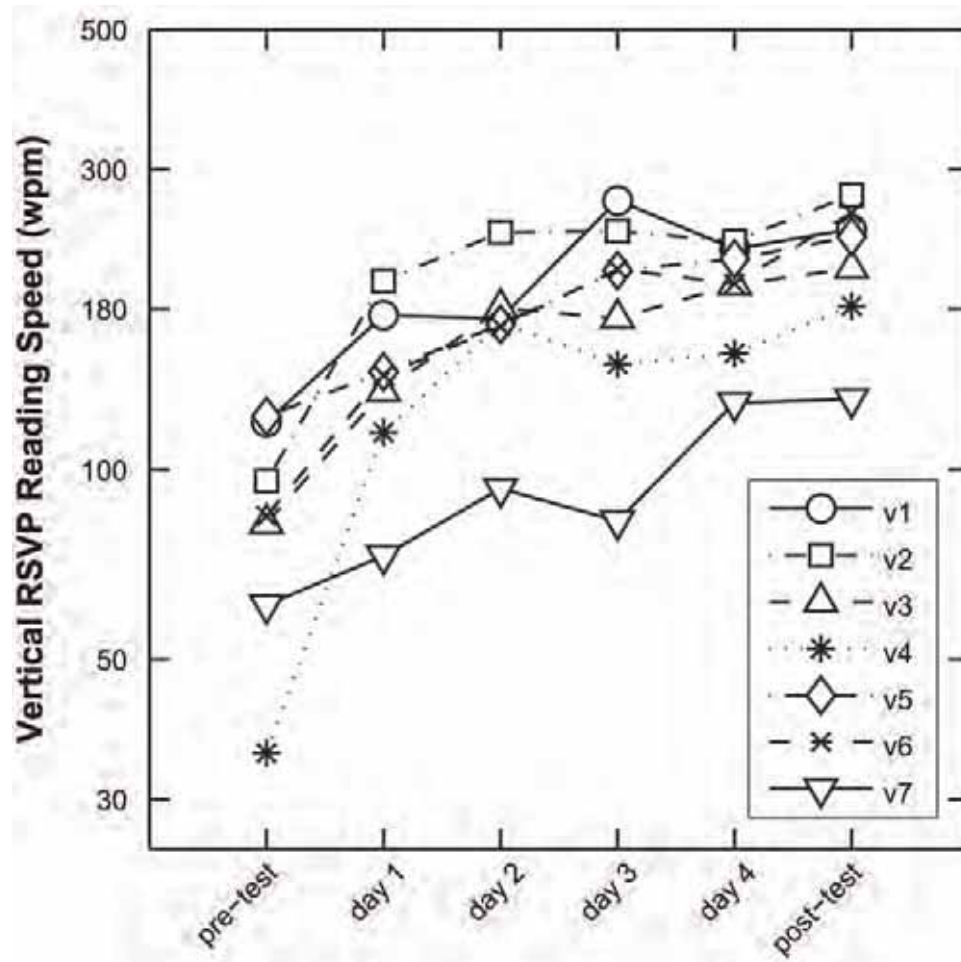
B)

fancy

Upper Visual Field

10°

fancy

Lower Visual Field

1 **Table 1:** Mean and standard deviation for RSVP reading speeds and ratios pre and post training for vertical training, horizontal training and

2 control groups. It should be noted that the post/pre RSVP ratios have been computed by taking an average of each individual post/pre RSVP

3 ratio and not from the group average of the RSVP reading speeds. Shaded boxes represent the trained conditions.

Group	Pre Test RSVP			Post Test RSVP			Ratios Post/Pre		
	Horizontal	Vertical (Left)	Vertical (Right)	Horizontal	Vertical (Left)	Vertical (Right)	Horizontal	Vertical (Left)	Vertical (Right)
Vertical Training Group	203.50(94.52)	85.67 (30.68)	101.24(45.31)	270.14(91.17)	217.78(49.09)	173.08(44.28)	1.46(0.40)	2.80(1.1)	2.01(1.02)
Horizontal Training Group	158.05(76.84)	90.65(29.56)	106.24(47.10)	281.88(104.38)	158.88(33.26)	168.75(64.91)	2.08(1.08)	1.96(0.90)	1.68(0.39)
Control Group	157.34(31.27)	101.74(25.25)	112.11(24.29)	183.30(30.61)	126.31(32.26)	126.82(20.35)	1.19(0.27)	1.25(0.19)	1.14(0.14)

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