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The black superiority effect: Black is taller than gray

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ABSTRACT

A novel illusion entitled "the letter height superiority effect" has been demonstrated. This shows that letters are perceived as being taller than pseudoletters, while in reality their objective sizes are identical. An explanation of this illusion has been proposed in the framework of the Interactive Activation Model. Indeed, we postulated that the more a feature is activated, the taller a stimulus is perceived as being. The objective of the current study was to test this postulate by manipulating feature activation through signal-to-noise ratio. We presented gray stimuli (low signal-to-noise ratio) or black ones (high signal-to-noise ratio). In a first experiment, participants judged the size of pairs of either letters or pseudoletters presented as black or gray. In a second experiment we presented pairs consisting of a letter and a pseudoletter, of identical or different colors. In a third experiment, we presented pairs of letters or pseudoletters of identical or different colors by block to test the possible effect of previous exposure on perceptual judgments. The results showed that for identical objective size, participants perceive black stimuli to be taller than gray ones and that the effects of the nature of the stimuli and their color are cumulative. The results also indicated that the effects were not due to previous exposure to color or sizes. These results confirm the Interactive Activation Model as a credible explanation for the letter height superiority effect.

A novel illusion called "the letter height superiority effect" was recently highlighted (New, Doré-Mazars, Cavézian, Pallier, & Barra, 2016). This shows that letters are perceived as being taller than pseudoletters. Indeed, when a letter and a pseudoletter of the same objective size were presented to subjects, participants most frequently considered the letter to be taller than the pseudoletter. This illusion extends to words, which are judged to be taller than pseudowords made up of pseudoletters of the same objective size (for a similar result pertaining to words, see Reber, Zimmermann, & Wurtz, 2004).

The interactive activation model (IAM; McClelland & Rumelhart, 1981) has been proposed as an explanation of this effect. Three kinds of unit exist in the IAM (McClelland & Rumelhart, 1981): coding for features, letters, and words, respectively. When a stimulus is presented, it activates feature units that in turn propagate activation to letter and word levels. This model can explain the letter height superiority illusion if we postulate that the more active a feature is, the taller it is perceived to be. In this case, when a letter is presented, its features receive bottom-up, but also top-down, activation from the word level. In contrast, when a pseudoletter is presented, it only receives bottom-up activation as it does not activate any unit at the letter level.

The IAM can also explain the fact that the height superiority illusion is stronger for words than for letters (New et al., 2016). Indeed, features inside words can benefit not only from the letter level's back-propagation, but also from the word levels, while the features presented in a letter only benefit from activation from the letter level.

The aim of our study was to test the postulate that we made to explain this illusion in the IAM. We had proposed that a more activated feature should be perceived as being bigger. If some feature units receive greater activation, their signal-to-noise ratio will be better. Therefore, our idea is that if the signal-to-noise ratio is better, the stimulus should appear to be taller. We manipulated the signal-to-noise ratio by presenting black letters (high signal-to-noise ratio) or gray ones (low signal-to-noise ratio) on a white background. The contrast of the stimuli can be modulated by manipulating the color of the stimuli while retaining the same background color. Thus, a black stimulus on a white background presents a better contrast than a gray stimulus on the same background. If our hypothesis is correct and we present one black stimulus and a gray one of the same size, the black stimulus should be perceived to be taller than the gray one. According to this hypothesis, in Experiment 1 participants were asked to determine the size of stimuli presented in pairs: made of either a gray and a black letter or a gray and a black pseudoletter. Letters and pseudoletters were used since the nature of the stimulus is crucial in the letter-height illusion. The determination of the effect of color on both types of stimuli (letter and pseudoletter) was also essential to test a possible cumulative effect of the color and nature of the stimuli. In Experiment, 2 we tested this possible cumulative effect by asking participants to compare the height of stimuli presented in pairs composed of a letter and a pseudoletter of identical or different colors. Experiment 3 was carried out by repeating the design of Experiment 1 but controlling the order in which the stimuli were presented. We chose this approach since the contrasts between various iterations of stimuli exposures might drive some effects.

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In this experiment we presented pairs of 2 letters or 2 pseudoletters of identical or different colors in blocks, to test the possible effect of previous exposure on perceptual judgments.

1. Experiment 1 (letters)

1.1. Participants

Fifteen participants (3 men and 12 women; 21.5 ± 7.3 years old; 2 left-handed and 13 right-handed), who were students at Descartes University in Paris, participated to gain a course credit. All the participants had normal or corrected to normal vision and were native French speakers.

1.2. Stimuli and design

The stimuli were nine lowercase letters in Times New Roman font (i.e. *a*, *c*, *e*, *m*, *r*, *s*, *v*, *w*, *z*), and nine pseudoletters. The pseudoletters were constructed to match each letter's physical properties (height, width, number of pixels, contiguous pixels) by re-configuring the features of the original letter. Two sizes were created for each of the 18 stimuli, the small one taking up 0.28° of vertical angle (horizontal angle: 0.29°) and the taller one 0.30° of vertical angle (horizontal angle: 0.32°). We used two types of stimuli, letters and pseudoletters that were either black (RGB values of 0, 0, 0) or gray (RGB values of 204, 204, 204). An example of various stimuli is presented in Fig. 1.

Participants were seated in front of a 17-inch monitor (1024 × 768; 85 Hz); and their heads were stabilized 64 cm away from the screen using a chin rest. The experiment was presented using the E-prime 1.2.1.68 computer program. A trial started with the presentation of a central fixation cross for 200 ms, followed by the simultaneous display of two horizontally aligned stimuli (2.75° to the right and the left of the center) for 700 ms. Finally; a white screen was presented until the participant responded. We used this procedure because we wanted the stimuli to remain on the screen for the same duration for all subjects. As a consequence, reaction times (RT) were not recorded if the participant responded faster than 700 ms (when the pair of stimuli was still on the screen). Before beginning the experiment, participants took part in a training session until they reached 80% correct responses. This training session included 16 different configurations of stimuli using two letters that were not presented in the experimental session ("u" and "x"). Feedback was displayed after each trial. Furthermore, only letters and pairs of a single color (gray or black) were used to achieve the 80% success criterion. In the experiment, only pairs of letters or pseudoletters were presented. The colors of the stimuli could be identical (both stimuli were either black or gray) or different (one black and one gray). Participants were asked to compare the height of the stimuli. When they judged the two stimuli to be identical they had to press the down arrow on the keyboard with their dominant hand, and when they judged one stimulus was taller than the other one they had to indicate its position with the left or right arrow. The next trial began 750 ms after the response of the participant.

In half of the trials, stimuli were the same height (identical height trials), while in the other half they were of different heights (different height trials). The positions of the letter and of the other stimulus (in the right and left part of the screen) were counterbalanced. Each participant was the allottee of a different, randomized order of trials. The experimental session included 288 trials repeated three times and lasted about 45 min. Every 108 trials participants were offered a short break.

1.3. Results

Percentages of errors in the same objective size condition were analyzed using repeated measures of analysis of variance (ANOVAs). Furthermore, a one-sample *t*-test was used to determine whether subjects performed above a fortuitous level (50%). The results are presented in Fig. 2.

1.3.1. Same-objective-height condition

In the same-objective-height condition, when subjects made errors on letter pairs, the black stimulus was most often chosen as a taller stimulus than the gray one, since the percentage of errors directed towards the black stimulus was significantly different from 50% (92.7% vs. 50%, $t(14) = 20.42$; $p < .001$). When subjects made errors on pseudoletter pairs of the same-objective-height, the black stimulus was also most often chosen as a taller stimulus than the gray one (94% vs. 50%, $t(14) = 24.97$; $p < .001$). The black stimulus was not chosen more in the pseudoletter condition (94%) than in the letter one (92.7%; $F(1,14) = 0.85$; $p = .37$; $\eta^2 = 0.06$).

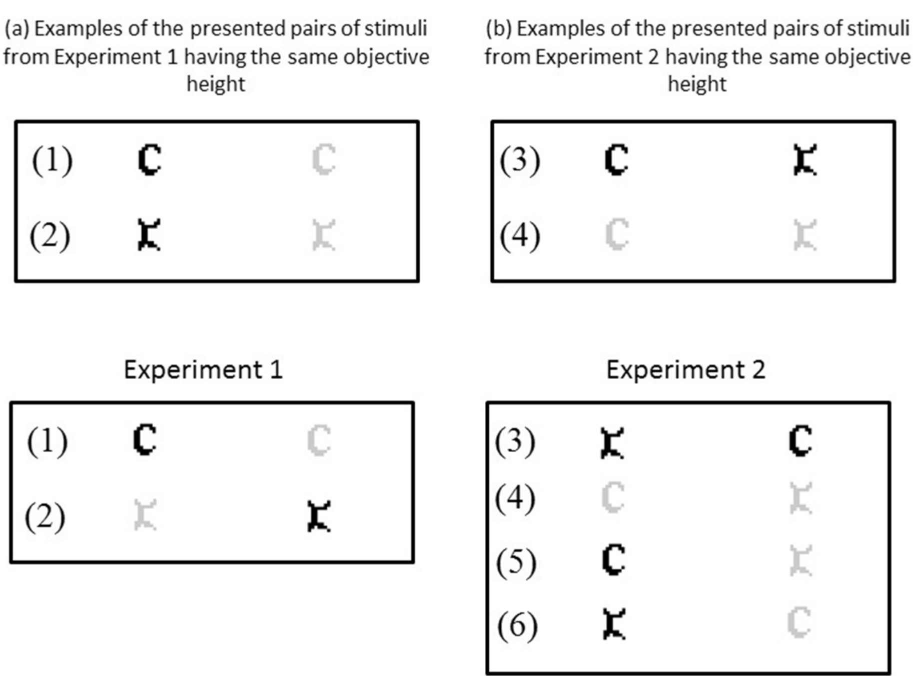


Fig. 1. Examples of the pairs of stimuli presented for Experiment 1 (left side) and Experiment 2 (right side) with the same objective heights: (1) a pair of letters of different colors; (2) pseudoletters of different colors; (3) pseudoletter and letter, both black; (4) letter and pseudoletter, both gray; (5) mixed pair of a black letter and a gray pseudoletter (6) mixed pair of a black pseudoletter and a gray letter.

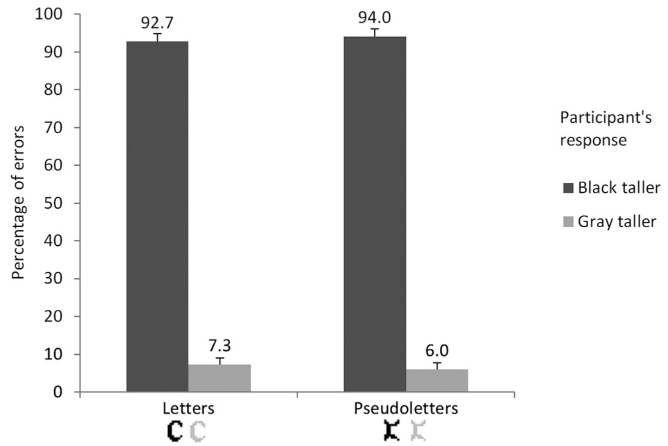


Fig. 2. Distribution (in percentages) of errors between black and gray stimuli in the same objective height condition when the participant gave an incorrect response. For example, the figure indicates that among all the errors made when stimuli were letters, 92.7% of errors consisted of considering the black letter as being the tallest. Error bars are standard errors.

1.3.2. Different-objective-height condition

The percentage of errors when the black and gray letters were of different heights (Fig. 3) was greater when the black stimulus was the smaller of the two, rather than when it was taller than the gray letter (52.1% vs. 15.4%) [$F(1, 14) = 55.02$, $p < .001$, $\eta^2 = 0.80$]. For pseudoletters, the percentage of errors when the black and gray stimuli were of different heights (Fig. 3) was greater when the black stimulus was the smaller one, rather than when it was taller than the gray one (69.1% vs. 23.3%) [$F(1, 14) = 138.59$, $p < .001$, $\eta^2 = 0.91$]. The ANOVA revealed an interaction according to both the type of stimulus (letter vs. pseudoletter) and the type of pair (small black/big gray vs. big black/small gray). This indicated that the effect of the type of pair was greater with pseudoletters than with letters ($F(1, 14) = 7.73$; $p < .05$; $\eta^2 = 0.36$).

The color of the stimulus had a clear effect on processing of perceived size. Indeed, black stimuli were perceived to be taller than gray ones, indicating that the signal-to-noise ratio influences size perception. This result suggested that raising the signal-to-noise ratio increased the perceived height of a stimulus. This could be explained by the fact that an increase in the signal-to-noise ratio also increases feature activation. In our previous study, we showed that the nature of the stimulus (letter vs. pseudoletter) might also influence feature activation (New et al., 2016). According to the hypothesis that the more a feature is activated, the taller the stimulus will appear, both color and the nature of the stimulus are manipulated. The feature's activation should therefore increase cumulatively. To investigate the question of cumulative effect, in Experiment 2 we presented a letter and a pseudoletter and each of these could be either black or gray (see Fig. 1). If the color and nature of the stimulus are cumulative, then a black letter should induce the strongest illusion, compared to a gray pseudoletter. In addition, Experiment 2 should duplicate the results of Experiment 1 and the letter height superiority effect (New et al., 2016).

2. Experiment 2

2.1. Participants

Thirty additional participants (4 men and 26 women; 19.8 ± 1.8 years old; 4 left-handed and 26 right-handed) from Paris Descartes University took part in the experiment to gain course credit. All participants had normal or corrected to normal vision and were native French speakers.

2.2. Materials

Experiment 1 was designed to study the effects of color (gray or black) on the perception of height in pairs of letters or pairs of pseudoletters, while Experiment 2 was designed to study the impact of color according to the nature of the stimulus (letter or pseudoletter). Indeed, in this experiment we presented pairs of stimuli comprised of one letter and one pseudoletter and each could be either black or gray (see Fig. 1). All the stimuli used were the same as in Experiment 1. The procedure was identical to that used in Experiment 1, including the pre-experimental training session.

2.3. Results

2.3.1. Same-objective-height condition

Percentages of errors in the same-objective-height condition were analyzed using repeated measures analysis of variance (ANOVAs). The results are presented in Fig. 4.

Most frequently, black letters are perceived to be taller than black pseudoletters, and this difference is significant (76.7% vs. 50%, $t(29) = 8.94$; $p \leq .001$). Similarly, and significantly, gray letters are perceived to be taller than gray pseudoletters (77.8% vs. 50%, $t(29) = 7.55$; $p \leq .001$). These results duplicate the letter height superiority effect (New et al., 2016). When the pair of stimuli are of the same color, the choice of the gray letter (77.8) was not significantly higher than the choice of the black letter (76.7%, $F(1,29) = 0.16$; $p = .69$; $\eta^2 = 0.005$). The analysis showed an interaction between the conditions ($F(1,29) = 47.48$; $p < .001$; $\eta^2 = 0.66$). The analysis of this interaction demonstrated that the percentage of errors concerning the letter was higher when a pair of a black letter and a gray pseudoletter was presented than when a pair of both black letter and pseudoletter was presented (95.3% vs. 76.7%; $F(1,29) = 56.17$; $p < .001$; $\eta^2 = 0.66$). Similarly, the percentage of errors towards the letter was

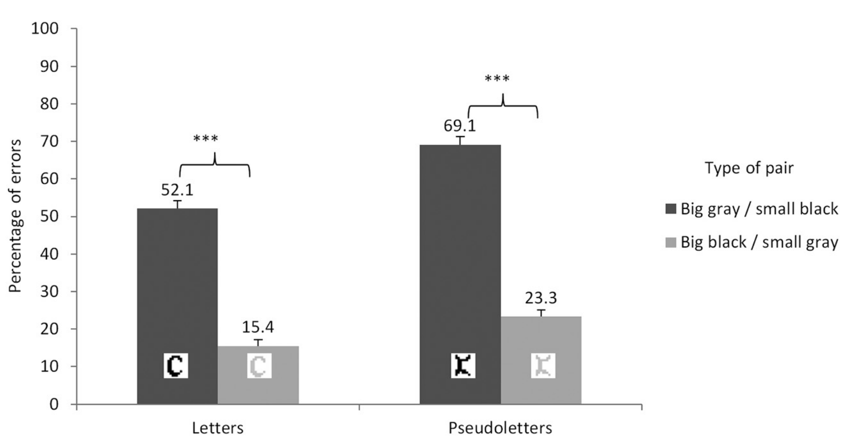


Fig. 3. Error rate (in percentage) for the 4 experimental conditions (big gray/small black letters; big black/small gray letters; big gray/small black pseudoletters; big black/small gray pseudoletters) in the different-objective-height condition. For example, the figure indicates that for pairs of letters participants made 52.1% errors when the big letter was gray and the small one was black. An error consisted either of considering the stimuli as identical or of considering the smaller one as being the bigger one. The percentages of errors presented for each condition are independent. The asterisks indicate a significant difference at $p < .001$. Error bars are standard errors.

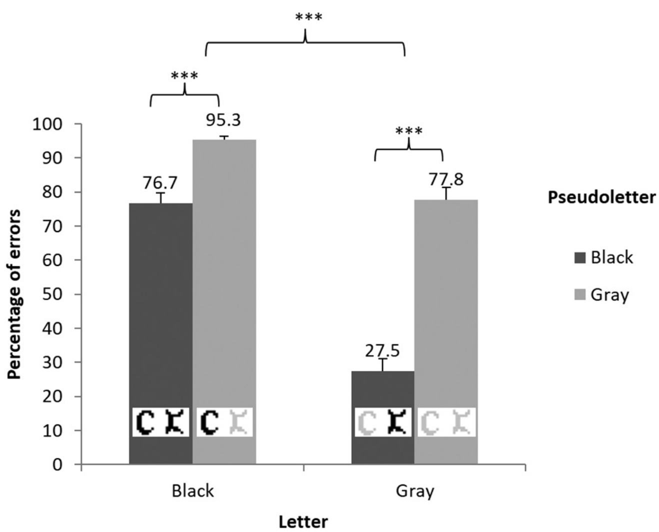


Fig. 4. Percentage of errors towards the letter for the 4 experimental conditions tested (black letters/black pseudoletters; black letters/gray pseudoletters; gray letters/black pseudoletters; gray letters/gray pseudoletters) in the same objective height pairs of stimuli, when the participants gave a wrong response. For example, the figure indicates that when a black letter and a black pseudoletter of identical height were presented, the letter was considered to be the highest in 76.7% of errors. Asterisks indicate a significant difference at $p < .001$, and error bars are standard errors.

lower when the pair consisted of a gray letter and a black pseudoletter than a pair of both a gray letter and pseudoletter (27.5% vs. 77.8%; $F(1,29) = 205.57$; $p < .001$; $\eta^2 = 0.88$).

2.3.2. *Different-objective-height condition*

Results are presented in Table 1.

For black elements, the condition small letter/big pseudoletter induces more errors than the big letter/small pseudoletter condition (62.7% vs. 35%, $F(1,29) = 60.65$; $p < .001$; $\eta^2 = 0.68$). Similarly, for gray elements, the condition small letter/big pseudoletter induces more errors than the big letter/small pseudoletter condition (67.4% vs. 43.6%, $F(1,29) = 55.45$; $p < .001$; $\eta^2 = 0.66$). These results duplicate the letter height superiority effect for both black and gray stimuli. Letters are perceived to be taller than pseudoletters. Furthermore, our results suggest an additive effect of the color (black vs. gray) and the nature of the stimulus (letter vs. pseudoletter). Indeed, the greatest error rate of the experiment in the different-objective-height condition was measured when the letter was both small and black, compared to a bigger gray pseudoletter (81.1%). Interestingly, the condition showing the smallest error rate was that comparing a black big letter to a small gray pseudoletter (18.3%).

In Experiments 1 and 2, we manipulated the contrast using black and gray stimuli presented on a white background to test whether a stimulus with a better signal-to-noise ratio is perceived as taller than a stimulus with a lower signal-to-noise ratio. The results of both experiments are in line with our hypothesis and can be interpreted as the result of the contrast (color) manipulation. Nevertheless, another type of potential contrast may also account for our results. Indeed, contrasts between various iterations of stimuli exposures might also be driving some effects. Nakatani (1989) showed that when experimental subjects were repeatedly shown a large light circle and a smaller darker circle, the subjective size of the dark circle increased. These changes in perception were presumed to be contrast effects produced by an experimentally fixed set. To test this potential effect of contrasts between stimuli, we designed a third experiment based on Experiment 1. Pairs of stimuli were presented by blocks. In these conditions, there was no previous exposure to other kinds of pairs of stimuli in the first block. Participants only saw one type of pair of stimuli for 10 trials before the presentation of a block of other stimuli. We tested whether or not the illusion still exists when controlling for prior exposure to other stimuli. The order of the blocks was counterbalanced and the RT measured.

3. Experiment 3

3.1. *Participants*

80 participants (29 men and 51 women; 21.2 ± 2.9 years old) participated in the experiment. Participants were recruited via the Prolific experimentation platform. All participants were students, with normal or corrected to normal vision, and were native English speakers.

3.2. *Materials*

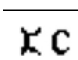
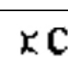
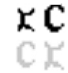
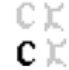
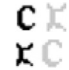
We used 5 letters (*a*, *c*, *e*, *m*, *r*) and the corresponding pseudoletters from Experiment 1. The procedure used in this third experiment was very similar to that used in Experiment 1, with three differences. We wanted to collect the reaction times. Thus, the pairs of items presented remained on the screen until the subject responded. We also wanted to test whether the results of Experiment 1 could be influenced by the previous items. The stimuli were presented in blocks (for instance a gray letter and a black pseudoletter having the same objective size were presented in the first block, ten times before the next block). Finally we had 4 experimental conditions for letters (black and gray stimuli having the same objective size, black and gray stimuli having the same bigger objective size, black stimulus bigger than the gray one, black stimulus smaller than the gray one) and the same 4 for pseudoletters. We used a Williams square to control for the order effect of the 8 experimental conditions, but also to present each of the 8 conditions in the first order for 1/8 participants. Therefore, we obtained the performances of 10 participants for each experimental condition in the first order. We first analyzed the error rate of the first block of each order for both identical and different height objective sizes.

3.3. *Results*

3.3.1. *Same-objective-height condition, first block*

Percentages of errors in the same objective size condition were analyzed using repeated measures analysis of variance (ANOVAs). The

Table 1
Error rate (in percentage) for the 8 experimental conditions (stimulus height (big versus small) * type of pairs) in the different-objective-height conditions. For example, when a large black pseudoletter and a small black letter were presented, participants made 62.7% of errors (they considered either the stimuli to be identical or the black letter as bigger).

	Big	Small			Small	Big	
	Black pseudoletter	Black letter	62.7% (19.7)		Black pseudoletter	Black letter	35% (17.5)
	Gray letter	Gray pseudoletter	43.6% (19.3)		Gray letter	Gray pseudoletter	67.4% (17.3)
	Black letter	Gray pseudoletter	18.3% (14.6)		Black letter	Gray pseudoletter	81.1% (16.7)
	Black pseudoletter	Gray letter	45.3% (19.6)		Black pseudoletter	Gray letter	63.5% (21.1)

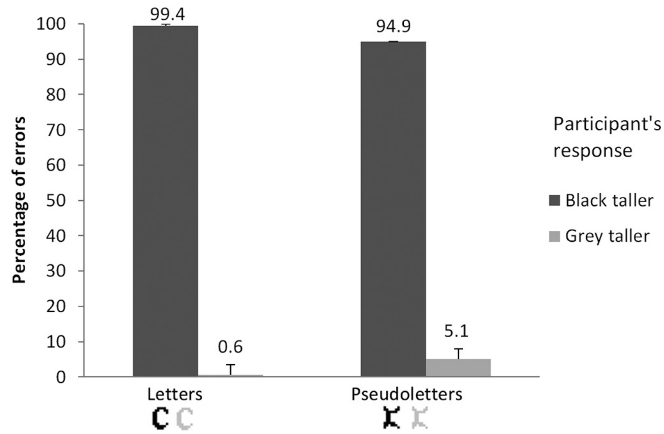


Fig. 5. Distribution (in percentages) of errors in the first block between black and gray stimuli with the same-objective-height condition. For example, this figure indicates that among all the errors made when stimuli were letters, 99.4% of the errors considered the black letter to be taller. Error bars are standard errors.

results are presented in Fig. 5.

In the first block, In the same-objective-height condition, when subjects made errors on letters pairs having the same-objective-height, the black stimulus was more often chosen as taller than the gray one since the percentage of errors towards the black stimulus was significantly different from 50% (99.4% vs. 50%, t(19) = 79; $p < .001$). When subjects made errors on pseudoletter pairs of the same objective height, the black stimulus was more often chosen as being taller than the gray one (94.9% vs. 50%, t(19) = 16.02; $p < .001$). The black stimulus was not chosen more in the pseudoletter condition (99.4%) than in the letter condition (94.9%; F(1,19) =2.32; $p = .145$; $\eta^2 = 0.06$).

3.3.2. *Different-objective-height condition, first block*

The percentage of errors when the black and gray letters had different heights (Fig. 6) was greater when the black stimulus was smaller than the gray letter compared to when it was the taller of the two (46% vs. 17%) [F(1, 18) = 7.11, $p < .05$, $\eta^2 = 0.28$]. For pseudoletters, the

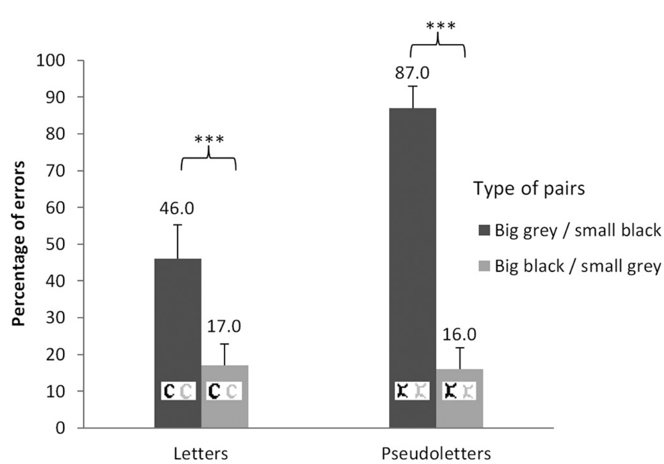


Fig. 6. Error rate (in percentages) in the first block for the 4 experimental conditions (big gray/small black letters; big black/small gray letters; big gray/small black pseudoletters; big black/small gray pseudoletters) in different-objective-height conditions. For example, Fig. 6 indicates that for pairs of letters, participants made 40.0% of errors when the large letter was gray and the small one black. An error consisted either of considering the stimuli as identical or the small one as taller. The error percentage presented for each condition is independent. Asterisks indicate a significant difference at $p < .001$. Error bars are standard errors.

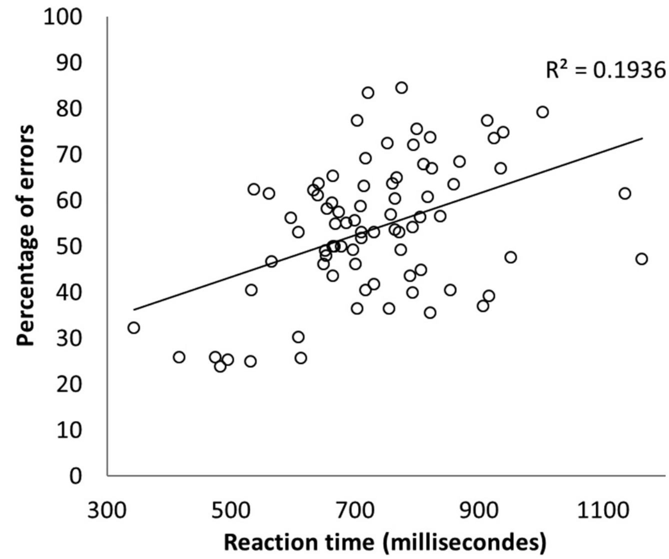


Fig. 7. Speed (reaction time in milliseconds)/accuracy (percentage of errors) trade off.

percentage of errors when the black and gray stimuli had different heights (Fig. 3), was greater when the black stimulus was the smallest one (87% vs. 16%) [F(1, 18) = 72.59, $p < .001$, $\eta^2 = 0.8$]. The ANOVA with the type of stimulus (letter vs pseudoletter) and the type of pair (small black/big gray vs big black/small gray) revealed an interaction indicating that the effect of the type of pairs was greater with pseudoletters than with letters (F(1, 36) = 9.39; $p < .01$; $\eta^2 = 0.09$).

To examine the possible existence of a speed/accuracy trade off in this experiment, we tested the link between the subject's average reaction time and subject's error percentage using a Pearson correlation (Fig. 7). This analysis revealed a statistical link between the two measurements ($r = 0.44$; t(78) = 4.33; $p < .001$). The faster the subjects responded, the more errors they made.

The reaction times (Fig. 8) were analyzed using repeated measures analysis of variance (ANOVAs), with the type of stimulus (letter vs pseudoletter) and the type of pair (big gray/small black; same objective height; big black/small gray) as within factors. The analysis only revealed an effect of the type of pair (F(2,79) = 29.51; $p < .001$). There were no effects of the type of stimulus (F(1,79) = 0.433; $p = .52$) or interaction between factors (F(2,158) = 0.17; $p = .84$). The post hoc decomposition of the type of pair effect using Tukey HSD indicated that

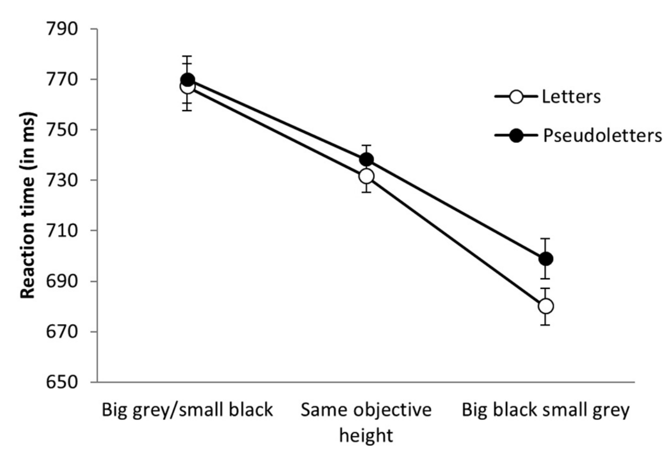


Fig. 8. Analysis of reaction to the first block (mean reaction times in milliseconds) as a function of the type of stimulus (letter vs pseudoletter) and the type of pair (big gray/small black; same-objective-height; big black/small gray). Error bars are standard errors.

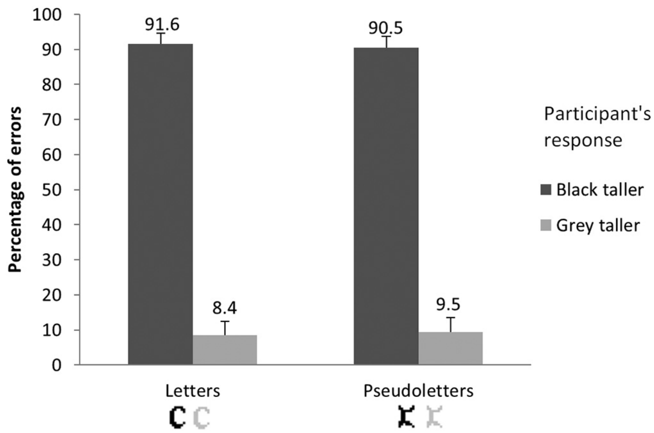


Fig. 9. Distribution (in percentages) of errors (all blocks) between black and gray stimuli in the same-objective-height condition when the participant gave an incorrect response for each type of stimulus (letters or pseudoletters). For example, the figure shows that among all the errors made when stimuli were letters, 91.6% of them consisted of the black letter being seen as the tallest. Error bars are standard errors.

the participants were slower when the stimuli were a big gray/small black combination than those of the same objective height ($p < .001$) or a big black/small gray couple ($p < .002$). Furthermore, participants were slower when the pairs were made of stimuli of the same objective height than when they were a big gray/small black combination ($p < .001$).

3.3.3. Same-objective-height condition, all blocks

The percentages of errors in the same objective size condition were analyzed using repeated measures analysis of variance (ANOVAs). The results are presented in Fig. 9.

In the same-objective-height condition (all blocks), when subjects made errors on letter pairs of the same-objective-height, the black stimulus was more often chosen as being taller than the gray one. Thus, the percentage of errors towards the black stimulus was significantly different from 50% (91.57% vs. 50%, $t(78) = 26.63$; $p < .001$). When subjects made errors on pseudoletter pairs of the same objective height, the black stimulus was also chosen more often as being taller than the gray one (90.05% vs. 50%, $t(76) = 19.97$; $p < .001$). The black stimulus was not chosen more in the pseudoletter condition (91.57%) than in the letter condition (90.05%; $F(1,75) = 0.129$; $p = .72$; $\eta^2 = 0.06$).

3.3.4. Different-objective-height condition, all blocks

The percentage of errors (Fig. 10) when the black and gray letters had different heights was greater when the black stimulus was smaller than the gray one, compared to when the black letter was the tallest (63.3% vs. 15.25%) [$F(1, 79) = 936.06$, $p < .001$, $\eta^2 = 0.99$]. For pseudoletters, the percentage of errors when the black and gray stimuli had different heights was greater when the black stimulus was the smaller one, rather than being taller than the gray pseudoletter (74% vs. 20.87%) [$F(1, 79) = 234$, $p < .001$, $\eta^2 = 0.99$]. According to the type of stimulus (letter vs pseudoletter) and the type of pair (small black/big gray vs big black/small gray), the ANOVA revealed no interaction. This indicates that the effect of the type of pairs was not greater for pseudoletters than for letters ($F(1, 79) = 1.82$; $p = .181$; $\eta^2 = 0.26$).

The reaction times (Fig. 11) were analyzed for the type of stimulus (letter vs pseudoletter) and the type of pair (big gray/small black; same objective height; big black/small gray) using repeated measures ANOVAs with the type of stimulus (letter vs pseudoletter) and the type of pair (big gray/small black; same objective height; big black/small gray) as within factors. The analysis only revealed an effect of the type of pair

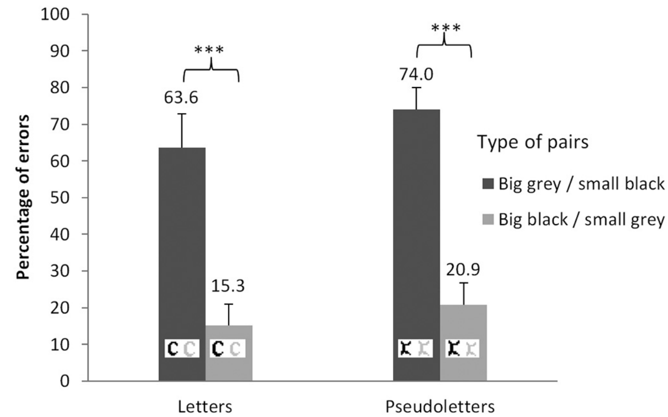


Fig. 10. Error rate of all blocks (in percentages) for the 4 experimental conditions (big gray/small black letters; big black/small gray letters; big gray/small black pseudoletters; big black/small gray pseudoletters) in the different-objective-height condition. For example, Fig. 10 indicates that for the pairs of letters, participants made 63.63% of errors when the big letter was gray and the small one black. An error consisted either of considering the two stimuli as being identical, or of considering the small one as the tallest. The error percentages presented for each condition are independent. The asterisks indicate a significant difference at $p < .001$. Error bars are standard errors.

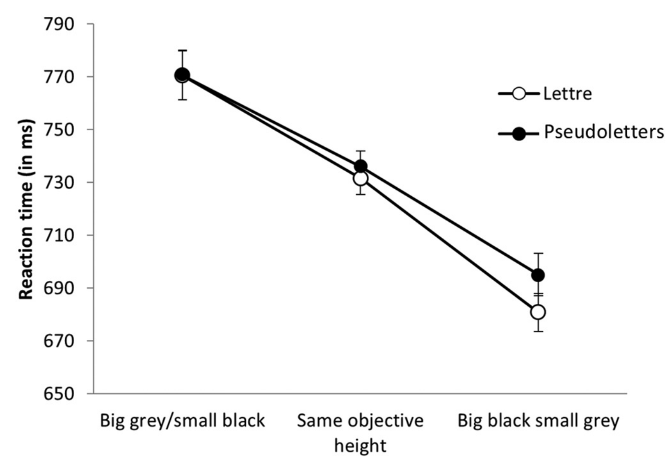


Fig. 11. Mean reaction times of all blocks (in milliseconds) as a function of the type of stimulus (letter vs pseudoletter) and the type of pair (big gray/small black; same-objective-height; big black/small gray). Error bars are standard errors.

($F(2,78) = 30.64$; $p < .001$). There were no effects of the type of stimulus ($F(1,78) = 0.26$; $p = .61$) or interaction between factors ($F(2,156) = 0.18$; $p = .84$). The post hoc decomposition of the type of pair effect using Tukey HSD indicated that the participants were slower when the stimuli were a big gray/small black combination than those made of the same objective height stimuli ($p < .001$), or big black/small gray stimuli ($p < .002$). Furthermore, participants were slower when the pairs were made of the same-objective-height stimuli than when they were made of a big gray/small black stimuli ($p < .001$).

4. Discussion

The major aim of this study was to test the hypothesis that higher feature activation should give an increased size perception of stimuli compared to lower feature activation. With this in mind, we manipulated the feature activation through the signal-to-noise ratio. The latter was high for black stimuli and low for gray ones. In our first experiment, we hypothesized that if we present gray and black stimuli with the same objective size, the participant will perceive the black stimulus to be taller than the gray one. Indeed, when participants made errors, these were such that black letters were perceived to be taller than gray letters. Similarly, black pseudoletters seemed taller than gray ones. To our knowledge, these results reveal for the first time that black stimuli that combine different features are perceived to be taller than gray stimuli with the same objective size. These results may seem inconsistent with those reported by Robinson (1954), who showed that brightness affects the perception of object size. This author found that brighter points were considered as larger than dimmer ones. However, in our experience it is the least luminous stimulus (black) that appears to be the taller. However, the two experiments are coherent if we examine contrast, which is another way of referring to the signal-to-noise ratio. Indeed, whether in Robinson (1954) or from studying our results, for very different stimuli (more or less luminous points, or more or less black letters or pseudoletters), the one with the best contrast is perceived as being the taller.

Our results confirm that stimuli having a lower signal-to-noise ratio (gray) are perceived as smaller than stimuli having a better signal-to-noise ratio (black). This "black superiority effect" cannot be explained by backpropagation, since both letters and pseudoletters demonstrated it. This means that we can only explain the effect by implying the feature level and not any higher level. This suggests that the decrease of the signal-to-noise ratio in the feature level influences the subjective letters' height. The higher the signal-to-noise ratio (black stimulus), the higher the perceived stimulus size. We concluded that the subjective perception of the stimulus' height may be modulated by the degree of feature activation. This result confirms that the more a feature's unit is activated, the taller the feature is perceived to be. Our results confirm that the height superiority effect observed by New et al. (2016) can be explained in the frame of the IAM model (McClelland & Rumelhart, 1981) by a greater activation of features by letters than by pseudoletters. This might induce a greater size perception of the letters.

The hypothesis of perceptual fluency could also account for this result. This hypothesis defends the premise that stimuli that are processed faster are more likely to be easier to recognize or preferred, or estimated as being more frequent (Reber & Zupanek, 2002; Wänke, Schwarz, & Bless, 1995). Perceptual fluency can influence physical properties such as clarity (Goldinger, Kleider, & Shelley, 1999), figure-ground contrast, or stimulus duration (Reber et al., 2004). So, in the theoretical framework of fluency, letters would be perceived to be taller than pseudoletters because they are processed more fluently (Reber et al., 2004). The fact that black stimuli were perceived as being taller than gray ones can be explained by the perceptual fluency theory, if we postulate that the most contrasted stimuli would take less time to be processed. But explanations in terms of associative models (computational), and fluency (phenomenological), are not mutually exclusive. In fact, backpropagation could be the mechanism that gives rise to perceptual fluency. Nevertheless, the involvement of perceptual fluency has been questioned recently on another digit sized judgment task (Reber, Christensen, & Meier, 2014). However, computational models can also be criticized because they give too much opportunity to adapt theory to data (Cook, 1995).

One other potential explanation for our results could be the implication of attention to the subjective size judgment. It could be imagined that the most contrasted stimulus, i.e. black, captures the subject's exogenous (overt) attention. This additional attentional treatment may explain the increase in the subjective size of the stimulus. Indeed, Hagtvedt and Brasel (2017) showed that objects with more saturated color appear larger due to an attentional process mechanism. Nevertheless, they used 3 dimensional colored objects while we tested 2 dimensional written stimuli in black and gray. Furthermore, the stimuli used in our experiments were much smaller. Even so, their results fit with our argument that higher feature activation leads to larger size perception. Anton-Erxleben, Henrich, and Treue (2007) previously conducted a study in which participants were asked to judge the size of two moving random dot patterns while manipulating attention orientation by presenting a spatial cue. The authors found that participants had a greater subjective perception of the stimuli on which their attention was focused. This result might explain our "black superiority illusion", but the nature of the stimuli are very different from those of our study. We used unitary and static stimuli whereas in the experiment of Anton-Erxleben et al. (2007) sets of points were presented in motion. A more comparable study to ours is that of Tsal and Shalev (1996), which used static unitary stimuli to test the effect of attention on subjective size judgment. These authors observed sequential presentation of 2 vertical lines to be compared. They found that the stimulus to which attention had been focused through a cue was judged to be shorter than expected. When the two lines were presented simultaneously, the directional effect of attention was eliminated. These results were criticized by Prinzmetal and Wilson (1997) and Masin (1999) but they were later duplicated and confirmed by Tsal, Shalev, and Zakay (2005). These results are not compatible with an attentional explanation of our results, because when attention is focused on a line, this is either perceived as being smaller or its size is not affected. In our experiment, attention was not controlled. The results from Tsal et al. (2005) suggested that such uncontrolled attention probably had no effect, or had only potentially reduced the illusion observed.

The black superiority effect constituted the main finding of Experiment 1, and this brought a strong argument in favor of the IAM model's explanation. The results also revealed that the "black superiority effect" (comparison of black and gray stimuli) is the same when the pair of stimuli are made only of either letters or pseudoletters. This can be explained by the fact that when a black letter is compared to a gray one, both activate the feature and the letter level. Hence, both stimuli benefit from the same backpropagation. Concerning the pair of a black and a gray pseudoletter, these activate the same level: only the feature level. In other words, it can be suggested that despite a different baseline level activation for letters and pseudoletters, the color of the stimuli had little effect on feature activation. Nevertheless, the results reported in experimental conditions where pairs made of stimuli of different height were not totally in line with this conclusion. Indeed, an interaction between the color and type of stimulus has been observed when stimuli were of different sizes. These results concerning pairs of stimuli of different sizes are more questionable than those pertaining to pairs of stimuli of the same size. Indeed, the results obtained for stimuli of different sizes depend on the size difference used. For example, the illusion would have been stronger if the size difference between the two stimuli had been reduced. This interaction may also be driven by a difference in the number of features between letters and pseudoletters. When we generated pseudoletters based on letters, we controlled their physical properties but not their number of features. For example, the pseudoletter presented in Fig. 1 is constructed from the letter "c" and is made of 7 different features. This contrasts with the letter "c" that is made of just 5 features, if we used the procedures commonly applied to research into visual features for letter detection (Courrieu, Farioli, & Grainger, 2004; Wiley, Wilson, & Rapp, 2016). The fact that pseudoletters potentially have more features than letters do, could explain why under our "different-objective-height" condition, the illusion is stronger for pseudoletters than for letters.

In Experiment 2, we presented pairs of stimuli that consistently included a letter and a pseudoletter. Black or gray stimuli were presented. The aim of this experiment was threefold: 1) to duplicate the letter height superiority effect under conditions where the two stimuli were of the same color 2) to duplicate the illusion of color superiority shown in Experiment 1 under conditions where one stimulus was black and the other gray 3) to test whether the effects of the color and the nature of the stimulus can be cumulative.

We duplicated the letter height superiority effect. Letters were perceived to be taller than pseudoletters when 2 stimuli of the same color and identical objective sizes were presented. We duplicated the results of Experiment 1 showing that black stimuli were perceived to be taller than gray stimuli. Indeed, when a black letter was presented along with a gray pseudoletter, the superiority effect of the black letter was greater than when it was presented with a black pseudoletter. Similarly, when a gray letter was presented with a black pseudoletter, the black pseudoletter was perceived to be taller than the letter. This contrasts with the situation where the two stimuli are gray. Then, the letter appeared taller than the pseudoletter. Finally, our results showed that the effects of color and type of stimulus are cumulative. Indeed, it is in the condition “black letter vs. gray pseudoletter” that we observed the greatest illusion of superiority. Congruently, we observed that the size superiority illusion was reversed in favor of the pseudoletter when we presented a gray letter with a black pseudoletter. Sternberg's additive factor logic (Sternberg, 1998) explains that stimulus type processing and color (or contrast) processing are two independent and discrete processing stages. These might be serial processing stages but this cannot be demonstrated using our results, as we did not measure reaction times in Experiment 2.

Nakatani (1989) had demonstrated that changes in subjective size perception could be due to contrast effects produced by an experimentally fixed set. Indeed, he had reported that when subjects were repeatedly shown a large light circle and a smaller darker circle, the subjective size of the dark circle increased. In contrast, when the subjects were repeatedly shown a small light circle and a larger darker circle, the subjective size of the dark circle decreased. A similar contrast effect may have occurred in Experiment 1 since the order of the presentation of the items was randomly controlled and the various iterations of letter exposures could have preclude our conclusion. In order to make sure that our illusion could not be contaminated by possible associations between the size and color of the stimuli from previous trials, we designed Experiment 3. In this third experiment we presented the main experimental conditions of Experiment 1 by block with a counterbalanced order. Thus, each experimental condition is found in the first block of a list because we have counterbalanced the orders of the blocks. The analyses of the first blocks allowed us to test the effect of the different experimental conditions without previous exposition to other ones. The results show that even without prior association, subjects see black stimuli as being larger than gray ones. Experiment 3 also allowed us to collect the reaction times of the subjects, and so determines that the faster the subjects respond, the more sensitive they are to the illusion. This may demonstrate that by making greater use of high-level processes it is possible to be less influenced by illusion, but it seems costly for the subject (especially as participants continue to experience an illusion, albeit a weaker one). Furthermore, Experiment 3 shows that our illusion remains if the participant makes his or her judgment while the stimuli are still on the screen. Since the analyses of the first blocks demonstrated that the presentation's order didn't preclude the analysis, all blocks were considered. The analyses of all the blocks confirmed the conclusions drawn from the first blocks but provided more experimentally powerful results since it corresponded to 80 participants rather than 10.

The main result of these experiments is that it is possible to modulate subjective perception of stimulus size by varying the signal-to-noise ratio of the stimulus. The higher the signal-to-noise ratio, the taller the stimulus appears. From a psychophysiological point of view, this means that when we present two stimuli of different sizes, the larger one should have activated more neurons in low visual level areas used to detect features such as V1. Recently, Szwed et al. (2011) compared normal words with ones where the features had been scrambled. These authors found stronger activation in the V1/V2 and V3/V4 areas for words than for words with scrambled features. This activation increase in the early visual fields could have a positive impact on the size of the V1 retinotopic structure. Recently, Madec, Rey, Dufau, Klein, and Grainger (2012) used a new method in electrophysiology to follow the temporal evolution of letter perception. Their results showed a significant correlation between their behavioral measures and ERPs at around 220 ms at occipital electrodes sites. They interpreted these correlations as evidence of recurrent processing in primary visual areas.

In conclusion, the modulation of the signal-to-noise ratio influences the perception of letter size. The higher the signal-to-noise ratio, the taller the letter is perceived as. This result supports the hypothesis that during presentation of a stimulus, the more the feature is activated, the taller the stimulus comprising this feature is perceived.

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Appendixes

Experiment 1: stimuli and subjects' average response given in percentages .Standard deviations are in brackets.

Stimuli		Subjects' Response			
Stimulus 1	Stimulus 2	Identical	Black taller	Gray taller	Global Accuracy
Letters					
Black	Black	77.2 (11.2)	22.8 (11.2)		77.2 (11.2)
Gray	Gray	79.3 (10.8)		20.7 (10.8)	79.3 (10.8)
Black	Gray	61.9 (14.6)	35.5 (14.6)	2.6 (2.2)	61.9 (14.6)
Big black	Black	25.4 (18.9)			74.1 (18.9)
Big gray	Gray	26 (15.4)			73.1 (15.3)
Big gray	Black	47 (22.9)	5.1 (4.8)	47.9 (22.7)	47.9 (22.7)
Big black	Gray	15.3 (12.9)	84.6 (12.9)	0.1 (0.5)	84.6 (12.9)
Pseudoletters					
Black	Black	85.6 (10.1)	14.4 (10.1)		85.6 (10.1)
Gray	Gray	85.7 (8.6)		14.3 (8.6)	85.7 (8.6)
Black	Gray	70.2 (16.7)	28.4 (16.9)	1..4 (1.3)	70.2 (16.7)
Big black	Black	36.3 (16.2)			62.5 (17.2)
Big gray	Gray	35.8 (17.2)			64 (17.6)
Big gray	Black	63.6 (18.5)	5.6 (7.3)	30.9 (15.8)	30.9 (15.8)
Big black	Gray	23 (15.4)	76.6 (15.4)	0.4 (1)	76.7 (15.4)

Experiment 2: stimuli and subjects' average response in percentages. Standard deviations are in brackets.

Stimuli		Subjects' Response			
Stimulus 1	Stimulus 2	Identical	Black taller	Gray taller	Global Accuracy
Gray letter	Gray pseudoletter	76.9 (15.3)	18 (13.3)	5.1 (5.2)	76.9 (15.3)
Black letter	Black pseudoletter	73.5 (18.5)	19.8 (14.5)	6.7 (6.3)	73.5 (18.5)
Black letter	Gray pseudoletter	51.6 (18.1)	46 (17.4)	2.3 (2.9)	51.6 (18.1)
Gray letter	Black pseudoletter	69 (18.4)	21.9 (13.3)	9.1 (9.4)	69 (18.4)
Big black pseudoletter	Black letter	58.2 (19.6)	37.3 (19.2)		37.3 (19.2)
Big gray letter	Gray pseudoletter	42.8 (19.6)			56.4 (19.3)
Big black letter	Gray pseudoletter	17.7 (14.6)		5.9 (12.9)	81.7 (14.6)
Big black pseudoletter	Gray letter	43 (19.7)		5.4 (9.1)	54.7 (19.6)
Big black letter	Black pseudoletter	34.4 (17.6)			65 (17.5)
Big gray pseudoletter	Gray letter	63.2 (18.4)	4.2 (7.1)	32.6 (17.1)	32.6 (17.3)
Big gray pseudoletter	Black letter	66.2 (21.9)	19.3 (16.8)		18.9 (16.7)
Big gray letter	Black pseudoletter	59.1 (22)	8 (10)		36.5 (21.1)

Experiment 3: stimuli and subjects' average response in percentages. Standard deviations are in brackets.

Stimuli		Subjects' Response			
Stimulus 1	Stimulus 2	Identical	Black taller	Gray taller	Global Accuracy
Letters					
Black letter	Gray letter	51.1 (25.7)	44.1 (23.6)	4.8 (8.4)	
Big gray letter	Black letter	39.6 (28.3)	24 (29)		36.4 (27.9)
Big black letter	Gray letter	13.5 (16.5)		1.8 (5.2)	84.7 (17)
Pseudoletters					
Black letter	Gray letter	50.5 (27.7)	44.1 (26.2)	5.4 (12)	
Big gray letter	Black letter	47.5 (29)	26.5 (28.9)		26 (22.4)
Big black letter	Gray letter	17.4 (18.4)		3.5 (9.5)	79.1 (20.3)

Stimuli and subjects' average response in percentage is only presented for the subjects having run the condition in their first block in Experiment 3. Standard deviations are in brackets.

Stimuli		Subjects' Response			
Stimulus 1	Stimulus 2	Identical	Black taller	Grey taller	Global Accuracy
Letters					
Black	Gray	35 (28.2)	64.5 (28)	0.5 (2.2)	35 (28.2)
Big gray	Black	29 (24.3)	17 (29.3)		54 (29.1)
Big black	Gray	15 (15.7)		2 (6)	83 (17.3)
Pseudoletters					
Black	Gray	36.5 (23.9)	59 (23.6)	35 (7.9)	36.5 (23.9)
Big gray	Black	67 (27.6)	20 (22.4)		13 (17.9)
Big black	Gray	14 (16.2)		2 (4)	84 (17.4)

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