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Optimizing the Strength of the Bourdon Effect by Varying the Triangle Arrangement

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16 **Abstract**

17

18 The *Bourdon illusion* refers to the perceived bentness of the straight collinear edges when two
19 right-angled triangles are placed apex to apex. We studied this illusion using a cancellation
20 method. In the first of three experiments, we manipulated the apex angle, with six different
21 angles ranging from 4 to 45 degrees. Results indicated that the Bourdon illusion is strongest
22 when the angle is around 12°. In the second experiment, we compared four scalene triangles
23 with a right-angled triangle. The angular shift was most salient when the shape corresponded
24 to a right-angled triangle. In the third experiment, the patterns were created by varying the
25 size of one right-angled triangle while holding the size of the second right-angled triangle
26 constant. Results indicated that the Bourdon illusion was strongest when both right-angled
27 triangles were of equal size. Our data suggest that the Bourdon illusion depends critically
28 upon the specific arrangement of shapes in the display.

29 *Keywords:* Bourdon illusion, angle perception, shape perception, geometrical illusion

30

31 **1. Introduction**

32 The Bourdon illusion occurs when two right-angled triangles are placed apex to apex so that
33 the sides opposite the hypotenuse are collinear (ABC in Fig. 1a). Under these conditions, this
34 perfectly straight edge appears to bend in the same direction as the opposite edges (DBE in
35 Fig. 1a). This effect is stronger in subjective contours than in real contours (Walker & Shank,
36 1987; Walker & Shank, 1988a, 1988b; Wenderoth, Criss, & van der Zwan, 1990).

37 This illusion was originally but briefly described by Bourdon (1902) in a horizontal
38 version. To our knowledge, he did not systematically study this effect, probably because it
39 was negligible in the original version. In the first experimental investigation of the Bourdon
40 illusion, Rozvany and Day (1980) showed that its strength depends critically on the
41 orientation of the pattern, with results indicating that the illusion is strongest when the whole
42 pattern is tilted about 22.5° from a vertical axis passing through its center (see Fig. 1b), and is
43 far weaker when the whole pattern is either vertical, or at an angle of 45° from the vertical
44 axis. Similar results have been found for different mirrored orientations (Verstijnen & van
45 Leewen, 1998). Studies of the Bourdon illusion have typically examined the stimulus
46 configuration that produces it. For example, the strongest illusion is produced when the
47 internal apical angles are equal to 12.5° (see Fig. 1b) (Rozvany & Day, 1980). It should be
48 noted that the Bourdon illusion also occurs in haptic mode, with similar parameters (Day,
49 1990). Other findings suggest that the illusory effect increases when a small gap is inserted
50 between the apices of the two right-angled triangles (Day, Mitchell, & Stecher, 1990;
51 Wenderoth & O'Connor, 1987a, 1987b).

52 The Bourdon illusion has been observed with a solid figure like that shown in Figure
53 1a, but the bentness effect persists when the right-angled triangles are formed by lines
54 (Rozvany & Day, 1980). Its strength increases as the thickness of the lines increases, until it is
55 similar to that of a solid figure (Walker & Shank, 1988a). The illusion tends to disappear

56 when the right-angled triangles are replaced by outlines of triangles where the short sides (AD
57 and CE in Fig. 1a) are missing, resulting in a nonsolid figure (Rozvany & Day, 1980;
58 Wenderoth & O'Connor, 1987a). This is consistent with the fact that a solid right-angled
59 triangle displayed against a white background is needed to create the full illusion.

60 The impact of triangle orientation on the Bourdon illusion has been extensively tested,
61 with most researchers showing that a specific oblique orientation creates the strongest
62 illusion, and a horizontal or vertical orientation the weakest one (Rozvany & Day, 1980;
63 Verstijnen & van Leewen, 1998; Wenderoth & O'Connor, 1987a). However, although the
64 right-angled triangle is known to be an important contributor to the illusion, the impact of
65 triangle shape has not yet been systematically explored. We therefore conducted three
66 experiments in which the Bourdon illusion was studied with different triangle shapes. The aim
67 of the first experiment was to directly test the strength of the Bourdon illusion as a function of
68 apical angles. When the internal apical angle β (see Fig. 1b) increased, the shape changed
69 from a scalene triangle to an isosceles triangle. This involved the use of a cancellation task,
70 and was a partial replication of earlier findings. In the second experiment, we investigated the
71 strength of the Bourdon illusion using different scalene triangles. Here, the apical angle β did
72 not change, whereas the angle γ (right angle in the original version; see Figs 1b and 3) varied
73 from an acute to an obtuse angle. In the third and final experiment, we studied how the
74 strength of the Bourdon illusion varied when the size of one right-angled triangle was
75 manipulated, but that of the other right-angled triangle was held constant (see Fig. 5).

76

77

Figure 1 about here

78

79

80

81 **2. Experiment 1**

82 *2.1. Observers*

83 We recruited 19 psychology undergraduates (age range: 18-25 years) from Rennes
84 University as our observers. All had normal or corrected-to-normal visual acuity, and were
85 naïve to the purpose of the experiment. Like the two subsequent experiments, Experiment 1
86 was conducted in accordance with the principles of the Declaration of Helsinki.

87

88 *2.2. Apparatus*

89 A PC was used to display the stimuli on a 22 in. CRT monitor (NEC MultiSync FP2141SB)
90 driven by a ViSaGe graphic board with a color resolution of 14 bits per gun (Cambridge
91 Research Systems, Rochester, United Kingdom). The experimental software was written to
92 generate the stimuli, control the stimulus presentation, and collect responses in MATLAB 7.9
93 (MathWorks, <http://mathworks.com>), using the CRS Toolbox extensions. The monitor was
94 calibrated using an OptiCal photometer with the calibration routines of Cambridge Research
95 Systems. Observers viewed the screen from a distance of 80 cm, with their head stabilized by
96 a chin rest. Both eyes were used for viewing. Participants used a Cedrus response box (RB-
97 530) to record their responses. The experiment was performed in a dark room.

98

99 *2.3. Stimuli*

100 Observers viewed two right-angled triangles connected by their apices, similar to those shown
101 in Figure 1a. All the figures were dark ($x = 0.30$, $y = 0.45$; $Y = 1.03$ cd/m²), displayed against
102 a neutral gray background ($x = 0.29$, $y = 0.32$; $Y = 60.32$ cd/m²).

103 In accordance with previous studies (Rozvany & Day, 1980; Verstijnen & van
104 Leeuwen, 1998), the figures were oriented at an angle of 22.5° from the vertical axis (see

105 angle α in Figs 1b and 1c), to maximize the Bourdon illusion. The stimuli were displayed in
106 the center of the screen. Each triangle had an AB/BC length of approximately 6.4° .

107 There were six values of angle β : 4° , 8° , 12° , 23° , 34° and 45° (see Fig. 1b). It should
108 be noted that the 12° angle formed a right-angled triangle similar to those used in previous
109 studies (Rozvany & Day, 1980; Verstijnen & van Leeuwen, 1998), whereas the 45° angle
110 formed an isosceles triangle.

111

112 *2.4. Procedure*

113 Prior to the experiment, observers familiarized themselves with the screen for 3 minutes. They
114 were then asked to simultaneously adjust two edges (AB and BC in Figure 1) in a series of
115 increments until they appeared collinear (cancellation task), by pressing the appropriate
116 buttons on a response box. The method was as follows: we determined a line (see the dashed
117 line in Fig. 1b) that ran perpendicular to the AC line and passed through point B ($y = 0.404,$
118 $x+167.03$). Participants could simultaneously adjust the edges (AB and BC) in small
119 increments (approximately 0.5 arcmin) in both directions defined by the dashed line. At the
120 beginning of each trial, the initial position of the apex coordinates (point B in Fig. 1) was
121 randomly picked from the line within the range of -5° to 5° .

122 This sequence was repeated until the observer deemed that the adjustment was
123 satisfactory and pressed the central button on the response box. There was then a 1-s pause
124 before a new trial started. Each observer completed 10 trials in each angle β condition,
125 making a total of 60 trials, presented in random order. There was an initial practice block of
126 three trials. The experimental session only started when the observers felt at ease with the
127 task, otherwise they went through another practice session.

128

129

130 2.5. Results

131 Illusion strength was measured as the difference in degrees (angular error) between the
132 apparent (mean cancellation adjustment) and actual collinearity of the two edges. If the
133 cancellation adjustment was identical to the coordinates of the AC line, then the angular error
134 would be zero. This would mean that observers did not compensate for the illusory effect.
135 However, if the value of the cancellation adjustment differed from the coordinates of the AC
136 line, the angular error would be greater than or less than zero. This would mean that observers
137 compensated for the illusory effect by moving the stimulus edges in the opposite direction. It
138 should be noted that a positive value corresponded to an adjustment toward the top lefthand
139 corner, and a negative value to an adjustment toward the bottom righthand corner. The mean
140 angular errors for the six values of angle β are plotted in Figure 2.

141 The angular error increased as the angle β increased until the latter was equal to 12° ,
142 beyond which the angular error decreased. The greatest adjustment (1.83°) was therefore
143 made when the angle β was 12° . Smaller adjustments (0.17° and 1.12°) were required for
144 angle β of 4° and 8° . Results were relatively symmetrical on both sides of the 12° angle. Thus,
145 the adjustments were around 1.03° when the angle β was 23° , and 0.05° for angle β of 34° .
146 When the angle β was 45° , the angular error was -0.23° .

147 This pattern was confirmed by a repeated-measures analysis of variance (ANOVA).
148 An analysis of angular error for angle β ($4^\circ \times 8^\circ \times 12^\circ \times 23^\circ \times 34^\circ \times 45^\circ$) yielded a significant
149 effect, $F(5, 940) = 113.261$, $p < .001$, $\eta^2_G = 0.306$, $\eta^2_p = 0.377$. Post hoc t tests with
150 Holm-Bonferroni correction for multiple comparisons are presented in Table I. Results
151 indicated significant differences between the angle β of 12° and the other five conditions
152 (Holm-Bonferroni correction, $p < 0.001$ for 5 tests). Interestingly, no significant differences
153 were found between angles 4° and 34° (Holm-Bonferroni correction, $p > 0.5$) or between
154 angles 8° compared to an angle β of 23° (Holm-Bonferroni correction, $p > 0.5$). These

155 comparisons also revealed significant differences between all other conditions (Holm-
156 Bonferroni correction, $p < .02$ for 8 tests). We concluded that the Bourdon illusion is strongest
157 when the angle β is around 12° .

158

159 **Figure 2 about here**

160

161 **Table I about here**

162

163 **3. Experiment 2**

164 *3.1. Observers*

165 We recruited 20 different psychology undergraduates aged 18-25 years as observers
166 for the second experiment. All had normal visual acuity, and all were naïve to the purpose of
167 the experiment. This second experiment was conducted in accordance with the Declaration of
168 Helsinki.

169

170 *3.2. Apparatus*

171 The same apparatus was used as in Experiment 1.

172

173 *3.3. Stimuli*

174 Figures were made up of two right-angled triangles connected by their apices. These triangles
175 were displayed in black ($x = 0.30$, $y = 0.45$; $Y = 1.03$ cd/m²) against a neutral gray
176 background ($x = 0.29$, $y = 0.32$; $Y = 60.32$ cd/m²). The ABD/CBE apex angle was
177 systematically 12.5° (see angle β in Fig. 1), and the vertical orientation of the figure was 22.5°
178 (angle α in Fig. 1). These values had produced the strongest illusions in previous studies
179 (Rozvany & Day, 1980; Verstijnen & van Leeuwen, 1998). In the present experiment, the

180 triangles were displayed with five different angle γ values, ranging from 4° to 135° in steps of
181 22.5° (see Fig. 1b). Figure 3 shows the stimuli used in this experiment. It should be noted that
182 in one condition, there was an angle of 90° , corresponding to a right-angled triangle (type of
183 triangle used in the first experiment).

184

185 **Figure 3 about here**

186

187 *3.4. Procedure*

188 The procedure was identical to that used in Experiment 1. There were a few minutes of dark
189 adaptation prior to the experiment, and practice trials preceded the data collection. Each
190 observer performed 10 trials in each γ angle condition, making a total of 50 trials, presented in
191 random order each time.

192

193 *3.5. Results*

194 We calculated the mean angular error for each condition (see Fig 4) as the difference between
195 the mean cancellation adjustment made by each observer and the coordinates of the AC line
196 (see Fig. 1b). The results of the cancellation task showed that the strength of the illusion was
197 modulated by the γ angle value. The angular error increased as the γ angle increased up to a
198 value of 90° . Corresponding mean angular errors were 0.889° (angle $\gamma = 45^\circ$), 1.487 degrees
199 (angle $\gamma = 67.5^\circ$) and 2.696 degrees (angle $\gamma = 90^\circ$). Beyond 90° , the angular error decreased
200 from 1.947° (angle $\gamma = 112.5^\circ$) to 1.209° (angle $\gamma = 135^\circ$).

201 This finding was supported by a repeated-measures ANOVA. Results revealed a
202 significant effect of the γ angle value ($45^\circ \times 67.5^\circ \times 90^\circ \times 112.5^\circ \times 135^\circ$), $F(4, 792) = 68.519$, p
203 $<.001$; $\eta^2_G = 0.084$, $\eta^2_P = 0.257$. A post hoc paired t test (with Holm-Bonferroni correction)
204 revealed a significant difference between all γ angle conditions, these multiple comparisons

205 are shown in Table II. We concluded that the Bourdon illusion is strongest when γ angle is
206 equal to 90° (i.e., corresponding to a right-angled triangle).

207

208 **Figure 4 about here**

209

210 **Table II about here**

211

212 **4. Experiment 3**

213 *4.1. Observers*

214 We recruited 19 different psychology undergraduates aged 19-25 years as observers. All had
215 normal or corrected-to-normal vision and were naïve to the purpose of the experiment. This
216 third experiment was conducted in accordance with the Declaration of Helsinki.

217

218 *4.2. Apparatus*

219 The apparatus was identical to that used in Experiment 1.

220

221 *4.3. Stimuli*

222 Figures were composed of two right-angled triangles connected by their apices. These
223 triangles were displayed in black ($x = 0.30$, $y = 0.45$; $Y = 1.03$ cd/m²) against a neutral gray
224 background ($x = 0.29$, $y = 0.32$; $Y = 60.32$ cd/m²). The apex angle was systematically 12.5°
225 (see angle β in Fig. 1), and the vertical orientation of the figure was 22.5° (angle α in Fig. 1).
226 These values had produced the strongest illusions in previous studies (Rozvany & Day, 1980;
227 Verstijnen & van Leeuwen, 1998).

228 Figure 5 shows the stimuli used in this experiment. The patterns were created by
229 varying the size of one right-angled triangle while holding the size of the second right-angled

230 triangle constant. Each of the two right-angled triangles was displayed in four versions of
231 varying size. For the triangle that varied in size, the AB (or BC) lengths corresponded to the
232 distance of A (or C) from the central apex (see Fig. 1b) and were approximately 8.6°, 6.4°,
233 4.2° and 2.1°, while the AD (or CE) lengths (see Fig. 1b) were 2.4°, 1.8°, 1.2° and 0.6°. For
234 the triangle that stayed the same size, the AB (or BC) length was approximately 8.6° and the
235 AD (or CE) length was around 2.4°. It should be noted that in one condition, the two right-
236 angled triangles were the same size. There were seven different conditions.

237

238 **Figure 5 about here**

239

240 *4.4. Procedure*

241 The procedure was identical to that used in the two previous experiments. There were 3
242 minutes of screen adaptation prior to testing. Each observer performed 10 trials in each
243 condition, making a total of 70 trials. Practice trials preceded the data collection. The order of
244 the trials was randomized for each observer.

245

246 *4.5. Results*

247 For each observer, the strength of the illusion was measured as the angular error, obtained by
248 computing the difference between the cancellation adjustment and the coordinates of the AC
249 line (see Figure 1b). Mean angular errors for all seven conditions are shown in Figure 6. The
250 angular error increased as the distance of C from the central apex increased: gradually at first
251 (angular error of 1.572° at 2.1°), then levelling off (1.884°-1.845° between 4.2° and 6.4°),
252 before rising steeply (2.674° at 8.6°). The angular error decreased as the distance of A from
253 the central apex decreased: steeply at first (angular error of 2.674° at 8.6°), then levelling off
254 (1.443°-1.263° between 4.2° and 6.4°), before gradually decreasing (0.754° at 2.1°).

255 A repeated-measures ANOVA assessed significant differences in illusion strength
256 across conditions, $F(6, 1128) = 53.940, p < .001; \eta^2_G = 0.162, \eta^2_p = 0.223$. A Holm-Bonferroni
257 post hoc test revealed significant differences between the condition where A and C were the
258 same distance from the central apex and all other conditions as shown in Table III
259 (Holm-Bonferroni correction, all $ps < .001$). Comparisons between the conditions where the
260 distance of C (or A) from the central apex was either 4.2° or 6.4° were not significant. All
261 other comparisons were significant (Holm-Bonferroni correction, all $ps < .05$). We conclude
262 that the Bourdon illusion is strongest when the two triangles are of equal size.

263

264

Figure 6 about here

265

266

Table III about here

267

268 **5. Discussion**

269 *Summary of Results*

270 Our experiments were designed to test the effect of shape arrangement on the strength of the
271 Bourdon illusion. A cancellation method was used for quantification. In this task, observers
272 simultaneously adjusted two sides (AB and BC in Fig. 1) until they appeared straight. Results
273 demonstrated that triangle shape plays a critical role in inducing the illusion. In Experiment 1,
274 the strongest Bourdon illusion occurred when the internal apical angle (β) was around 12° .
275 The second experiment showed that the illusion was stronger for right-angled triangles, and
276 weaker when the right angles were replaced by acute or obtuse ones. Finally, Experiment 3
277 indicated that the strongest Bourdon illusion occurs when the two triangles are the same size.
278 These findings show that the use of the triangle shape is crucial for creating the Bourdon

279 illusion, and suggest that the right-angled triangle is the predominant figural determinant for
280 cancellation adjustments.

281

282 *Comparison with Previous Studies*

283 The first experiment indicated that the greatest angular error was for an internal apical angle
284 of 12° , consistent with previous findings (Rozvany & Day, 1980). In our first experiment, this
285 angular error was 1.83° , and in the two subsequent experiments where the value of angle β
286 was held constant at 12.5° , the maximum angular errors were 2.696° and 2.674° . These values
287 are similar to those found in previous studies when authors used similar displays to create the
288 Bourdon illusion ($3-4^\circ$ in Rozvany & Day, 1980; $2-4^\circ$ in Verstijnen & van Leeuwen, 1998;
289 3.75° in Walker & Shank, 1987; $1-2^\circ$ in Wenderoth, O'Connor, & Johnson, 1986; 2° in
290 Wenderoth & O'Connor, 1987b). We interpret these results to mean that an angle β of 12.5°
291 contributes to a robust Bourdon illusion.

292 There is nonetheless considerable variability between studies. One possible
293 explanation is that there are differences in the methods adopted to collect the data and in the
294 apparatuses used. Verstijnen and van Leeuwen (1998) reported three different tasks in which
295 the Bourdon illusion was studied in different orientations while the inner apical angle was
296 held constant at 12.5° . Results showed that the strength of the Bourdon illusion varied
297 according to the task. When the pattern had an orientation of 22.5° , authors found a mean
298 angular error of around $2-3^\circ$ for a multiple-choice task and a construction task, and $3-4^\circ$ for an
299 adjustment procedure. In the present study, we used a cancellation task that had not
300 previously been administered, which may explain why our results differed.

301 In the first experiment, results indicated that the Bourdon illusion was stronger when
302 scalene triangles were used rather than isosceles triangles (e.g., angle β equal to 45°). These
303 data were consistent with previous studies using an angle discrimination task, in which

304 performances on angles forming an isosceles triangle were more precise than those forming a
305 scalene triangle (Kennedy et al., 2006, 2008). Increasing angle β may conceivably have
306 reduced the strength of the illusion because the salience of the apical angle increased. When
307 the apical angles were well discriminated, observers correctly dissociated the collinear (AB
308 and BC in Fig. 1) edges from the hypotenuse (BE and BD in Fig. 1). Consequently, the use of
309 isosceles triangles reduces an even cancels the Bourdon illusion.

310 Our second experiment showed that scalene triangles did not produce the same effect,
311 indicating that the angle γ values influenced the strength of the Bourdon illusion. These
312 results suggest that angles β and γ interact to create the illusion. Right angles are easily
313 perceptible, whereas acute angles tend to be overestimated, and obtuse angles underestimated
314 (Chen & Levi, 1996; Nundy et al., 2000). Thus, the use of a right angle does not change the
315 perception of angle β , and maximizes the illusion. By contrast, the perception of angle β is
316 modulated by acute or obtuse angles. The illusion is therefore weaker, consistent with our
317 psychophysical results.

318 Our data indicated that the strongest Bourdon illusion occurred when the triangles
319 were of equal size (Exp. 3). This result suggests that increasing the visibility of the
320 symmetrical display increases the illusion. These data are consistent with those reported in
321 previous studies showing that an unbalanced pattern decreases the strength of many visual
322 illusions. For instance, changes at the intersection between oblique and parallel lines on one
323 side of the Poggendorff illusion reduce the misalignment phenomenon (Day, 1988). Similarly,
324 the strength of the Zöllner illusion decreases when the inner or outer parts of the oblique lines
325 are removed (Oyama, 1975).

326

327 *Previous Explanations for the Bourdon Illusion*

328 Various explanations for the Bourdon illusion have been put forward. Walker and Shank
329 (1987, 1988a) developed a model based on interactions between orientation-selective neurons.
330 For these authors, there are no interactions when two lines have very different orientations.
331 By contrast, when two lines have similar orientations, they mutually induce a specific neural
332 distribution. This results in a peak of firing from the summation of lateral inhibition from the
333 edges with the neural excitation from the solid figure, resulting in a mutual attraction effect.

334 According to another explanation put forward by Wenderoth, O'Connor, and Johnson
335 (1986) (see also Wenderoth, 1991), every stimulus is processed along three separate neural
336 channels coding orientation, position, and collinearity. These authors postulated that the
337 illusion arises from conflicting signals between these channels. Under normal circumstances,
338 the neural signals are not in conflict, but this is not the case with the Bourdon edges (lines AB
339 and BC in Fig. 1a) and so a neural compromise occurs. The Bourdon illusion involves a
340 failure to dissociate the orientation of the collinear edges (e.g., AB and BC in Fig. 1) from the
341 orientations and positions of the hypotenuse edges (e.g., BD and BE in Fig. 1). This failure
342 results in the collinear edges being attracted in the direction induced by the hypotenuse edges.

343 Finally, Day (1989, 1990) suggested that multiple cues define a visual pattern. When
344 these cues are in conflict, the perception is a compromise between them. In the Bourdon
345 illusion, the collinear edges have one specific orientation, and each hypotenuse edge has a
346 different one. The compromise between these orientations results in the collinear edges being
347 perceived to follow the direction of the hypotenuse edges.

348 According to these models, the collinear and hypotenuse edges combine to explain the
349 Bourdon illusion, albeit via different mechanisms. However, they fail to consider other figural
350 parameters. Our data suggest that the use of right-angled triangles generates a stronger
351 illusion, and thus increases the angular error (Exp. 2). Furthermore, our angular error analysis

352 showed that the strongest illusion occurred when the right-angled triangles were of equal size
353 (Exp. 3).

354 The present study suggests that the Bourdon illusion arises from a combination of
355 configural processing. It is constructed by integrating multiple sources of information,
356 including the object's geometric properties. Thus, models such as those described above
357 should be extended to take the different figural parameters into account.

358

359 *Role of Inhibitory Processes*

360 The Bourdon illusion can be classified as an illusion of orientation, whose effects are
361 associated with misalignment or nonparallelism (Day, 2010; Hamburger et al., 2017). This
362 type of illusion has different stimulus properties, but the oblique factor is a common condition
363 (Day, 2010).

364 Rozvany and Day (1980) noted that the Bourdon illusion is stronger when the figures
365 are oblique, rather than vertical or horizontal, as is the case of the Zöllner (Parlangeli &
366 Roncato, 1995; White, 1975), Poggendorff (Day & Dickinson, 1976; Weintraub et al., 1980),
367 and tilt (Clifford, 2014; Clifford, Wenderoth & Spehar, 2000) illusions. These illusions are
368 weaker when the figures are vertical or horizontal. These illusions and the Bourdon illusion
369 may conceivably share common mechanisms.

370 One classic explanation is that these illusions stem from neural inhibitory processes
371 (Gillam, 2017; Westheimer, 2008). It is well known that any given orientation is coded by
372 neurons sensitive to a range of orientations. The illusion is attributed to the fact that a bias is
373 introduced by lateral inhibition between neighboring orientation channels (Blakemore,
374 Carpenter, & Georgeson, 1970; Blakemore & Tobin, 1972; Carpenter & Blakemore, 1973).

375 Lateral inhibition was also a central aspect of Walker and Shank (1987, 1988a)'s
376 theory explaining the Bourdon illusion. However, Wenderoth et al. (1990) noted that this

377 explanation holds good not only for a two-triangle display such as that in the original Bourdon
378 figure, but also for a single-triangle display. The role of lateral inhibition has also been
379 disputed in other phenomena. For example, Gillam (2017) discussed the role of lateral
380 inhibition because the illusion persists when the original lines are replaced by subjective
381 contours. It is still present when the parallel lines are replaced by empty interspaces in the
382 Zöllner illusion (Earle & Maskell, 1995) or by dots in the Wundt-Hering illusion (Coren,
383 1970). This has also been observed for other figures using subjective contours, such as the
384 Poggendorff (Gregory, 1972; Tibber et al., 2008) and Bourdon (Walker & Shank, 1987,
385 1988a, 1988b) illusions, indicating that physical angles and lateral inhibition processes are not
386 necessary because the illusion persists.

387 Nonetheless, Seymour et al. (2018) confirmed the inhibition of cortical responses, by
388 performing functional neuroimaging of area V1 of the human visual cortex during the
389 perception of the tilt illusion. Results showed that participants who exhibited strong neural
390 suppression perceived a stronger illusory effect. This could be the result of lateral inhibition,
391 but feedback projections from extrastriate cortical areas may also be involved. This is a
392 relevant idea, in view of studies suggesting that feedback signals play an important role in the
393 perception of Kanisza shapes (Kok & de Lange, 2014; Kok et al., 2016). Feedback projections
394 have been ignored in previous theories, even though they are just as numerous as feedforward
395 projections in the visual cortex (Markov et al., 2014).

396 The present study shows that figural parameters modulate the Bourdon illusion. Taken
397 together, our data support the hypothesis that the mechanisms underlying the distortions in
398 contour perception involve multiple levels of processing. It would be interesting for future
399 research to clarify the role of feedforward, feedback and lateral processes in orientation
400 illusions.

401

402 **Data availability**

403 Materials created and used for this study were described in the manuscript. The data obtained
404 during this study were reported in the manuscript along with figures and tables. Any
405 additional information, materials, and datasets are available from the corresponding author.

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506 **Figure Legends**

507 Fig. 1: Example of the Bourdon illusion. (a) The edges AB and BC are collinear, but
508 appear to bend in the same direction as the chevron formed by the arms of the angle
509 DBE. (b) Here, α refers to the orientation of the long axis of the figure relative to
510 the vertical axis, β refers to the internal apical angles of the figure, and γ
511 corresponds to the right angles. In our study, angle α was systematically equal to
512 22.5° . In the first experiment, apex angle β values ranged from 4° to 45° . In the
513 second experiment, we manipulated the angle γ so that its values ranged from 45° to
514 135° . The dashed line indicates the direction of possible adjustments to edges AB
515 and BC.

516
517 Fig. 2: Mean cancellation adjustments in degrees as a function of the internal apical angle
518 β (Experiment 1). The dashed line indicates the expected response when AB and
519 BC are collinear. Error bars are $\pm 1 SEM$.

520
521 Fig. 3: Stimulus figures used in Experiment 2. Here, five different angle γ values were
522 used: 45° (a), 67.5° (b), 90° (c), 112.5° (d) and 135° (e).

523
524 Fig. 4: Cancellation adjustments plotted as a function of angle γ values (Experiment 2).
525 Error bars are $\pm 1 SEM$.

526
527 Fig. 5: Stimuli used in Experiment 3. (a-c) In three patterns, the right-angled triangle at the
528 top was smaller than the right-angled triangle at the bottom. (d) Classic Bourdon
529 figure in which the two right-angled triangles are of equal size. (e-g) In three

530 patterns, the right-angled triangle at the bottom was smaller than the right-angled
531 triangle at the top.

532

533 Fig. 6: Mean adjustments made to cancel the Bourdon illusion as a function of the distance
534 of A (bottom triangle) or C (top triangle) from the central apex (Experiment 3).
535 Error bars are +/- 1 *SEM*.

536

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