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Time perception in children with developmental dyscalculia

Monica Pellerone*

"Kore" University of Enna, Faculty of Human and Social Science, Via Cittadella Universitaria, Enna, 94100, Italia

Abstract

The present work evaluates time perception in children with dyscalculia (DD) to verify whether DD can interfere with timing tasks. Sample includes: 12 DD subjects (*M*=9.5 years) and 12 healthy subjects (*M*=9.2 years). Two studies are carried out: a time comparison task (to judge whether an interval was longer or shorter than a reference interval) and a time reproduction task. The ANOVA shows the effect of factor GROUP on temporal relationship and errors on temporal comparison. In sub-second duration timing task, DD children are less accurate than healthy children; boys seem to have a lower level of performance than girls.

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Keywords: Learning disability; Dyscalculia; Temporal comparison; Temporal reproduction

* Corresponding author. Tel.: +393294324311
E-mail address: monica.pelleronenikore.it

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1. INTRODUCTION

The quality and quantity of learning in school age requires optimum efficiency of cognitive functions: perception, memory, information processing abilities, and associative capacity, and functions requiring multiple data processing, as for example reading with the comprehension of a text. So, during school period, the cognitive disorder (underestimated or not relevant disorders) can became Learning Specific Disability.

The learning specific disabilities are classified in three subtypes: reading learning (RLD), written learning (WLD) and mathematic learning disability (MLD).

Developmental Dyscalculia (DD) is a congenital and specific learning difficulty of the calculation; it is a primary cognitive disorder of childhood affecting the disability of an otherwise intelligence and healthy child to learn arithmetic (the understanding of numerical concepts and arithmetical information).

A classification of developmental dyscalculia divides this disorder to (Badian, 1983): a) Alexia and agraphia for number; b) Spatial dyscalculia; c) Anarithmetia; d) Attentional sequential dyscalculia; e) Myxed type.

Although poor teaching, environmental deprivation, and lack of intelligence are involved in the etiology of developmental dyscalculia, current data indicate that this learning disability is a brain-based disorder with a familiar-genetic predisposition. Developmental dyscalculia is a common cognitive handicap; its prevalence in the school population is 5-6%, a frequency similar to developmental dyslexia and attention deficit hyperactivity disorder (Barberesi, Katusic, Colligan, Weaver, & Jacobsen, 2005).

Developmental dyscalculia is the most frequently encountered in neurologic disorders (fragile X carriers, epilepsy and Turner's syndrome) and developmental disorders of childhood such as attention deficit hyperactivity disorder and developmental language disorder (Jordan, Hanich, & Kaplan, 2003; Pellerone, Schimmenti, & Collura, 2012; Shalev & Gross-Tsur, 2001). Whereas isolated learning disabilities other than developmental dyscalculia are more common in boys, developmental dyscalculia is more prevalent in girls with epilepsy and in female carriers of fragile X (with a combination of low arithmetic, digit span and block design subtest scores).

Recent literature shows the presence of some measures as indicators of potential Mathematical Disorder in kindergartners, that is (Gersten, Beckmann, Clarke, Foegen, Marsh, Star, & Witzel, 2009): a) magnitude comparison (i.e., knowing which digit in a pair is larger); b) sophistication of counting strategies; c) fluent identification of numbers; d) working memory (as evidenced by reverse digit span).

Among the possible errors in comprehension and production systems there are: a) lexical errors, or errors concerning the production or comprehension of single figures; b) syntactic errors, since child is able to encode the single digits but he cannot establish the relationship between them in a correct syntactical structure.

The development of mathematical competence originates from the activation of the frontal and parietal areas of the brain. The execution of timing tasks for shorter periods than a second shows a cluster of activation in the right inferior parietal lobe (IPL). Many recent imaging studies have revealed the involvement of the frontal cortex, particularly the dorsolateral prefrontal cortex, in the processing of brief (< 1 sec) intervals (Tregellas, Davalos, & Rojas, 2006), and in the right hemispheric prefrontal cortex with sub and supra-second intervals (Koch, Oliveri, Carlesimo, & Caltagirone, 2002). This evidence confirms what electrophysiological investigations have already indicated regarding the role of the frontal lobe in the coding of temporal information.

Recent evidences (Frassinetti, Magnani, & Oliveri, 2009; Vicario, Caltagirone & Oliveri, 2007; Vicario & Martino, 2010) documents the disposition to spatial coding from left to right of the intervals timing respectively from shorter to longer ones in healthy children; from these results we could deduce that a trend toward the left (along the mental number line) is supposed to be responsible for the underestimation of time in children with dyscalculia.

Time, space and numbers are closely linked in the world of the psyche, however, the effects exerted by the space and other variables on the time estimation processes remain poorly investigated.

A recent study (Vicario , Caltagirone, Turriziani, Koch, & Oliveri, 2008) shows that the feedback of the duration of visual stimuli can be influenced by their location (left vs. right) along the space, as well as from information related to the number's magnitude. Several groups of healthy subjects have executed tasks of temporal evaluations about various types of visual stimuli. In the first two experiments, the visual stimuli consisted of decimal numbers, presented at the center of the screen or on the right and left of the space. In a third experiment, visual stimuli were constituted by circles blacks. The duration of the reference stimuli was set at 300 msec: the subjects had to indicate the relative duration of the test stimulus compared with the reference one. The main results showed that the duration of the stimuli presented in the left hemisphere is underestimated, and the duration of the stimuli presented in the right hemisphere is overestimated. On the other hand, in the median position, the feedback of the duration is affected by the number's magnitude of the stimulus presented, with a time underestimation of the test whether its dimension is smaller than the reference stimulus and vice versa an overestimation of the test if the number's magnitude is higher than the reference stimulus.

A further investigation (Oliveri, Caltagirone, Turriziani, *et al.*, 2008) shows a similar trend of results: in a first experiment, a group of healthy subjects was subjected to a time estimate task, requiring to assess whether the duration of the test stimulus was longer or shorter than a previous reference stimulus. The main results show that the perception of time was influenced by the digit's magnitude: for the lower numbers (for example: 1) the underestimation prevails whilst as regards higher decimal numbers (for example, 9) dominates the overestimation of duration. These findings confirm a functional interaction between time and numbers in the cognitive system.

1.2 METHOD

1.2.1 Objectives and research hypothesis

The present work aims to measure the perception of time in children with dyscalculia. The aim of the study has been to examine whether a deficit in calculation ability could influence with a time comparison task and a time reproduction task in sub-second and supra-second intervals.

In accordance with the literature (Vicario *et al.*, 2008) it is assumed that there is no gender difference in sub- and supra second timing tasks.

The group dimension is also assumed (healthy subjects and subjects with dyscalculia) to have an influence on the factor of temporal relationship and on percentage error in time comparison in sub- and supra second intervals, according to the literature (Oliveri, Vicario, Salerno, Koch, Turriziani, Mangano, Chillemi, & Caltagirone, 2008; Vicario, 2011).

1.2.2 Participants

The sample is formed by 24 students of primary school in Sicily: the first group is composed of 12 subjects (a experimental group), including 7 males and 5 females (M = 9.5 years; SD = 0.57), with pure dyscalculia (that is a form of dyscalculia in which is excluded any other form of co-morbidities); the second group of 12 healthy subjects (control group), including 7 males and 5 females (M = 9.2 years, SD = 0.50).

1.2.3 Procedure: Study one (Time comparison task)

The task was earlier described to participants; afterward they have been requested to perform a series of practical tests to verify whether participants had understood the progress of the test. The subjects were placed in front of monitor of a laptop.

The purpose of the experiment was to determine whether a test stimulus (a black circle) was presented for a time interval longer or shorter than the duration of a standard stimulus (a red circle).

For each session, there were two separate and consecutive blocks, the first one including sub-second intervals and the second one the supra-second intervals.

In the block of sub-second intervals, the duration of the standard stimuli was 400 milliseconds in each test. This block consisted of 18 trials including subjects, estimating 6 sub-second intervals (300, 440, 500 ms), each of which was submitted for 6 times in random order, but immediately after the stimuli reference. The standard stimuli were presented immediately before the test stimuli in each of the 18 tests.

In the block of supra-second intervals, the duration of stimuli reference was of 1400 milliseconds in every test. This block consisted of 18 trials, including subjects estimated 3 supra-second intervals (1200, 1440, 1520 ms),

presented in random order for 6 times. The standard stimulus was presented immediately before the test stimulus in each of the 18 trials.
In both blocks, thus, 9 trials contained stimuli tests major than standard stimulus, and 9 trials contained test stimuli lower than standard stimulus. Each interval between the trials was 2000 msec. The order of presentation of the sub-second blocks and supra-second blocks was counterbalanced between subjects in each group.
The performance of each subject was analyzed by calculating the average percentage of wrong answers (errors) on 9 sub-second trials and 9 supra-second trials.

1.2.4 Procedure: Study two(Time Reproduction task)
The subjects were positioned in front of the monitor to a laptop. Each of them completed two tasks in a random order for the production of time intervals: in the first task, the way of production was independent (Self Time Production - STP), in the second task the way of production was given by the computer (Computer Time Production - CTP), according to indications Van Der Meer, Marzocchi and DeMeo (2005), who had applied this methodology in subjects with ADHD.
The two tasks were presented in a counterbalanced way. The execution of the task was preceded by a training phase in which (through the use of a stopwatch) the experimenter showed the real length of each interval. The data were collected in the form of response time expressed in milliseconds.
In the first task, the way of production was independent; it is consisted of a block of 18 trials in which subjects estimated 3 independent intervals presented in random order, each of which was submitted for 6 times; alia block consisted of 50 trials in which subjects estimated 3 sub-second intervals (300, 400, 500 ms), presented in random order for 6 reps too.

1.2.5 Measures
Instruments used are: *AC-MT* Test for evaluation of calculus disorders (Cornoldi, Lucangeli & Bellina, 2002) and Weschler III for QI evaluation (Wechsler, 1991).
● The test AC-MT was born as a response to the need to have an instrument to assess the numerical and calculation skills, in children from 6 to 11 years.
The tool serves to determine the detail of calculation (baseline assessment) and the difficulties of calculation (diagnosis of the first level), through six specific indices: the first two indices refer to the "accuracy" variable, the third index refers to the speed of calculation, provides an individual administration; the fourth index regard the presence of basic elements, related to the ability to lexical comprehend and produce, syntactic and semantic number; the other two indexes refer to written operations and solving mathematic problems.
● The WISC-III (Wechsler Intelligence Scale for Children; Wechsler, 1991) is a clinical tool for the diagnosis and evaluation of intellectual abilities of children aged from 6 to 16 years and 11 months; it is constituted by it 13 subtests divided into two groups: verbal subtest and subtest performance. Verbal subtests are oral questions without time limits except for Arithmetic; performance subtests are nonverbal problems, all of which are timed and some of which allow bonus points for extra fast work. The subtest select different mental abilities which will together contribute to the overall intellectual ability (IQ).
The verbal subtests measure: Information, Similarities, Arithmetic (Numerical Reasoning), Vocabulary, Comprehension, Digit Span. The Performance subtests are: Picture Completion, Coding, Picture Arrangement, Block Design, Object Assembly, Symbol Search, Mazes.
The ability of the child is synthesized through three different scores: Verbal IQ, Performance IQ, and Total IQ, (a combination of subtest scores for verbal and performance).

1.3 DATA ANALYSIS

The Univariate Analysis of Variance tree way (ANOVA) is used to measure the percentage of errors in temporal comparison task; in particular the Anova between subjects is used in the experimental group (child with dyscalculia) and in the control group (healthy child); The Anova within subjects is used to measure the dimension

of BLOCK (sub and supra-second intervals) and the dimension of TEMPORAL REPORT between the test and standard stimulus (test stimulus longer than the reference test, against shorter than the reference stimulus).
Student's t test for independent samples was used for the inter-group and intra-group comparison.

1.4 RESULTS: PRELIMINARY ANALYSIS

A preliminary analysis is made in order to measure the level of IQ in both groups (subjects with dyscalculia and healthy subjects). The WISC III test shows that all participants have an IQ in the standard.
Another preliminary analysis is done to confirm the absence of symptoms of dyscalculia in the group of healthy children. The test AC MT- indicates that the 12 healthy child reported a normative score.
The Univariate Analysis of Variance to verify the influence of gender variable on performance tests emphasises the following:

- the significant effect of gender on time comparison task in sub-second block ($F(1,11) = 5.16$, $p < .05$) and supra-second block ($F(1,11) = 13.78$, $p < .01$): specifically boys obtain higher average score than girls in sub and supra-second intervals than girls;
- the effect of the variable of gender on temporal relationship in supra-second intervals ($F(1,11) = 9.76$, $p < .05$): boys show a highest average score than girls in time relationship task with supra-second intervals.

1.4.1 Temporal Comparison

The three-way ANOVA for repeated measures shows the influence of the factor GROUP on temporal relationship ($F(1,11) = 7.34$, $p < .05$), and on the percentage of error in temporal comparison ($F(1, 11) = 5.42$, $p > .05$), but also a significant effect of the within-subjects factor BLOCK ($F(1,11) = 6.92$, $p < .05$).
The factor REPORT TIME has a main effect ($F(1,11) = 5.48$, $p <.05$) on the percentage of errors in the work of the temporal comparison.
Comparing the average scores, data show that: there is no difference between the two groups in the percentage of errors for the block supra-second intervals; while in sub-second test, children with dyscalculia are significantly less accurate than healthy children.
In children with DD, the temporal relationship is broader compared with healthy children but only in tasks of sub-second timing.
The interaction GROUP * BLOCK * REPORT TIME proves statistically significant ($p <.05$).

1.4.2 Temporal Reproduction

Student's T for independent samples shows a significant difference between experimental and control group in sub-second intervals ($F = 5.31$; $p < .05$).
The two-way ANOVA for repeated measures shows a main effect of factor BLOCK ($F(1,11) = 64.2$, $p < .01$), while there was found no main effect of the factor GROUP ($F(1, 11) = 1.35$, $p = .275$).

1.5 DISCUSSION

The present study is designed to assess the ability of children with DD to compare and reproduce time intervals. Compared to the tasks of temporal comparison, the research has shown that there are differences due to gender variables: in particular in the group of children with dyscalculia, boys seem to have a lower level of performance than girls. This result confirms some studies that show an increased incidence of disorder on girls than boys, because dyscalculia is associated to dysfunction in both hemispheres brain with a significant contribution of right hemisphere. As the girls are probably more dependent on verbal cognitive processes are higher than boys in this cognitive function they may be more phone to learning disabilities that depend of right hemisphere (Badian, 1983).

Disconfirming the initial hypothesis, there isn't difference between children with dyscalculia and healthy children as regards to the percentage of errors demonstrated in the resolution of the task.

Furthermore, confirming the research hypothesis**,** the factor Temporal Relation has a major effect on the percentage of errors: in detail, the interaction Block * Temporal Relation is also found to be significant as the Group * Block.

In reference to this interaction, the difference between the two groups concerns only the sub-second intervals, that is to say children with dyscalculia were significantly less accurate than the control group in the timing test of sub-second durations, because they manifest more errors in over timing comparison task, giving a judgment of underestimation compared to the standard stimulus.

Moreover, the post hoc analysis showed that the dyscalculia group significantly underestimates the duration of visual stimuli compared to the control group, whereas it was reported no difference between the subjects for the supra-second block.

In the task of reproduction time, the only significant value concerns the temporal factor BLOCK in the sub-second intervals: in fact children with DD give a judgment of underestimation compared to the standard stimulus, that is to say children with dyscalculia reproduce the test stimulus for a shorter duration than the standard stimulus.

The research shows that participants with dyscalculia did not differ from control group in comparison of supra-second intervals, but only in sub-second intervals. This temporal abnormality of child with DD is confirmed by the literature, that shows the presence of parietal and frontal activation during performance of works similar to ours.

The execution of timing tasks for sub second periods shows a cluster of activation in the right inferior parietal lobe (IPL) for perceptual and motion timing works.

1.6 CONCLUSION

The examination of neuroimaging studies (TMS - Transcranial Magnetic Stimulation) allows us to explain the temporal abnormalities in our group with dyscalculia, but it remains to explain why children with DD underestimate the time.

According to some recent evidence documenting a spatial encoding from left to right of the time intervals respectively from shorter to longer ones (Frassinetti *et al*., 2009; Vicario *et al.*, 2008) one might assume that a trend toward the left along the mental number line may be responsible for the underestimation of time.

The results of a recent work document the presence of a pseudo-neglect (ie an attentional bias to the left) higher in the DD group compared with the control group, when they are asked to perform a task bisection of mental number line (Ashkenazi & Henik, 2010). In particular, these authors showed that the group whit dyscalculia tends to identify the center of a segment leftmost of the control group. This study is the first to highlight the difficulty of spatial attention in children with DD (Corbetta & Shulman, 2002).

Knops and colleagues (Knops, Thirion, Hubbard, Michel & Dehaene, 2009), has further highlights the presence of a pattern of involuntary eye movements to left or to right, during the execution of arithmetic operations (subtraction vs. Addition, respectively) in association with activation of posterior parietal cortex.
On the basis of this evidence, it is assumed that an attentional bias to the left like the one recently reported by Ashkenazi and Henik (2010), may reflect the phenomenon of underestimation highlighted in children with DD, as predicted by the Time line model (Vicario et *al*., 2007) which proposes a similar orientation from left to right also for time intervals as well as for the numbers (Dehaene, Bossini & Giraux, 1993).
It was recently proposed a possible association between poor math skills and visual deficits in the temporal processing, considering the performance of DD in exploration tasks of sensitivity to visual motion (Sigmundsson, Anholt & Talcott, 2010). This study provides the first direct evidence on changes in the processing capacity of the explicit time in children with DD in absence of comorbidities. These deficts seem to be selective for sub second intervals.
The results of this study corroborate the hypothesis of a recent Mental Time Line (Vicario, Caltagirone, Pecoraro, et *al*., 2008;. Oliveri et *al.*, 2008) in which the representation of the inferior duration is positioned in the left side of a mental space, while the representation of a longer duration is positioned in the right side of the same mental space.

1.7 IMPLICATIONS FOR PRACTICE

Research in literature should be conducted in order to test the impact of arithmetic training sessions, which have been recognized to be able to improve the dyscalculia deficiency, changing the activation of both parietal and frontal circuits (see Ansari, 2008, for a comprehensive review), the ability to perform time estimate tasks.
There are four type of treatment to increase the math abilities:
- early intervention with children with difficulties in reading and writing;
- global training on the difficulties of numerical processing and calculation;
- training on transcoding numbers;
- training on specific components of numbers and calculation with the use of compensatory instruments.

In the first arithmetic tasks (such as sets, perceptual and manipulative activities), these children haven't particular difficulties because these activities do not provide abilities that are really difficult for them.
The first treatment is focused about the recovery of lexical labels (to read and write numbers, to count backwards, for multiplication tables), the working memory (to read and write numbers, to count); the ability to automate procedures (for calculating written and counting). Skills that would be favored with this type of intervention are: a) Increased efficiency in the number line, with exercises ascending and descending count, games such as the identification of the following or preceding number; b) The identification of the semantic aspects of numbers, such us their arrangement and placement on the number line, the mental calculation, the addition and subtraction.
The second model of treatment promotes: a good control of the processes of transcoding number; good executive skills and control measures relating to the calculation in children who started the second cycle of elementary school. Among the most frequent difficulties, together with those in arithmetic facts, there are the tasks of numerical transcoding and serial backward counting. A good ability in the use of the number line helps in the performance of any activity with numbers and calculations.
The training of numerical transcoding is intensive and of short duration; this is made during the last years of primary and secondary schools; it rests mainly on exercise of transcoding numbers, but also draws from some activities related to the number line. This treatment promotes a more efficient reading and writing of numbers in terms of speed and accuracy.
At the last, training on specific components of numbers influences: the specific components of numerical and calculation abilities; the promote awareness and the use of compensatory measures (using timing and mode of intervention shorter). During this treatment, you can teach, depending on requirements, to: a) use the calculator

and the multiplication table; b) monitor the written calculation; c) to learn strategies to simplify mental calculations.

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