DESCRIPTIVE PROPERTIES OF A SET OF SELECTED TASKS FOR DYSLEXIA SCREENING IN FRENCH SCHOOL AGE CHILDREN

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ABSTRACT

Dyslexia is a specific disorder of language. Researches led on dyslexia origin have conducted to multiple hypotheses and various rehabilitation treatments. In this context, practitioners can be interested in using an automatic tool to help in diagnosing dyslexia. This tool should evaluate children's own deficit and advise adapted rehabilitation. This paper presents the first step of the conception of such a tool and the development of a preliminary test containing the most representative dyslexia evaluation tasks from literature. The first results concerning the descriptive properties of this preliminary test in French school age children (8-10 years) are also presented.

1. INTRODUCTION

Developmental dyslexia affects in France about 5% of school age children. It is traditionally defined as an enduring and heavy impairment of reading ability in spite of normal intelligence and adequate educational opportunities. Dyslexics have a specific disorder of written language and can have some associated deficits like: attention deficit, visuo-attentional deficit, auditory and memory deficits. Researches led on dyslexia origin have conducted to multiple theories (*i.e*. phonological theory, rapid auditory processing theory, cerebellum theory, *etc*.). These multiple theories created various diagnosis methods and treatments which are sometimes inadequate. In this context, practitioners can be interested in using an automatic tool to help in diagnosing dyslexia. This tool should evaluate children's own deficit and advise adapted rehabilitation. In order to develop this tool, we must in a first step select dyslexia evaluation tasks and study their descriptive properties in two populations that they are expected to discriminate: children with dyslexia and normal children. At the moment, such an efficient tool does not exist.

The present article describes a set of selected tasks named "preliminary test" containing the most representative dyslexia evaluation tasks and reports its descriptive properties. The first part presents the context of this work. The preliminary test of dyslexia screening is described in a second part. The third section shows the results we obtained with the preliminary test and the study of its descriptive properties thanks to Multiple Correspondence Analysis (MCA).

2. CONTEXT

Three forms of developmental dyslexia are generally identified: phonological dyslexia [1], surface dyslexia [3] and mixed dyslexia. Given multiple etiologies, it is particularly difficult to determine its causes. During the 20 last years, many behavioural studies and neurological investigations demonstrated that dyslexics have difficulties in phonological processing in reading new words reading, phonemic analysis and short-term memory. Such a deficit concerns at least 70% of dyslexic children. Although this phonological theory is defended by a dominant current, four main hypotheses have been suggested: auditory hypothesis, visual hypothesis, magnocellular hypothesis and cerebellar hypothesis.

According to auditory theory, dyslexics would have poor performance on a number of auditory tasks - tone discrimination, temporal order judgment [16], repetition tasks [11], backward masking - and would have more difficulties in perceptual discrimination of speech sounds [12]. Visual hypothesis is based in the observation of visual deficits such as bi-ocular fixation instability, a visual stress and visuo-attentional disorder [17].

Magnocellular hypothesis [15] integrates the preceding theories (auditory and visual) in defending a theory that would affect auditory and visual magnocellular pathway. At last, cerebellar hypothesis [9] is based on the observation that some dyslexic children have a motor deficit. They would have a poor capacity in motor coordination, problems of equilibrium, *etc*. Most of these theories are based on a unique modality (auditory, visual or motor). More recent studies show that 40% of bad readers have an auditory deficit, a minority has visual problems and around 30 to 50% of them have a motor deficit [10]. It appears that only phonological deficit constitutes a common factor to developmental dyslexia. The other deficits associated to dyslexia are considered by Ramus [10] as relevant to co-morbidity. The development of an automatic tool to help in diagnosing dyslexia would allow taking in consideration the other deficits associated in order to facilitate the diagnosis and to guide the remediation. The first step of this elaboration consists in proposing a set of selected tasks for dyslexia and evaluating its descriptive properties in the children with or without dyslexia.

3. THE PRELIMINARY TEST

3.1 Principle

Fourteen French children with developmental dyslexia aged 8-10 years old and forty-eight normal school children of the same age were tested with the preliminary test. The poorest reading ability in the normal children group was 18 months below their chronological age and the reading ability of dyslexics was on average 25 months below their chronological age, which defined them as severely impaired in reading impaired according to the "Alouette test" defined in § 3.2. The preliminary test is a set of selected tasks for dyslexia screening. More precisely, it should recover all suitable deficits implicated in dyslexia and should be able to recognize dyslexic children profile (what are the main deficits? what are the associated deficits? what is the degree of severity?). In order to carry out the test in the best conditions, each child was assessed individually (except for the dictation *cf.* § 3.2) during three sessions of 45 minutes. Some experiments were controlled by a PC where a software platform was developed [6]. All sound stimuli were digitally generated and were delivered idiotically via Sennheiser HD 180 earphones.

3.2 Description of the preliminary test

The preliminary test is composed of 8 categories of tasks:

1) Reading tasks:

- The Alouette test [5]: it gives lexical age (*i.e.* reading level). The child reads a text during three minutes. The level of reading is defined by the speed and the accuracy of reading.
- Reading of words and pseudo words: it is carried out on 4 sheets of 20 words which are grouped according to their frequency and regularity and on 2 sheets of 20 pseudo-words. Exactitude of pronunciation and reading time are recoded and each sheet is evaluated on 20 points. This test allows to determine the form of dyslexia (phonological, surface or mixed).

2) Memory tasks: they are composed of two tasks: number span tasks (forward and backward) and spatial span tasks (forward) via Corsi's blocks. They give a verbal short-term memory span, spatial span and work memory span. The work memory appears to be implicated in reading and notably in its learning. According to some studies, dyslexics would have poor performance in verbal short-term memory [14].

3) Attention task: it is extracted from the BREV ("Batterie Rapide d'EValuation des fonctions cognitives"): children must cross out as quickly as possible all "3" placed on a test sheet. The score is evaluated on 26 points.

4) Phonological test:

- Metaphonological tasks: they require phonological awareness. Four different tasks are assessed: phonemic segmentation task (segment the word in phonemes), spoonerism task (switch syllables), initial phonemic omission task (omit the first phoneme of each word presented) and task of rimes judgment (find the word which does not rime with the three others). These tasks return a score on respectively 16, 10, 12, 8 points.
- Phonological automatism task: it regroups two tasks: speed denomination (denominate as quickly as possible a series of letters and a series of colours) and lexical discrimination (recognize if the pronunciation of two words is the same or not).
- Morphology task: children must find a pseudo-affixed word among affixed words (example in French: recoller, *regretter*, repartir, reparler). It gives a score on 6 points. The knowledge of word morphology is considered by some author as a capacity called up during the reading [3].

5) Motor task: it is an extract from NEPSY ("bilan Neuro-PSYchologique"): the children must execute manual motor sequences noted on 60 points and an exercise of "tapping", that is an evaluation of digital sleight and motor speed.

6) Visuo-attentional task: dyslexics would have difficulties in the treatment of visual information when this information is presented rapidly [17]. A partial report of letters was integrated in the PC: following a central point on computer's screen, a series of 5 letters appears during 250 ms, a dash comes under one of the letters, and then the children must indicate which letter it is.

7) Writing test: dictation extracted from the BELEC [8].

8) Auditory tests:

- TMTF (Temporal Modulation Transfer Function) task. This task evaluates the ability to process auditory temporal-envelope cues. According to Lorenzi [7], modulation sensitivity seems poorer for children with dyslexia than for normal children. To address this issue, temporal modulation transfer function is measured. TMTF is the detection threshold of sinusoidal amplitude modulation applied to a white noise carrier, as a function of frequency. For practical purposes, children are asked to listen to two sounds of 500 ms: a white noise and a modulated white noise at a given modulation depth. For each trial, these two sounds are successively presented in random order to the listener. This test must run less than 45 minutes due to the children fatigability. Consequently, only three frequencies were experimented (4 Hz, 16 Hz and 128 Hz). The test begun by a modulation depth of 0dB and then changed according to the child response. The threshold detection was obtained using an adaptive two-interval (2I), two-alternative forced-choice (2AFC) [4]. So, three thresholds of modulation for each frequency are noted.
- VOT (Voice Onset Time) tests: VOT is the time between the release of the consonant and the start of vocal fold vibration (voicing), and it is measured in milliseconds (ms). By convention, when voicing starts before the release of the consonant, VOT is negative; when voicing and consonant release happen simultaneously, VOT equals 0 ms; when voicing starts after the release of the consonant, VOT is positive. VOT quantifies the degree of phonetic voicing. The test consists in producing a continuum whose extremities are constituted of two syllables which differ by their VOT and intermediate syllables allow linking the extremities by progressive variation of VOT. A difference of 20 ms between VOT values of two syllables is perceptible only if the syllables belong to distinct phonemic categories. For example, the syllables /ba/ and /pa/ differentiate by respectively negative and positive VOT. The production of several intermediate

VOT values generates a continuum of syllables perceived like either /ba/ or /pa/. From a continuum ranging from -40 ms to 40 ms, two exercises are proposed: (*i*) identification task where the child listens to a syllable. He must indicate if he hears rather /ba/ or /pa/. This test allows evaluating an identification slope that is calculated using a linear regression analysis performed on the data point 100% /pa/ identification to 100% /ba/ identification, (*ii*) discrimination task where two syllables are presented. The VOT difference between these two syllables is 20 ms. In this second exercise, the child must indicate if the syllables are the same or not. Normal subjects present a discrimination peak around a VOT of 0 ms. Such a peak is not recovered for children with dyslexia [13]. Moreover, predicted VOT discrimination values were calculated from VOT identification values. Then the differences, for each pair of syllables, between predicted discrimination values and observed discrimination values are summed in order to give only one value.

To resume, all results obtained by children to the preliminary test are stored in a data table where the rows correspond to the subjects and the columns to the variables (*e.g.* Alouette test, verbal forward span, *etc.*). So, this data table is composed of many different quantitative variables. First, thanks to these results, we want to determine which tests have a real capacity to discriminate dyslexics from normal children and secondly we want to determine their descriptive properties by MCA method.

4. METHODS

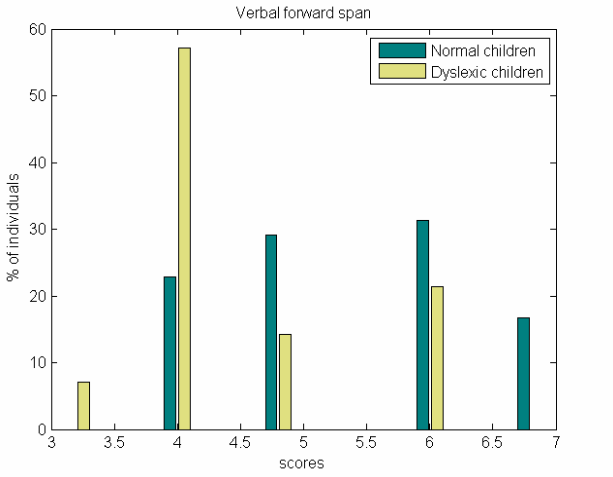
4.1 Analysis of discriminatory properties of individual tasks

A Mann-Whitney test was used to compare the results obtained by normal children and children with dyslexia on each task. This nonparametric test compares the distributions of a variable in two independent samples. A 0.05 significance level is chosen to state whether each task is discriminative (H): H=0 indicates that the null hypothesis (*i.e* the medians are equal in both groups) cannot be rejected at the 5% level ($p>0.05$). H=1 indicates that the medians differ between both groups, then the null hypothesis can be rejected at the 5% level ($p<0.05$).

4.2 Variables recoding

In order to use a MCA (Multiple Correspondence Analysis) for the multivariate analysis of the tasks, we need to recode the raw score variables as categorical variables. The distribution of each raw score was splitted into two, three or four levels. The number of levels and the boundaries used were determined informally from the distributions, the number of possible values and the quartiles' values in the two groups (normal children and children with dyslexia). We illustrate this technique hereafter through the recoding of the verbal forward span task. The scores of this task can take 7 possible values, ranging from 1 to 7.

As an example, Figure 1 shows the verbal forward span task scores distributions in both populations (dyslexic and normal children). Only 5 values ranging from 3 to 7 are used by both populations, so the distribution will be splitted into two levels only. Furthermore 60% of the dyslexic children have a score lower than 4 and the third quartile in the dyslexic group (5.25) equals to the median quartile in the non-dyslexic group. We finally decide to define the cut-off as 4: children having a score less than (or equal to) 4 are classified into the first level and children having a score upper than 4 are classified into the second level.



	Verbal forward span			
Normal children	Q1=5	Q2=5	Q3=6	Q4=7
Dyslexic children	Q1=4	Q2=4	Q3=5.25	Q4=6

Figure 1: distribution and quartiles of verbal forward span scores

All quantitative variables are recoded this way into categorical ones with 2, 3 or 4 levels. The bad scores are represented by the first levels except for the time variables where the first levels represent the best performances.

4.3 Multiple correspondence analysis (MCA)

Multiple correspondence analysis (MCA) is an extension of correspondence analysis (CA) which analyses the pattern of relationships of several categorical variables. As such, it can also be seen as a generalization of principal component analysis (PCA) when the variables to be analysed are categorical instead of quantitative. This method was applied to the variables which show discriminative properties in the univariate approach (Mann-Whitney test). The MCA produces factors which are linear combinations of the variables levels. These factors define a new space where individuals can be represented. The analysis of the most contributing variables to each factor gives the interpretation of the factor and the conjoint analysis of the position of the individuals on each factor gives a multivariate characterization of them.

5. RESULTS

5.1 Determination of discriminatory tasks

The scores of visual memory span, attention, lexical discrimination morphology and tapping tasks do not differentiate between the two groups ($p<0.05$). Moreover, contrary to the visuo-attentional and auditory hypotheses, the partial report of letters and TMTF tasks do not seem to have any capacity of discrimination. These results suggest that the

poor performance in treatment of visual information and the poor modulation thresholds measured in children with dyslexia concern probably a minority of dyslexics. For the reading tasks, only the score for the reading of frequent regular words did not show significant difference between the two groups (p=0.0659). But this task is important to determine the form of dyslexia (phonological, surface or mixed). The other reading tasks have a lower probability ($p<10^{-4}$). Speed denomination and all metaphonological tasks, except segmentation task, discriminate dyslexics and normal children. We can conclude that a majority of dyslexics have some phonological deficits. The dictation scores and the slope of identification curve in the VOT task appear to be different between the two populations.

Tasks	P-value	Decision (H)
Alouette test		
Lexical age (in months)	< 10-3	1
Memory tests		
Verbal forward span	< 0.05	1
Verbal backward span	< 0.05	1
Spatial span	NS	0
Attention test		
Barr 3 (1')	NS	0
Reading tests		
Frequent regular words	< 0.10	0
Reading time of frequent regular words	< 10-3	1
Frequent irregular words	< 10-3	1
Reading time of frequent irregular words	< 10-3	1
Few frequent regular words	< 10-3	1
Reading time of few frequent regular words	< 10-3	1
Few frequent irregular words	< 10-3	1
Reading time of few frequent irregular words	< 10-3	1
Near phonologically pseudo words	< 10-3	1
Reading time of Near phonologically pseudo words	< 10-3	1
Pseudo words	< 10-3	1
Reading time of pseudo words	< 10-3	1
Metaphonological tests		
Segmentation	< 0.5	0
Ommission	< 10-3	1
Judgment of rime	< 0.5	1
Spoonerism	< 10-3	1
Phonological automatism tests		
Lexical discrimination	NS	0
Speed denomination letters	< 10-3	1
Speed denomination colours	< 0.5	1
Test of capacity call up during reading		
Morphology	NS	0
Visuo-attentional test		
Partial report of letters (total score)	NS	0
Motor tests		
Manual motor sequences	< 10-3	1
Tapping	< 0.05	1
Dictation		
Acontextual consistant writing form	< 10-3	1
Contextual consistant writing form for unfrequent words	< 10-3	1
Contextual consistant writing form for frequent words	< 10-3	1
Differentiate writing form by morphology for unfrequent words	NS	0
Differentiate writing form by morphology for frequent words	< 0.5	1
Auditory tests		
TMTF 4	NS	0
TMTF 16	NS	0
TMTF 128	NS	0
Slope of identification VOT curve	< 10-3	1
VOTdiscrimination score	NS	0

Figure 2: Results of the Mann-Whitney tests comparing normal children to children with dyslexia (NS=Non Significant)

5.2 Multivariate characterization of dyslexic vs. non dyslexic children

The MCA was applied to the variables which showed discriminative properties in the univariate approach: Alouette test, verbal span memory tasks, reading tasks, metaphonological tasks (except segmentation task), phonological automatism task (except lexical discrimination task), motor tasks, dictation and VOT slope. This analysis extracted 56 independent factors whose importance is distributed according to the graph in Figure 3 (the number of factors corresponds to the difference between the total number of levels of all the variables *i.e.* 84 and the number of variables *i.e.* 28).

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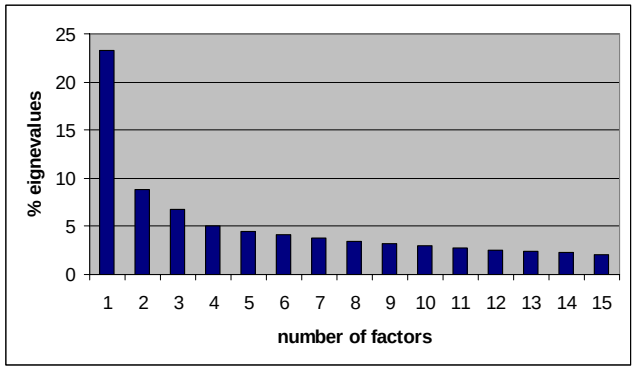

Figure 3: Eigenvalues (% inertia) for the first fifteen factors

The coordinate's graph of the subjects according to the factors F1 and F2 is given on Figure 4. Each dyslexic subject is labelled by a number between 501 and 514. All other points represent normal children. The children with dyslexia are all projected on the positive part of the first factor, when the normal ones are projected on the negative part, except for five of them. This first factor shows good discriminative properties for dyslexia. The five points representing normal children which are projected on the same part of the factor 1, are quite close to the origin (near the borderline between "dyslexic and normal areas"). This is explained by the fact that they have a performance similar to dyslexic children on some of the tasks (but not all of the tasks).

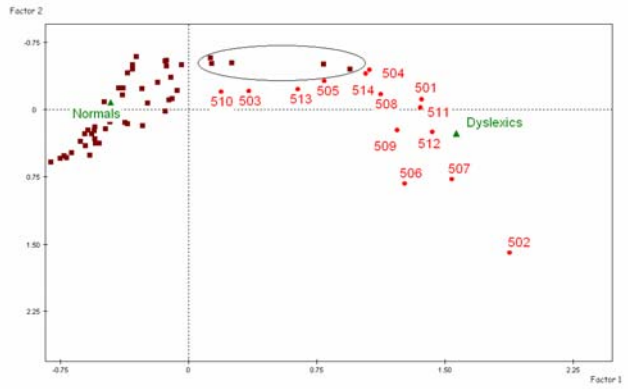

Figure 4: Representation of individuals (children) on the first factorial plan

The analysis of the graph representing the coordinates of the variables (*cf.* Figure 5) indicates which tasks (and levels of tasks) are the most representative of this first factor: the worst levels of all the tasks seem to be systematically projected on the positive part of the factor, the best levels being projected on the opposite part. The lexical age appears to be decreasing with the first factor (*cf.* dotted line in Figure 5). This indicates a strong relationship between a poor performance on a task and a poor performance on any other task. The tasks which are particularly significant on this factor are:

reading times (highest cumulative contribution of 35%), dictation (cumulative distribution of 15%), phonological tasks (cumulative distribution of 10%), lexical age (cumulative distribution of 6%), speed denomination of letters (cumulative distribution of 2%). Other tasks, as verbal span or VOT are less convergent with the other tasks to discriminate children.

Analysing conjointly children's and variable's positions on the first factor indicates that dyslexic children seem to cumulate a poor performance on different tasks that the MCA exhibited.

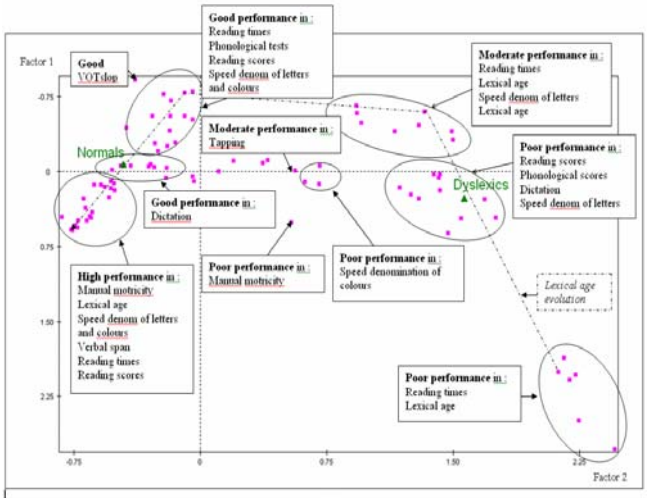

Figure 5: Representation of variables (and their levels) on the first factorial plan

6. CONCLUSION

To conclude, this study allowed to evaluate the discriminatory validity of some dyslexia detection tasks proposed in the literature and to describe properties of the most discriminatory tasks in both population (dyslexics and non dyslexics). Moreover, thanks to this study, the duration of the preliminary test could be reduced by deleting the tasks which revealed non-discriminatory. Five tasks seem to have a poor discriminatory capacity: spatial span memory, morphology, lexical discrimination, visuo-attentional and TMTF tasks. But we do not want to remove visuo-attentional and TMTF tasks because some dyslexics (a minority, not represented in our sample) have high difficulties in these tasks and they could help to define sub-groups of dyslexia.

Dyslexic population is mainly characterized by its poor performance in reading tasks, phonological tasks, dictation and speed denomination tasks. So these tasks must be preserved in the new version of the preliminary test. This new version will constitute a "pre-test" of an "adaptive" protocol of dyslexia screening and will be followed by a full test. Two approaches are envisaged in order to develop this full test. In the first approach, the tasks of the full test will be determined by the results of the "pre-test" and in a second approach the full test will be a succession of tasks according to the results of preceding tasks. In the future, all these results should be confirmed by a larger number of subjects in both groups.

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