

CHILDREN AFFECTED BY DEVELOPMENTAL DYSLEXIA SHOW REDUCED SENSITIVITY TO VISUAL MOTION ILLUSIONS

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Abstract

Although developmental dyslexia is often described in terms of selective phonological deficit, visual Magnocellular-Dorsal (M-D) deficit hypothesis gains an increasing consent, even if it remains a controversial theory. Several experimental data supporting the M-D deficit hypothesis, indeed, can also be interpreted as a consequence of a perceptual noise exclusion deficit. In our psychophysical experiments, we measured sensitivity for two visual motion illusions proved to involve specifically the M-D pathway. The results show that dyslexic group differed, in comparison to the control group, in perceiving both illusions. Specifically, dyslexics needed more luminance contrast to perceive the motion illusions, although contrast sensitivity for these specific stimuli did not differ between the two groups. These results are the first supporting the M-D deficit hypothesis in dyslexia by measuring sensitivity to visual motion illusion, without involving any perceptual noise exclusion mechanism.

Although current research on visual illusions provides several insights about how the visual system works, surprisingly it seems that illusory phenomena are rarely employed in the study of clinical populations. Few noticeable exceptions to this “not-written rule” are present in the literature. Cestnick & Coltheart (1999) found a relationship between the Ternus’ (1938) apparent motion display performance and the nonword reading abilities in dyslexics. Dennis, Rogers, & Barnes (2001) showed that children affected by spina bifida, interestingly perceived several visual illusions but were not able to perceive multistable figures. Happé (2006) reported that autistic children were not fooled by the Ebbinghaus-Titchener illusion (Titchener, 1901) as typically development children do. Finally, Savazzi, Posteraro, Veronesi, & Mancini (2007) highlighted the space distortion along the horizontal meridian in the neglect subjects by means of the Oppel-Kundt illusion (Kundt, 1863; Oppel, 1855). Besides these intriguing works the contact between clinical populations and visual illusions remains almost unexplored. In this study our aim was to link Developmental Dyslexia (DD) with motion illusion perception, trying to test the Magnocellular-Dorsal (M-D) stream deficit hypothesis in dyslexia (Stein & Walsh, 1997). DD is a neurobiological disorder characterized by a difficulty in reading acquisition despite adequate intelligence, conventional education and motivation. Although DD is often described in terms of selective phonological deficit (Ramus, 2003), visual M-D deficit hypothesis (Stein & Walsh, 1997) gains an increasing consent (Boden & Giaschi, 2007; Vidyasagar & Pammer, 2010 for reviews), even if it remains a controversial theory. Several experimental data supporting the M-D deficit hypothesis, indeed, can also be interpreted as a consequence of a perceptual noise exclusion deficit in DD (Sperling, Lu, Manis, Seidenberg, 2006).

In our psychophysical experiments, we measured sensitivity for two visual motion illusions presenting characteristics that specifically required the M-D pathway processing. The two illusions are the Rotating Tilted Lines Illusion (RTLTI) (Gori & Hamburger, 2006) and the Accordion Grating (AG) illusion (Gori, Giora, Yazdanbakhsh, & Mingolla, under review). The RTLTI (Figure 1, left) seems to be the simplest pattern able to trigger illusory rotation in presence of only radial expansion motion on the retina. Approaching the RTLTI pattern, vivid illusory rotation is experienced. The

origin of this illusory effect seems to rely on the aperture problem and on the competition between motion signals originating from two different motion-processing units in visual primary cortex (V1) (Gori & Yazdanbakhsh, 2008).

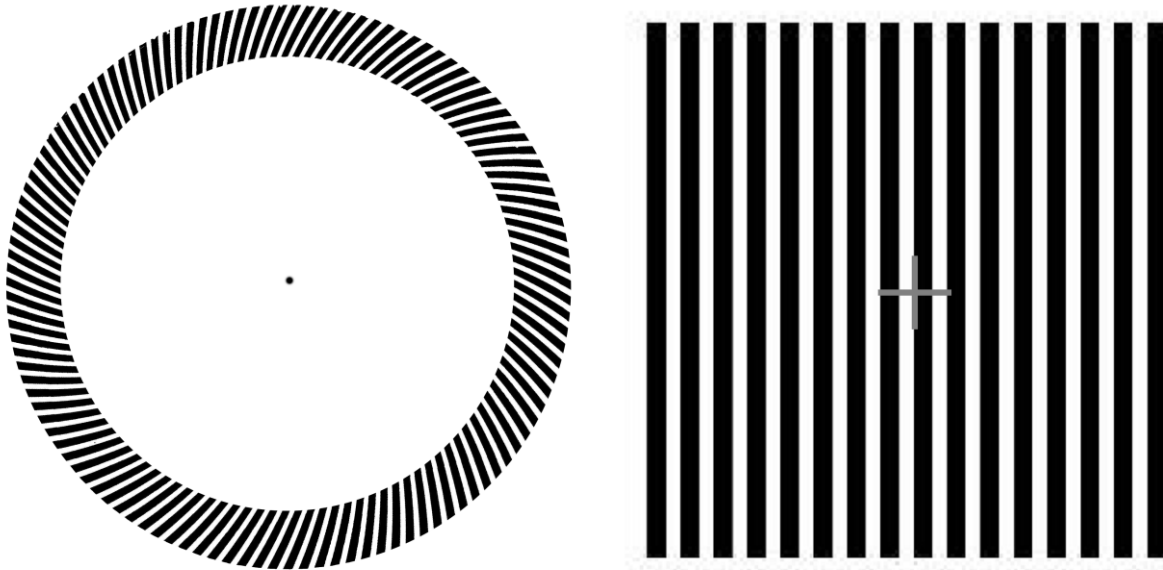


Figure 1. *Left:* RTLTI: when one approaches the pattern, the radial lines appear to rotate counter-clockwise, whereas when one recedes from it, they appear to rotate clockwise. *Right:* the AG illusion: when one approaches the pattern, two illusory effects are perceived: (i) an expansion only perpendicular to the stripes and (ii) a curvature of the stripes.

The AG phenomenon consists in a square-wave grating (Figure 1 right) and exhibits two distinct illusory effects. Approaching this pattern it appears (i) to expand only perpendicularly to the stripes while (ii) the rigidity of the stripes is lost and a curvature is experienced. Also the origin of this illusory effect seems to rely on the aperture problem and on the competition between motion signals originating from two different motion-processing units in V1 (Gori, Giora, Yazdanbakhsh, & Mingolla, under review), but the illusory effect is weaker than with the RTLTI. Both illusions occur in presence of a fast radial expansion/contraction motion (high temporal frequency) and they break down with isoluminant colors. Motion, high temporal frequency and luminance difference are all characteristics that are processed specifically by the M-D pathway (Boden & Giaschi, 2007) and made them an appropriate candidate to be used in testing if this visual stream presents some deficits.

Experiment 1. In this experiment we tested dyslexic and normally reader children, in two tasks for the RTLTI: a detection task and a illusory effect task.

Method

Subjects. Two groups of naive subjects matched for chronological age (age range = 9-13 years) participated in the study. The dyslexic group was composed by 7 children with specific reading disability whereas 9 normally reading children composed the control group. All children had normal IQ and normal or corrected-to-normal visual acuity.

Stimuli. Eleven Michelson contrast values (with a 1% step between each other), ranging from 0 to 10% between the RTLTI and the background, were used. A 98% contrast and a equiluminant colored version of the RTLTI were used too. These stimuli contracted and expanded continuously on the screen varying in diameter size in the range of 12.7 deg to 14.6 deg with a speed of 5.33 mm/s.

Procedure. Before the experiment, the subject familiarized with the 98% contrast RTLTI watching that pattern contracting and expanding on the screen and with the isoluminant colored version. All subjects reported to see rotation motion in the high contrast RTLTI and no rotation but only expansion in the isoluminant RTLTI. Two different tasks were asked to the subjects using the same

stimuli: a detection task and an illusory effect task. *Detection task*: in each trial the subjects were exposed to one of the 10 movies differing in contrast. The subject task was a Yes/No task: he/she had to say if the circle of lines was present or not. The subjects viewed the stimuli binocularly without time constraints. Each movie was presented 5 times in random order. The aim was to obtain a contrast detection threshold in the same condition of the illusory effect task. *Illusory effect task*: in each trial the subjects were exposed to one of the 10 movies differing in contrast. The subject task was a Yes/No task: he/she had to say if rotation was perceived or not. The subjects viewed the stimuli binocularly without time constraints. Each movie was presented 5 times, in random order.

Results and discussion

All subjects, regardless the group, reached the 100% of detection for the RTLI stimulus at 1% of contrast showing how the contrast detection in this specific condition was not different between dyslexics and controls. The cumulative curves for the illusory effect task in the two groups (Dyslexics and Controls) were fitted by a logistic function. The upper bound was set to 1 and the lower bound to $y_0 = 0$, where $y = 0$ means that the rotation was never perceived, and $y = 1$ that it was always perceived. Thus, the only free parameters of the function are b (the function slope) and t (the threshold). The resulting logistic function is:

$$(1) \quad y = \frac{1}{1 + e^{-b(x-t)}}$$

In this equation, x represents the percentage of size increment of the control stimulus, y the relative response frequency and e the Euler's number.

In Figure 2, relative response frequency is plotted as a function of the contrast increment. The left curve (black) is the fitted function for the controls and the right curve (dashed gray) the fitted function for the dyslexics. The 50% threshold for the controls corresponds to a contrast of 1.48%, whereas the threshold for dyslexics equals 3.58%. The resulting ratio is 2.42.

The dyslexics needed more contrast to perceive the illusion even if the contrast detection threshold did not differ in the two groups. It strongly suggests an M-D deficit in the dyslexics that require more information (luminance difference) to process the illusory rotation. This results cannot be attributed to a deficit in the perceptual noise exclusion deficit in dyslexics (Sperling et al., 2006) because no noise at all was present in the stimulation. The difference between the two groups thresholds (based on the group mean of the individual thresholds identified by fitting the individual data with the same logistic functions) was statistically significant ($t_{(14)} = -2.828$, $p = .011$ for independent samples t-test) as shown in Figure 3

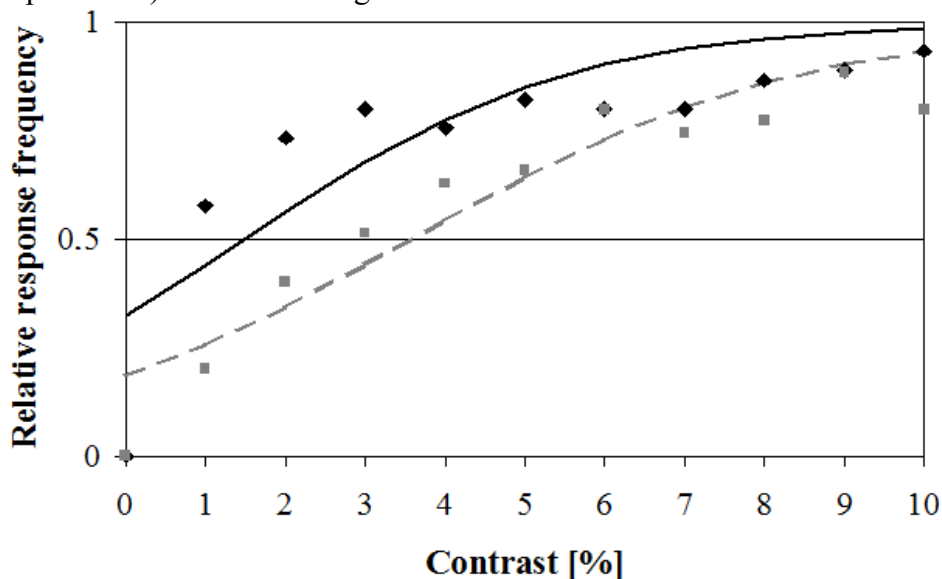


Figure 2. Results for Exp. 1. Relative response frequency for rotation in the control group (diamonds) and in the dyslexics group (squares) is plotted as a function of the contrast between the RTLI and the background. Data were fitted with a logistic function.

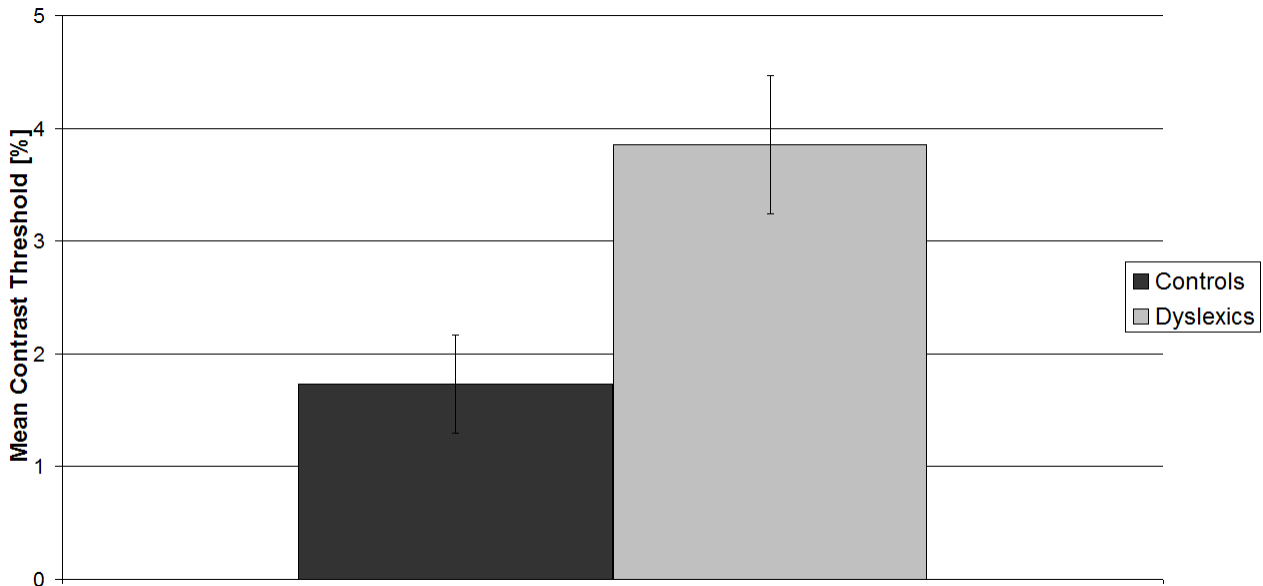


Figure 3. Difference in mean contrast thresholds between controls (black) and dyslexics (gray) for the rotation perception. Error bars indicate standard errors.

Experiment 2. In this experiment, we tested the same dyslexic and normally reading participants of the previous experiment, in two tasks for the AG illusion: a detection task and an illusory effect task. The interest of this experiment is not only to replicate the previous results but, because of the wicker illusory effect for this illusion, it provides an internal control to assure that the subjects responded for the illusory effect and not for the visibility of the patterns itself: if the subjects really do the task for the illusory effect we would expect different (i.e., higher) contrast thresholds in comparison to what was obtained with the RTLI, but a comparable difference between the two groups.

Method

Subjects. The same subjects as in Expt. 1 participated in this study.

Stimuli. Ten Michelson's contrast values (0, 2, 5, 10, 15, 20, 25, 30, 35, 40%) between the AG illusion and the background were used. A 98% contrast and a equiluminant colored version of the AG were used too. All these stimuli contracted and expanded continuously on the screen varying in size in the range of 10.1 x 10.1 deg to 13.3 x 13.3 deg with a speed of 5.33 mm/s.

Procedure. The procedure was the same used in Expt. 1.

Results and discussion

All subjects, regardless the group, reached the 100% of detection for the AG stimulus at 2% of contrast, showing how the contrast detection in this specific condition was not different between dyslexics and controls. The cumulative curves for the illusory effect task in the two groups (Dyslexics and Controls) were fitted by a the same logistic function employed in Expt. 1.

In Figure 4, relative response frequency is plotted as a function of the contrast increment. The left curve (black) is the fitted function for the controls and the right curve (dashed gray) the fitted function for the dyslexics. The 50% threshold for the controls corresponds to a contrast of 5.98%, whereas the threshold for dyslexics equals 11.03%. The resulting ratio is 1.84.

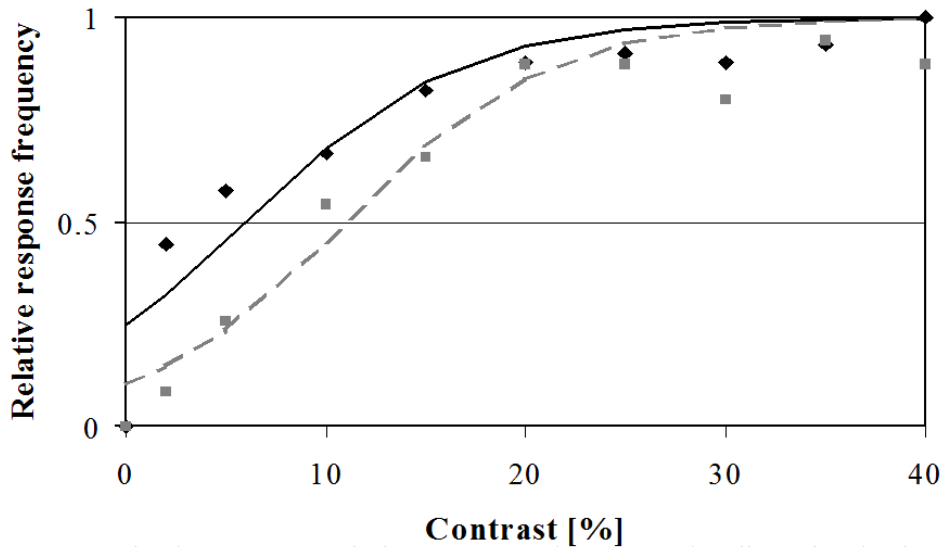


Figure 4. Results for Exp. 2. Relative response frequency for distortion in the control group (diamonds) and in the dyslexics group (squares) is plotted as a function of the contrast between the AG and the background. Data were fitted with a logistic function.

The difference between the two groups thresholds (based on the group mean of the individual thresholds identified by fitting the individual data with the same logistic functions) is statistically significant ($t_{(14)} = -2.375, p = .032$ – for independent samples t-test), as shown in Figure 5.

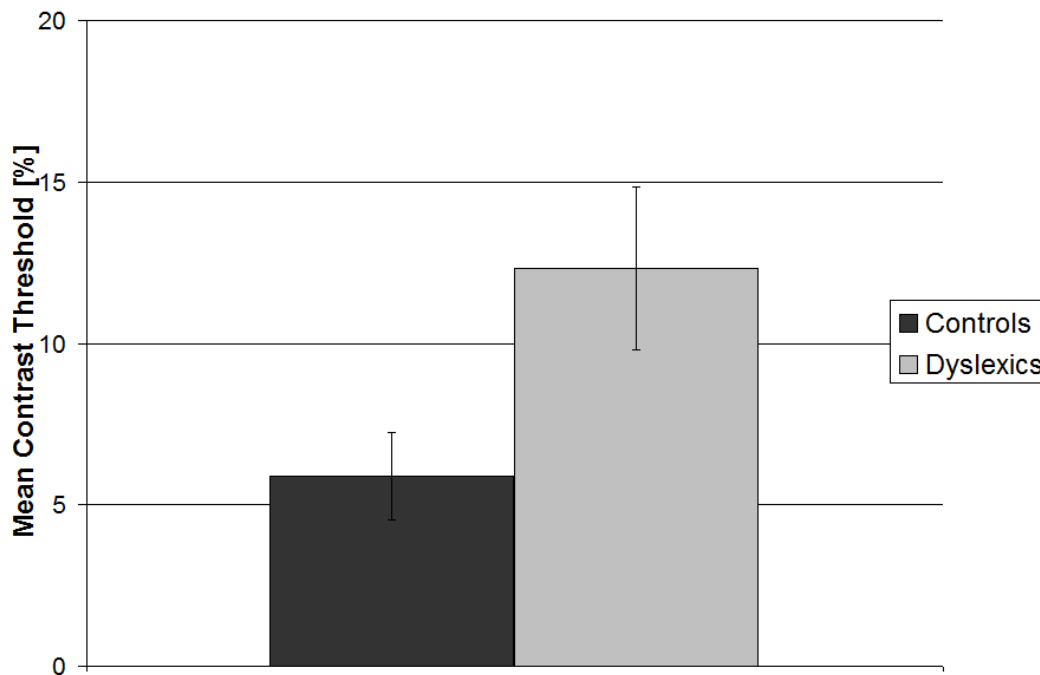


Figure 5. Difference in mean contrast thresholds between controls (black) and dyslexics (gray) for the rotation perception. Error bars indicate standard errors.

The dyslexics needed more contrast to perceive the illusion although the contrast detection threshold did not differ between the two groups. These data suggest an M-D deficit in the dyslexics that requires more information (luminance difference) to process the illusory deformation. Also these results cannot be attributed to a deficit in the perceptual noise exclusion deficit (Sperling et al., 2006) in dyslexics because no noise at all was present in the stimulation. Finally the difference in thresholds between Expts. 1 and 2 were coherent with the different strength of the two motion illusions and confirms that the subjects did the task based on the illusory effect and not on the visibility of the pattern.

Conclusions

This study shows the employment of visual illusions for investigating a specific clinical population. Our results provide evidence in support to the M-D deficit hypothesis in dyslexia without involving any signal-from-noise extraction paradigm.

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