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Detecting Visuoperceptive Defects in Adult Disabled Readers with the TETRA Analyzer™. Normative Data and Test-retest Reliability

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Authors' contributions

This work was carried out in collaboration between all authors. Author CA designed the study, performed the statistical analysis, wrote the protocol and wrote the final draft of the manuscript. Author MB managed the literature searches, wrote the first draft of the manuscript and collected the data. Author LC managed the recruitment of the patients. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To collect normative data in adult readers with the TETRA Analyzer™, a tool developed to detect the visuoperceptive alterations supposedly involved in dyslexia.
Study Design: Epidemiological study.
Place and Duration of Study: Service of Neuro-Ophthalmology, University of Turin, Italy, between June 2015 and March 2016.
Methodology: We enrolled 95 normal adolescent and adult readers (34 males, 61 females; age 12-26 years), with BCVA 60/60 and satisfying academic achievement. In the recruited subjects three visuoperceptive functions believed to play a major role in reading have been examined with the TETRA Analyzer™. The instrument is made up of three exams suitable to evaluate ocular dominance (Domitest-M), spatial relationship perception (Eidomorphometry), and interocular sensory pattern (Domitest-S). In case one or more of these functions were found abnormal, a fourth exam (REPORT) checks their effective involvement in the reading disability. In addition, retest reliability has been estimated.

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Results: The prevalence of strong, stable dominance in the sample was 86.3%; the remaining 13.7% showed dominance instability to a variable degree. Mean spatial relationship anisotropy was 1.32% (±2.5%). The binocular sensory pattern was overall balanced: in fact, almost one third (30.8%) of the sample did not show asymmetry of the visual input. The distribution of the interocular inhibition was weak, with median interocular inhibition index (an index of interocular suppression ranging from 0 to 2) = 0.10 (IQR: 0.3). Reading rate was insensitive to interletter spacing (words: R^2=0.12, p=.29; non words: R^2=0.01, *P*=.72). Reliability was overall satisfying in all the exams.

Conclusion: Considering the role impaired visuoperceptive functions can have not only in children but even in adult dyslexics, the collection of normative data, so far only available for school age pupils, has been extended to adolescents and adults, with the aim to allow future investigations in this type of patients.

Keywords: Adults; spatial relationship perception; crowding; dyslexia; interocular inhibition; ocular dominance; TETRA Analyzer™.

1. INTRODUCTION

Developmental dyslexia is a specific reading disability that affects subjects with adequate instruction and education, normal intellective capacities and socio-cultural situation and normal visual acuity, in absence of psychiatric pathologies [1]. Even if basically it is a phonological and neuropsychiatric condition, over the last three decades mounting evidence suggests that an impairment of the visual system may play a causal role as well. Even if the nature of this deficiency is not clear, it has been theorized to involve both the visuomotor and sensory domain. In particular, a strand of research supports that fixation instability due to unstable ocular dominance may have a causal role in the so-called "visual dyslexics", accounting for delayed reading rate, frequent omissions of letters and positional changes of syllables [2-8]. Indeed, the dyslexic patients considered in the aforementioned studies were children; to date, so far as we know, the stability of ocular dominance in adult dyslexics has not been measured. To achieve this goal, normative estimates of dominance stability in adult readers need to be collected.

In addition to unstable ocular dominance, a subgroup of disabled readers suffers from a reinforcement of crowding, so that the enhanced reciprocal interference occurring between adjoining letters hampers the readability of the text [9-17].

As we have suggested, reinforced crowding depends on increased spatial relationship anisotropy, that leads to a perceptual contraction of the visual space along the horizontal axis [16,17]: it follows that in visual dyslexics reading rate is expected to improve by widening the space between the letters, while non-visual dyslexics (as well as normal readers) would be insensitive to this perceptive modification. Evidence to this hypothesis, indeed, has been recently provided [16-18]. In a previous study we showed that spatial relationship perception of school-age disabled readers (3^{rd}-5^{th} grade) is abnormal, with SRP-related anisotropy (SRA) almost double compared to normal age-matched subjects. Moreover, as expected, positive correlation between interletetter spacing and reading rate is found significant in the dyslexic sample, but not in controls [16]. Whether abnormal SRA depends on retarded maturation or on a primitive impairment of the function is an issue worth to be studied. In this respect, spatial relationship perception in adolescent and adult dyslexics should be investigated, comparing their level of anisotropy with that of age-matched normal readers. To do this, evidently, normative data are needed.

Finally, the alteration of the binocular sensory input, namely abnormal inhibitory interaction, could be an additional factor that affects the reading function in dyslexics: in fact, inhibitory binocular interaction is the basis of those selection processes involved in image segmentation and grouping [19]. Moreover, the reciprocal interocular inhibitory effect documented during dichoptic rapid serial visual presentation paradigms (RSVP) can be regarded under a visuoattentive perspective, and could therefore play a role in determining the reading disability. As a matter of fact, the occurrence of "attentional blinks" when subjects perform multiple-task RSVPs has been documented [20-23]. In a previous investigation we suggested that (based on a similar mechanism) the

suppressive effect of the target presented to one eye affects to a variable degree the next stimulus presented to the fellow eye. This might have a relevance when dealing with sequential scanning of reading strings, since it could lead to reduced reading rate and errors for defective positional encoding [24]. In a previous study we found that the distribution of the interocular inhibition in normal children (we have referred to as "immature readers") is bimodal, with a cluster of observations of strong interocular inhibition and a second cluster showing weak interocular inhibitory interference [24]. It is worthwhile to investigate whether the distribution of the interocular inhibitory pattern in the "mature readers" (i.e. adults) lacks the strong inhibitory cluster and, if it were the case, if it persists in adult dyslexics.

In order to detect unstable ocular dominance, significant SRA, abnormal interocular inhibitory pattern, and the effect of these variables on the reading performance, a diagnostic tool has been developed, the TETRA Analyzer™. The TETRA Analyzer™ is a set of four exams, we have called:

- Domitest-M: to quantify and characterize the stability of ocular dominance (ocular motor dominance).
- Eidomorphometry: to estimate SRA.
- Domitest-S: to evaluate the interocular inhibitory pattern in terms both of overall strength and degree of right/left input asymmetry (ocular sensory dominance).
- Reading Performance Test (REPORT), that checks whether positive correlation exists between interletter spacing and reading rate in case one or more of the visuoperceptive functions supposedly affecting reading were found abnormal: evidently, positive correlation is a marker of visual dyslexia.

In previous investigations [17,24,25] normative data for the exams that make up the TETRA have been collected for scholars aged 8-10 (3^{rd}-5^{th} grade). Compared to normal readers, a subpopulation of school age disabled readers has been found to suffer from increased spatial relationship-related anisotropy, showing a positive correlation between reading rate and interletter spacing [16]. In addition, a consistent proportion of the dyslexic population had increased interocular inhibition (Aleci et al., submitted).

The present report extends the normative data in subjects from 11 years till the adult age (26 years old).

2. MATERIALS AND METHODS

2.1 The TETRA Analyzer

The exams making up the TETRA analyzer have been described in detail in our previous works [16,17,24,25]. Here only a brief summary is provided.

2.1.1 Domitest M

The Domitest M is a modified version of the pinhole test [26]. The observer is asked to look binocularly at a target displayed on a background through a hole in a cardboard placed in from of his/her face. The target is flanked at each side by a graduated scale (Fig. 1, upper panel). Occluding alternatively one or the other eye:

a) The observer continues to perceive the target: the open eye is the dominant one.
b) The target disappears and the observer perceives a number on the graduated scale: the open eye is the dominated one. The degree of dominance lateralization is expressed by the angular value the observers report when their dominant eye is occluded. By repeating the procedure 5 times and considering the number of univocal responses (5 left, 0 right; 4 left, 1 right, 3 left, 2 right or vice versa), dominance stability can be graded as stable, partly stable, and unstable (Fig. 1, lower panels).

2.1.2 Eidomorphometry

The Eidomorphometry [16,17,25] is a psychophysical test developed to measure spatial relationship perception (SRP). SRP is defined as the function able to detect the difference in the extent of a bidimensional shape along the x/y cardinal coordinates [25]. The test makes use of a staircase psychophysical algorithm to estimate the discrimination threshold between circles and ellipses horizontally- or vertically-oriented (Fig. 2, left panel). The threshold is expressed as Interaxis Ratio (IR), that is the difference in percentage between the focal axis and the perpendicular axis (See Aleci et al. [25] for details).

If the recognition threshold is the same irrespective of the orientation of the ellipse, spatial relationship perception in isotropic. Otherwise, the visual system of the observer is affected by SRA, whose severity is computed as the difference between the discrimination threshold of horizontal and vertical ellipses (Horizontal Threshold, HT and Vertical Threshold, VT, respectively): the higher this difference, the higher the SRA (Fig. 2, right panel). Since, according to our hypothesis, abnormal SRA would lead to an illusory contraction of the horizontal extent of the visual space, perceptually reduced interletter spacing, thereby increased crowding between adjoining letters would make reading more demanding.

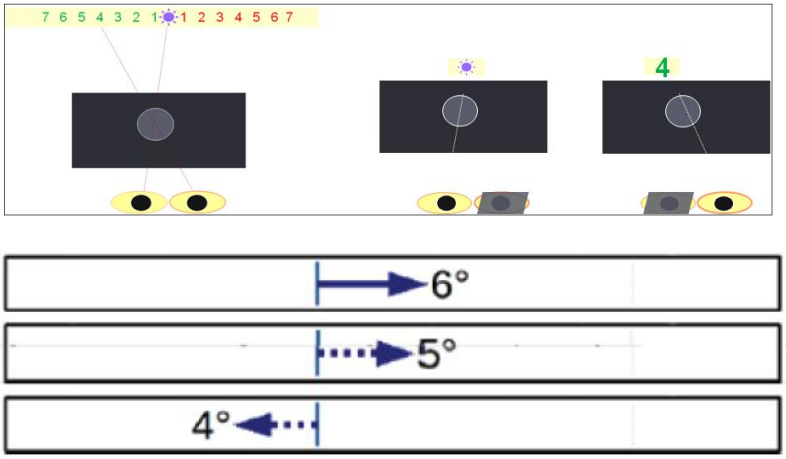

Fig. 1. Domitest M. Upper panel: Example of left dominance, lateralization 4 degrees. Lower panels: examples of graphical representations. Top: stable and well lateralized right ocular dominance; middle: unstable right ocular dominance; bottom: even more unstable left ocular dominance

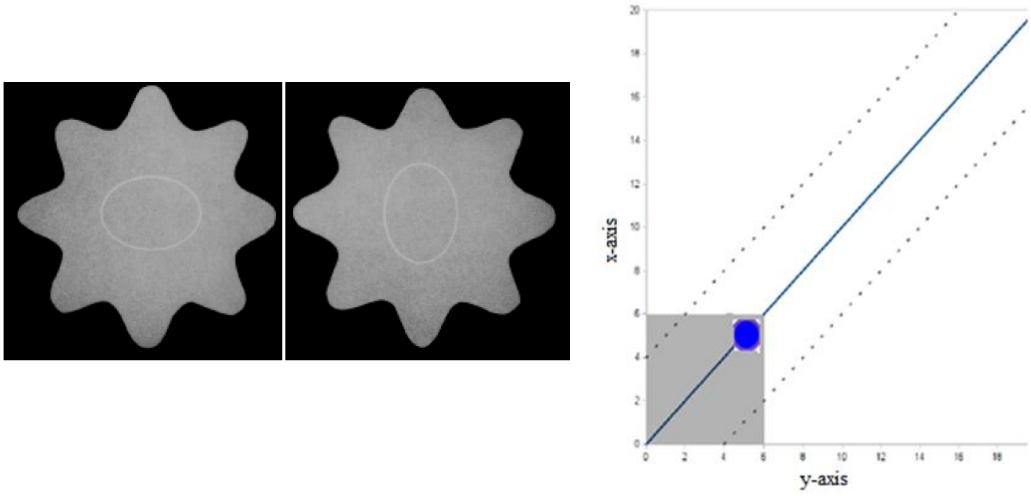

Fig. 2. Left: Example of the elliptical targets as displayed to the subject.* Right: Graphical representation of the SRP patter in a normal subject. Grey area: Normality range. Dotted line: Normal limit of anisotropy in the normal pediatric population

**From Aleci et al. [25]*

2.1.3 Domitest S

The Domitest S [24] is based on the paradigm called *rapid serial visual presentation (RSVP)* [21]. In the RSVP a sequence of different stimuli is displayed tachistoscopically in the same position. In the domitest S two streams of stimuli are presented dichoptically: within each sequence the null stimuli are checkerboard-like patterns, whereas the target is a checkerboard pattern whose matrices are arranged so as to form a "X". The observer is asked time after time to report the target embedded in the left or right stream, and the interocular inhibitory pattern is assessed based on the proportion of left/right correct responses as well as on the overall correct responses.

The Imbalance Value (IBV, ranging from -1 to +1) quantifies the asymmetry between the left/right input based on the proportion of correct responses.

In turn, the Inhibitory Interocular Index (III, ranging from 0 to 2) quantifies the reciprocal inhibition of the two eyes (Fig. 3).

2.1.4 Reading performance test (REPORT)

Finally, the Reading Performance Test [REPORT] checks the effect of the three variables on reading. Words and non-words samples are randomly presented at different values of interletter spacing (from 0.2 to 0.51 deg at a reading distance of 40 cm) and the reading rate as well as the number of errors is computed. The REPORT computes the correlation coefficient r between reading rate and interletter spacing.

In summary, the parameters considered as potential markers of visuoperceptive impairment during reading, thereby of "visual dyslexia", are reported in Table 1.

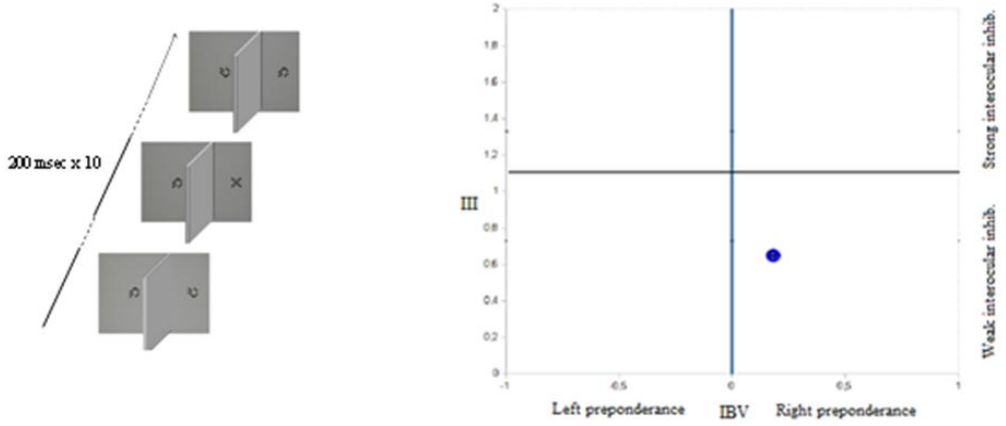

Fig. 3. Left: the last three presentations of a stream of stimuli in the dichoptic RSVP technique used in the experiment. Right: graphical representation of a case of overall balanced sensory input, with low interocular inhibition (normal subject)

See text for explanation. Left panel from Aleci et al. [24]

Table 1. The parameters considered as potential markers of visuoperceptive impairment during reading. See text for explanation

Visuoperceptive function	Related test	Marker
Spatial Relationship Percept.	Eidomorphometry™	-Abnormal Spat. Relationship Anisotropy [SRA]
Ocular Dominance	Domitest-M™	-Unstable dominance -Abnormal dominance lateralization
Binocular Sensory Input	Domitest-S™	-Abnormal Imbalance Value [BV] -Increased Interocular Inhibitory Index [III]
Presumed involvement of the three variables in the lexical task	REPORT™	-Positive correlation between reading rate and interletter spacing ($p<.05$)

2.2 Participants

Ninety-five normal subjects (34 males, 61 females) have been recruited from the Department of Ophthalmology, University of Turin. Median age was 19 years (range 12-26 years, IQR: 8 years).The recruited subjects were in good health, not affected by ophthalmological or systemic diseases. The learning performance of all the subjects was satisfying. In all cases BCVA was 60/60 and spherical refraction ranged from -4 to +4 diopters with astigmatism defect, when present, lower than 2 diopters. In order to rule out potential learning effect, each exam has been repeated (time interval: 15 minutes) and normative data have been collected from the results recorded after the second administration. In addition, comparison between the two examinations has been performed to estimate the test-retest reliability.

Before carrying out the descriptive statistical analysis, each series of data has been tested with the Generalized Extreme Studentized Deviate (ESD) test [27] for outliers detection.

3. RESULTS AND DISCUSSION

3.1 Ocular Dominance

In the adult sample the proportion of right motor dominants is slightly higher compared to the left, being respectively 51.5% and 44.2%. The remaining 4.2% of subjects did not show any dominance laterality. The prevalence of strong, stable dominance in the sample was 86.3%; the remaining 13.7% showed dominance instability to a variable degree.

Descriptive statistics referred to the median value of dominance in the left and right dominant subjects is reported in Table 2.

The frequency distribution of the value of dominance in the adult population departed from normality (KS=0.17, P<.001: Fig. 4, left panel). The nonparametric distribution is even more evident when considering the value of dominance as an absolute value KS: 0.20, P<.001: Fig. 4, right panel). The median absolute value of dominance is 6.00 (IQR: 3). The variability of this parameter in the sample is evidenced by the wide span of values (from -16 to 10).

3.2 Spatial Relationship Perception

Of the 95 examinations, 6 (6.3%) have been identified as outliers and removed. Mean spatial relationship anisotropy is 1.32 (±2.5). Considering the individual cases, no anisotropy higher than 5% has been estimated in the sample (apart in one case that was 7%). This means that in average the difference between the discrimination threshold along the x, y coordinate in the adult normal population is little more than 1%, that is to say it is negligible. To be noted that a consistent proportion of the sample shows opposite anisotropic orientation, as indicated by the negative value: this means these subjects reveal a perceptual "stretching" (rather than a perceptual "shrinking") of the visual space along the x-axis (Fig. 5). No correlation is found between spatial relationship anisotropy and age in the observed adult sample (R^2=0.00095, P=.77).

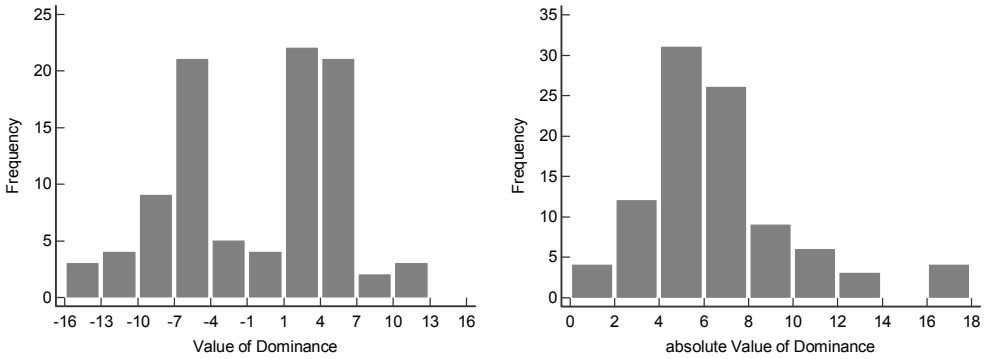

Fig. 4. Frequency distribution of dominance lateralization (value of dominance) in the adult population

In the left panel negative values refer to left dominance, positive values express right dominance

Table 2. Motor dominance in the normal population

	Proportion	Median	IQR	Mean	SD
RIGHT dominants	51.5%	5	2	5.38	±2.67
LEFT dominants	44.2%	-6.50	-3	-7.28	±3.44

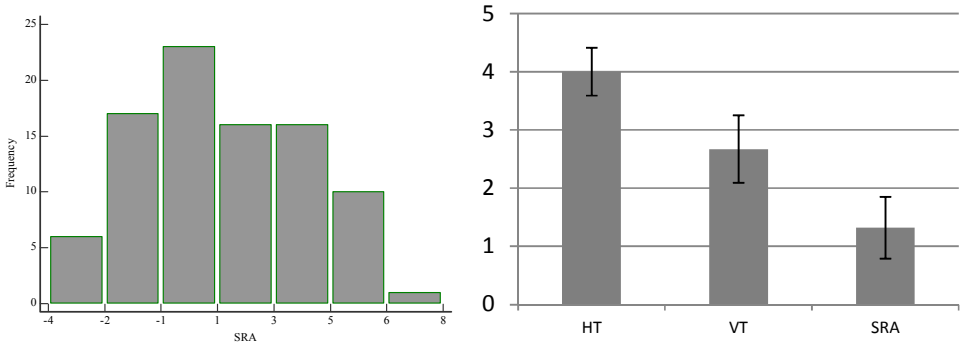

Fig. 5. Left: frequency distribution of SRA in the adult population. Right: discrimination threshold along the x-axis (horizontal threshold, HT), along the y-axis (Vertical threshold, VT), and relative difference (SRA)

Threshold and SRA are expressed as Interaxis Ratio (IR%). Bars refer to the confidence interval (CI 95%)

3.3 Binocular Sensory Interaction

In the adult population the binocular sensory pattern is overall balanced. In fact, almost one third (30.8%) of the sample did not show asymmetry of the visual input, and in the remaining proportion of subjects it is negligible, with most of the cases showing IBV less or equal than 0.2.

Summary descriptive statistics referred to the IBV in the left and right dominant subjects is reported in the table below (Table 3).

Table 3. Summary statistics of the Imbalance Value in the adult normal population

	Proportion	IBV Median	IQR
R asymm	37.2%	0.10	0.10
L asymm	31.9%	-0.10	0.10
No asymm	30.8%		

Like ocular dominance, also the frequency distribution of the IBV in the adult population departed from normality (KS=0.23, *P*<.001). Nonparametric distribution of the asymmetry of the binocular input in the normal adult population is even more evident when considering the IBV as an absolute value (KS=0.34, *P*<.001: Fig. 6, right panel). The median absolute IBV is 0.10 (IQR: 0.0-0.10). Compared to the value of motor dominance, the variability of BV is lower, with almost 90% (89.4%) of the observations falling between -0.2 and +0.2 (Fig. 6, upper panels).

The distribution of the Interocular Inhibition Index in the adult population is positively skewed, with median III= 0.10 (IQR: 0.3). Interestingly, despite in the overall sample the interocular inhibitory effect does not correlate with age (R^2= 0.0005, *P*=.82) it is found to decrease in the subgroup of subjects aged 12-14 years (R^2= 0.158, *P*=.04, Fig. 6, lower panels).

3.4 Reading Performance

Mean reading rate was higher for words compared to non-words (6.36 syl/sec [±0.75] vs 4.08 syl/sec [± 076], Fig. 7, upper panels).

No correlation was found between age and reading rate for words (R^2= 0.00001, *P*= .97). In turn, the coefficient of determination was significant when non-words were administered (R^2= 0.13, *P*= .0002. Fig. 7, middle panels). A further analysis of the linear model for different age cutoffs reveals that cumulative reading rate increases with age till 14 years (R^2 = 0.40, *P*= .0007), while in the older sample the relationship is lost (R^2 = 0.03, *P*= .13: Fig. 7, lower panels).

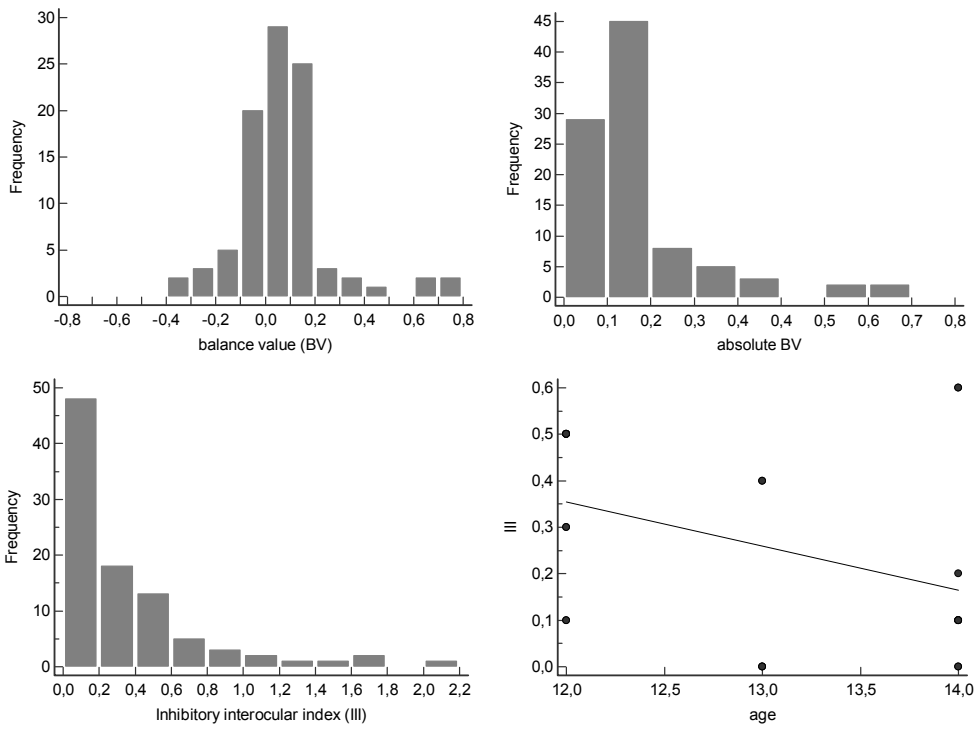

Fig. 6. Upper panels: asymmetry of the binocular sensory input. Lower panels: the Interocular Inhibitory Index

Upper left: frequency distribution of IBV in the adult population. Negative values refer to left dominants; upper *right: absolute values.*
Lower left: frequency distribution of III; lower right: correlation with age in subjects less than 15 years

To confirm what reported in the introduction, in adult normal readers reading rate is insensitive to the interletter spacing when both words and non-words are administered (words: R^2=0.12, *P*=.29; non words: R^2=0.01, *P*=.72).

As a matter of fact, correlation between interletter spacing and reading rate was found just in 4.2% (words) and in 5.2% of cases (non words).

Even if no overall correlation has been found between lexical performance and interletter intervals, it is presumable that a significant local difference along the spectrum of spacing may be indicative of the extent of the critical spacing during reading [17]. At words, repeated measures analysis of variance showed statistical difference between reading rate at 0.2, 0.27 and 0.36 deg, that is lower, and reading rate at 0.4 deg, that is higher (F=2.76, *P*=.005, Tukey-Kramer [$q_{4.55}$]: 6.77, *P*<.001, 4.69, *P*=.05, and 4.68, *P*=.05 respectively). We therefore hypothesize that the limit of crowding in normal adult readers during the lexical task is 0.36 deg.

3.5 Test-retest Reliability

As a novel procedure, reliability of the estimations provided by the four exams making up the TETRA analyzer needs to be verified. To assess test-retest reliability, during the same session each subject has been retested 15 minute after the first examination.

3.5.1 Domitest M

The L/R dominance of all but two subjects (one right, the other left dominants) has been confirmed at the re-test.

All fully stable and unstable cases have been confirmed at the re-test, while the majority of subjects (64%) who were classified as partly stable at the first examination have been confirmed after being re-examined.

Finally, the correlation between the values of dominance obtained at the first and second examination was significant (r=0.56, *P*< .001).

3.5.2 Eidomorphometry

The main issue to be considered when evaluating test-retest reliability of the Eidomorphometry is that the estimate of spatial relationship perception is affected by consistent learning effect. In fact, in the adult normative sample both the discrimination threshold along the x- and y-axis were lower at the retest (median x-threshold at the first examination vs second examination: 5.0 vs 4.0, Wilcoxon: *P*=.001; median y-threshold at the first examination vs second examination: 4.0 vs 2.0, Wilcoxon: *P*< .001). However, the proportional reduction of the x-, y- thresholds does not lead to significant variation of the measured anisotropy (*P*= .96).

In summary, in order to improve the reliability of the estimate of the spatial relationship perception the subject should be get accustomed to the task, therefore two trials should be carried out, and the first examination should be discarded.

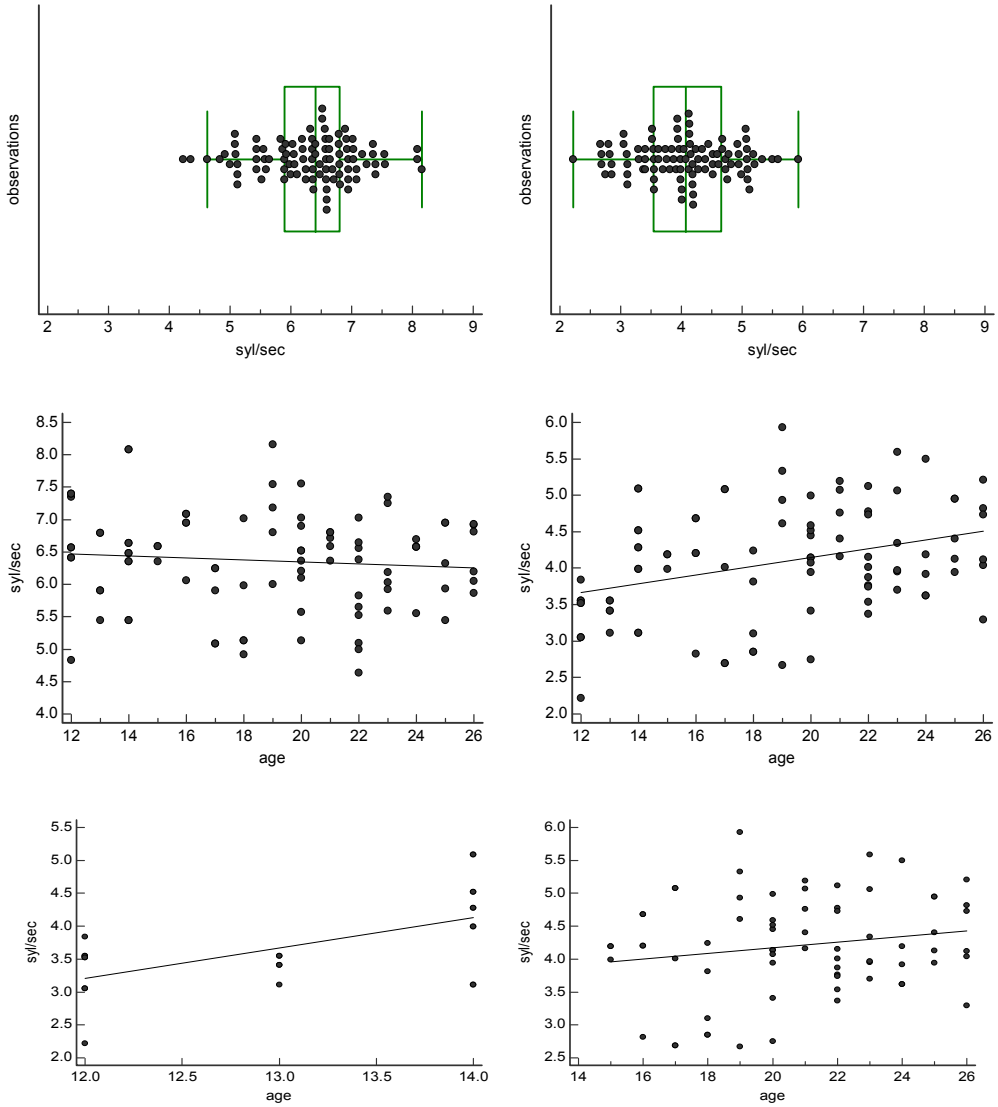

Fig. 7. Top: Distribution of the reading rate. Middle: Reading rate as a function of age in the whole adult population. Left: Words; right: Non words. Bottom: Reading rate of non-words as a function of age in subjects aged 12-14 years (left), and >14 years (right)

3.5.3 Domitest S

After defining as "sensorially balanced" those cases who showed IBV ≤ ±0.2, 97.5% of the sensorially balanced subjects and 67% of the remaining (unbalanced) observations have been confirmed at the re-test. The correlation between the IBV measured at the first and second examination was significant (r=0.64, *P*< .001).

Left/right binocular sensory asymmetry has been confirmed at the second examination just in 49% and 42% of the observations, respectively. Considering that the majority of the subjects (87.3%) in the recruited sample were sensorially balanced, this result, indeed, is not unexpected. In fact, as hypothesized in a previous investigation performed on children [24], subjects with the lowest IBVs are those whose sensorial input is less lateralized, therefore less stable: it is therefore predictable that their prevalent input tends to switch from left to right when performing the task in different sessions, making the inter-test results variable. In support of this explanation, the concordance correlation coefficient computed on the sensorially asymmetric observations (i.e. after the sensorially balanced cases have been ruled out) is 0. 80 (precision: 0.86, accuracy: 0.92).

Fig. 8 shows the agreement between the Interocular Inhibitory Index measured at the first and at the second examination. The concordance of the results at retest is overall satisfying (intraclass correlation coefficient= 0.81, *P*<.001).

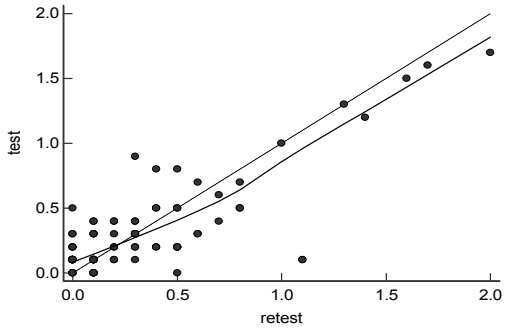

Fig. 8. Interocular Inhibitory Index (III). Test-retest reliability

3.5.4 REPORT

A mild, albeit statistically significant increase of reading rate for both words and non-words at the second examination suggests the presence of a learning effect referred to the lexical performance (mean reading rate difference at words: 0.43 syl/sec, t-test: *P*<.005; mean reading rate difference at non-words: 0.28 syl/sec, t-test: *P*<.01). At non-words the learning effect seems stronger in the faster readers. In both experimental conditions the intra-subject concordance in reading rate between first and second examination is satisfying (words: precision: 0.80, accuracy: 0.93; non-words: precision=0.86, accuracy: 0.91: Fig. 9).

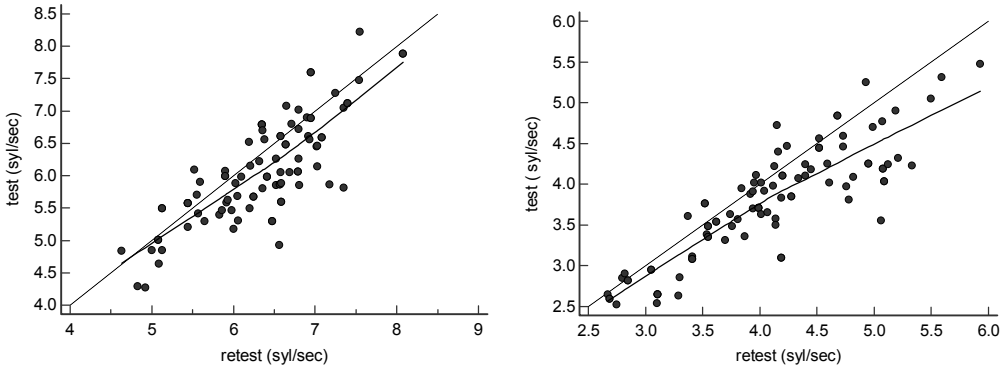

Fig. 9. Concordance of reading rate between the first and second examination. Left: Words, right: Non-words. To be noted the mild learning effect as indicated by the trend line set below the line of perfect agreement, and that at non-words the learning effect seems stronger in the faster readers

3.6 Discussion

In dyslexic subjects visuoperceptive signs are commonly found and visuoperceptive symptoms are often reported. Even if they are clinically normal at the orthoptic and opthalmological examination, it has been hypothesized they are affected by subtle visuoperceptual impairments, requiring a specific diagnostic approach for their detection. More specifically, unstable dominance and reinforced crowding has been advanced to have a causal role in the so-called "visual dyslexics". In addition, there is reason to believe that abnormal interocular inhibitory patter is involved to a certain amount as well. On this basis, the TETRA analyzer has been devised, specifically aimed for detecting such alterations, when present. The normative data for children aged 8-11 years old have been reported in previous publications [16,17,24]. In this paper the normative data in adult subjects have been collected, and test-retest reliability of the tests making up the TETRA analyzer have been evaluated.

In the adult group the proportion of right ocular dominants is slightly higher compared to the left dominants. Contrary to this finding, Seijas et al found no difference in right/left proportion of dominance laterality in their sample. However, in their group older subjects (age 36-60) showed a slight preponderance of right dominants, very similar to the proportion found in our survey [28]. In turn, Pointer computed 71% of right dominants, but classified all the subjects as right and left dominants: thereby he did not considered the unstable subjects [29].

The great majority of our sample (95.8%) showed strong, stable dominance. This finding is in line with previous studies: Zeri for example found with the hole-in-the card test (6 trials) 100% of stable dominants in his sample of 40 adult subjects [30]. Sejias, too found no cases of unstable dominance.

Compared to the values computed in a scholar population (mean age 8.4±1.9 years [16]), SRA is lower in the adult sample (mean SRA: 1.32 vs 2.36, one sample t-test: P=.002). This finding suggests that spatial relationship perception along the x,y coordinates tends to be balanced with the development of the visual system. Interesting, like in the normative pediatric sample, also in the adult population spatial relationship perception, as assessed by the discrimination threshold along the x,y-axis provided by the Eidomorphometry, does not correlate with age: this finding confirms that the results of the test is not affected by cognitive or intellective state, both in childhood and in adulthood. However, due to the learning effect, it is strongly recommended to discard the first examination and to be sure the subject to be tested is well accustomed to the task.

In the adult sample the proportion of cases whose binocular sensory input was asymmetric to the right is found to be slightly higher compared to those asymmetric to the left; moreover, almost one third of subjects did not showed binocular input asimmetry. This proportion turns out to be three times higher in the adult population compared to scholar children (30.9% vs 9.15% [24]). Accordingly, the median absolute (i.e. irrespective of the R/L laterality) IBV in adults was lower compared to the pediatric population (0.10 vs 0.20).This finding suggests that like spatial relationship perception, also interocular sensory processing tends to be equalized with the maturation of the visual system.

Interestingly, in children the distribution of the interocular inhibition was found to be bimodal, showing two peaks: one localized at the higher inhibition levels (stronger inter-inhibitory effect), the other localized at the lower inhibition levels (weaker inter-inhibitory effect [24]). This study shows that the bimodal pattern is lost in adults, with the median inhibitory effect that is consistently lower (0.10) than the lower peak of the bimodal distribution of children (Fig. 10).

In sum, compared to children in adults the binocular sensory processing looks to be more balanced and the reciprocal inter-inhibitory effect reduced.

As expected, reading rate is higher in the adult population ("mature readers") compared to what previously reported in a pediatric sample ("immature readers": age 8-10) both at words and non-words. Like in children, also in adults reading rate is insensitive to changes of interletter spacing, suggesting that parafoveal crowding is within the normal limits. The extent of the critical spacing during reading in adult subjects, that is about 0.36 deg, is in overall agreement with the values previously found in children [17].

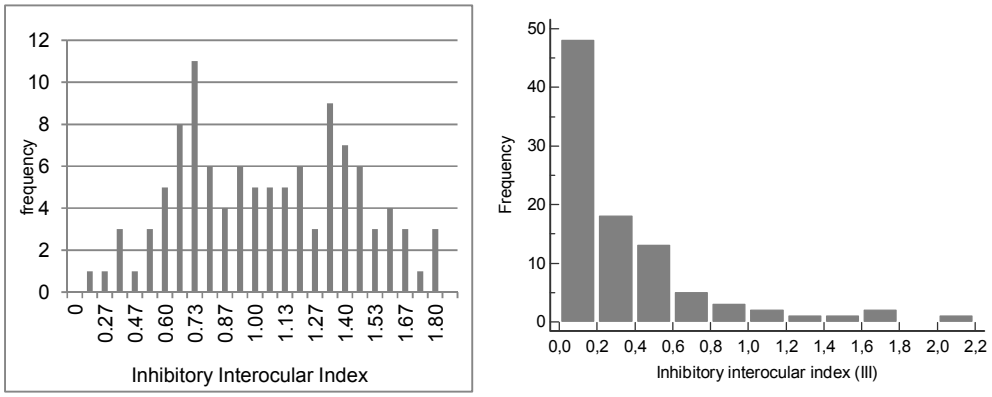

Fig. 10. Inhibitory Interocular Index. Comparison between the bimodal distribution in children*(left) and the skewed distribution in the adult population (right)

**From Aleci et al. [24]*

4. CONCLUSION

It being understood that developmental dyslexia is basically a logopedic and neuropsychiatric condition, the TETRA Analyzer™ proved to be a reliable tool to investigate the visuoperceptive function of disabled readers. Having acquired the normative data, it can now allow to detect and (in case) characterize the visuoperceptive impairment not only in dyslexic children but also in adult subjects.

CONSENT

All authors declare that written informed consent was obtained from the patient (or other approved parties) for publication of this paper.

ETHICAL APPROVAL

This study was approved by the University of Turin as part of a bachelor's thesis (ref n. 771790, registration October, 1st, 2015).

All authors hereby declare that the experiment has been performed in accordance with the ethical standards laid down in the 1964 declaration of Helsinki.

COMPETING INTERESTS

The TETRA Analyzer™ is a trademark registered by author CA who receives paid consultancy for its development. Authors MB and LC have declared that no competing interests exist.

REFERENCES

1. Remschmidt H, Schmidt M, Poustka F. Multiaxiales klassifikationsschema für psychische storungen des kindes-und jugendalters nach ICD-10 der WHO. Bern, SWI: Verlag Hans Huber; 1994.
2. Bigelow ER, McKenzie B. Unstable ocular dominance and reading ability. Perception. 1985;14:329-35.
3. Stein JF, Fowler S. Diagnosis of dyslexia by means of a new indicator of eye dominance. Br J Ophthalmol. 1982;66(5): 332-6.
4. Stein JF, Fowler S. A physiological theory of visual dyslexia. In: Rose editor. Advances in Neurology. Progress in Aphasiology. New York: Raven Press; 1984.
5. Stein JF, Fowler S. Effect of monocular occlusion on visuomotor perception and reading in dyslexic children. Lancet. 1985; 2:69-73.
6. Stein JF, Fowler S. Unstable binocular control in children with specific reading retardation. J Read Res. 1993;16(1):30-45.
7. Stein JF, Riddell PM, Fowler S. Fine binocular control in dyslexic children. Eye. 1987;1(pt3):433-8.
8. Riddell P, Fowler MS, Stein JF. A comparison of sighting dominance and the Dunlop Test reference eye in reading disabled children. Br Orthopt J. 1987;44: 64-9.
9. Bouma H, Legein CHP. Foveal and parafoveal recognition of letters and words by dyslexics and by average readers. Neuropsychologia. 1977;15:69-80.

10. Geiger G, Lettvin JY. Peripheral vision in persons with dyslexia. N Engl J Med. 1987; 316:1238-43.
11. Geiger G, Lettvin JY, Zegarra-Moran O. Task-determined strategies of visual process. Cogn Brain Res. 1992;1:39-52.
12. Atkinson J. Review of human visual development: Crowding and dyslexia. In: Stein editor. Vision and visual dyslexia. London: MacMillian Press, Houndmills; 1991.
13. Atkinson J. Vision in dyslexics: letter recognition acuity, visual crowding, contrast sensitivity, accommodation, convergence and sight reading music. In: Wright and Groner editors. Facets of dyslexia and its remediation, Studies in Visual Information Processing. Amsterdam: Elsevier; 1993.
14. Spinelli D, De Luca M, Judica A, Zoccolotti P. Crowding effects on word identification in developmental dyslexia. Cortex. 2002; 38:179-200.
15. Martelli M, Di Filippo G, Spinelli D, Zoccolotti P. Crowding, reading, and developmental dyslexia. J Vis. 2009;9(4): 14:1-18.
16. Aleci C, Piana G, Piccoli M, Bertolini M. Developmental dyslexia and spatial relationship perception. Cortex. 2012;48: 466-76.
17. Aleci C. Dyslexia: A visual approach. New York: Nova Science Publishers Inc; 2013.
18. Zorzi M, Barbiero C, Facoletti A, Lonciari I, Carrozzi M, Montico M, et al. Extra-large letter spacing improves reading in dyslexia. PNAS. 2012;109(28):11455-9.
19. Blake R, Logothetis NK. Visual competition. Nat Rev Neurosci. 2002;3(1): 13-21.
20. Li J, Lam CS, Yu M, Hess RF, Chan LY, Maehara G, Woo GC, et al. Quantifying sensory eye dominance in the normal visual system: A new technique and insights into variation across traditional tests. Invest Ophthalmol Vis Sci. 2010; 51(12):6875-81.
21. Raymond JE, Shapiro KL, Arnell KM. Temporary suppression of visual processing in a RSVP task: An attentional blink? J Exp Psychol Human. 1992;18(3): 849-60.
22. Broadbent DE, Broadbent MHP. From detection to identification: response to multiple targets in rapid serial visual presentation. Percept Psychophys. 1987; 42(2):105-13.
23. Weichselgartner E, Sperling G. Dynamics of automatic and controlled visual attention. Science. 1987;238(4828):778-80.
24. Aleci C, Cavaglià L, Piana G, Usai T. Domitest-S: A novel dichoptic technique to assess ocular sensory dominance in children. A population study. Br J Med Med Res. 2014;4(6):1371-82.
25. Aleci C, Piana G, Anselmino F. Evaluation of spatial anisotropy by curvature analysis of elliptical targets. Open Ophthal J. 2010; 4:20-6.
26. Berens C, Zerbe J. A new pinhole test and eye-dominance tester. Am J Ophthalmol. 1953;36(71):980-1.
27. Rosner B. Percentage points for a generalized ESD many-outlier procedure. Technometrics. 1983;25:165-172.
28. Seijas O, Gómez de Liaño P, Gómez de Liaño R, Roberts CJ, Piedrahita E, Diaz E. Ocular dominance diagnosis and its influence in monovision. Am J Ophthalmol. 2007;144(2):209–16.
29. Pointer JS. Sighting versus sensory ocular dominance. J Optom. 2012;5(2): 52–5.
30. Zeri F, De Luca M, Spinelli D, Z.P., 2011. Ocular dominance stability and reading skill: A controversial relationship. Optom Vis Sci. 2011;88(11):1353–62.

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