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Rhythmic Reading Training (RRT)

A Computer-Assisted Intervention Program for Dyslexia

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Abstract. Developmental dyslexia is a specific learning disorder of neurobiological origin that causes a reading impairment. Since music and language share common mechanisms and the core deficit underlying dyslexia has been identified in difficulties in dynamic and rapidly changing auditory information processing, it has been argued that enhancing basic musical rhythm perception skills in children with dyslexia may have a positive effect on reading abilities. Therefore, active engagement with music provides an enjoyable environment that may improve motivation of children and thus enhance the efficacy of the intervention. Taking these findings and hypotheses into account, a computer-assisted training, called Rhythmic Reading Training (RRT), was designed to implement a treatment which combines a traditional approach (sublexical treatment) with rhythm processing training. Some preliminary test-training-retest studies showed the efficacy of RRT intervention on reading abilities of children with dyslexia.

Keywords: Reading · Developmental dyslexia · Music · Rhythm · Auditory processing · Intervention · Personalized training

1 In Search of an Effective and Easy-to-Administer Training for Dyslexia

Developmental dyslexia (DD) is a specific learning disability of neurobiological origin, which causes an impairment in the ability of reading in spite of normal education, intellectual functioning and socio-cultural opportunity [1]. DD is one of the most common neuropsychological disorders affecting children. Studies conducted in English-speaking countries report a prevalence ranging from 5 to 17.5 % [2]. In Italy, due to the transparency of Italian orthography, the prevalence of DD is lower and ranges from 1.5 to 5 % [3]. The consequences of this impairment on learning and scholastic achievements are relevant and often causing a decrease of the motivation for learning, self-esteem and self-efficacy.

Although the core mechanism underlying DD is still under debate, a specific dysfunction in phonological processing is currently widely assumed to be the primary deficit, as confirmed by many evidences [4, 5]. It has also been showed that the impairment in

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phonological representation, which is the distinctive feature of DD, is associated to difficulties in rapidly changing auditory information processing [6, 7]. Children with DD are typically poor in basic auditory perceptual and timing skills, such as sensitivity to speech prosody, pitch perception and rhythm (sound attributes cued by amplitude, duration and frequency changes of the acoustic signal) [8, 9]. These auditory perception difficulties could contribute to the development of impaired phonological representation for words [10].

Regarding the Italian context, a meta-analysis [11] suggested that the most effective treatments for DD are the interventions aimed at improving the automatic decoding of sublexical and lexical stimuli, such as the Sublexical Treatment [12] and the visual hemispheric-specific stimulation inspired by the Balance-Model [13]. These treatments are characterized by some weaknesses in their application for the rehabilitation of DD. First, they require to be performed in a clinical setting by a therapist who is expert in the methodology, thus demanding a time-consuming and economic commitment of the patient's family. Moreover, the characteristics and the abilities of the therapist are crucial for the effectiveness of the treatment. Therefore it is difficult to ensure a standardized procedure and the outcomes are quite variable. Finally, since both of these treatments involve an intensive and repetitive reading training that has to stress decoding in order to be effective, they are often experienced as boring and tiring, causing a decrease of the participants' motivation.

These concerns point out the need for a rehabilitation methodology that could provide (a) a supervised usage at home, therefore not requiring the physical presence of an expert for every session; (b) a standardized procedure which could adapt to the specific needs of each participant planning the activities systematically and gradually increasing the exercises' difficulty; (c) the invariance of the effects in spite of therapist's personal characteristics and level of expertise; (d) engagement and motivation of participants throughout the whole intervention period.

Taking all these requirements into account, we designed a computerized training program whose characteristics help overcoming the limitations of traditional treatments while guaranteeing the effectiveness in improving reading abilities of children with DD. The use of information technology (IT) could provide some benefits in a rehabilitation setting. It has been proven that children with DD are more motivated and less stressed when they use IT tools for dealing with tasks involving reading [14]. Moreover, another feature of IT tools that facilitates reading training process is the multimodal presentation of stimuli, which can therefore be delivered simultaneously as auditory and visual.

Concerning the motivation issue, we thought about introducing music as a rehabilitation tool. Active engagement with music provides an enjoyable environment that may improve motivation and self-efficacy of children with DD. Moreover, many considerable studies support the hypothesis that music training could be effective in enhancing auditory perception abilities and consequentially improve language processing and reading skills.

1.1 Music as an Empowering Tool for the Development of Reading Skills

Many evidences about the existence of shared mechanisms supporting the processing of both music and language have been reported. Neuroimaging studies provided

evidence of a significant overlap in the brain regions involved in processing the characteristic of both auditory speech and non-speech signals [15]. Furthermore, it has been proven that musical expertise has a positive effect on language and literacy abilities in normal-reading children, suggesting an association between music and reading skills [16]. In fact, music attributes discrimination abilities, assessed using tonal-melodic and rhythmic tasks, predict phonological and reading skills in both normal-reading children and children with DD [17]. These findings suggest that interventions aimed at enhancing basic auditory perception skills of children with DD may impact on reading abilities: improvements caused by music training might transfer to other domains, such as language, enhancing pitch, timing and timbre processing.

Some conjectures about how music could help children with DD have been put forward [18, 19]. So far, the attempts to improve reading skills through music training were carried out engaging poor readers, pre-schoolers or children with DD in activities involving mostly discriminating pitches, reproducing rhythmical patterns by tapping hands, foots or hitting the drums, evaluating the speed or the intensity of sounds and singing according to given instructions. In other words, music training occurred as a separate experience with no direct link to language and reading. It was expected that improvements produced by music activity in the basic auditory mechanisms in common between music and language should transfer from music to language.

A study conducted by Overy [18] examined the influence of a 15-week music training on reading skills of 9 children with DD. Music lessons were conducted 3 times per week in sessions of 20 min each. Reading skills were assessed across the music intervention period and the preceding 15-weeks control period. A significant improvement in phonological, spelling, rhythm copying and rapid auditory processing skills emerged, but reading skills were not significantly affected by the musical treatment. In a similar designed study, Register and colleagues [20] measured the efficacy of a short-term music curriculum, designed to target reading comprehension and vocabulary skills, on reading skills of second-grade students, some of which were diagnosed with DD. Significant improvements in word decoding, word knowledge and reading comprehension were found after the music intervention in the group of children with DD.

Even though the hypothesis of a positive effect of music training on the impaired auditory perception and timing processing of children with DD is supported by many studies, music education alone failed to produce improvements in reading skills comparable with those resulting from traditional intervention methods for DD, which hence should not be replaced [21]. We hence wondered if a more efficient way of taking advantage of music for the development of reading skills could be to incorporate the music dimension in the reading training. Better outcomes could be achieved if shared mechanisms between music and language are trained simultaneously through exercises involving both the musical and the linguistic dimensions. This combination should produce a synergy between the two dimensions, with both music sounds and verbal stimuli stressing the same elements (e.g., the rhythmical structure of language) and converging on the same results (such as hinting at temporal regularity in analysing and decoding the presented verbal stimuli).

For allowing the music and linguistic dimensions to interact and combine, IT appears to be the perfect choice. First, multimodal stimulation can be provided by a computerized

application, presenting music and verbal materials simultaneously. Additional cues, such as visual elements aimed at highlighting the relevant part of the stimuli to be processes, can be easily included. Second, computerized exercises enable trainers to have control over timing and difficulty of the stimulus presentation. Finally, the perfect synchronisation of the concurrent presentation of sounds, verbal materials and visual cues is assured. All these outcomes cannot be reached without the use of IT, since the presentation of the stimuli performed by a human agent cannot be as accurate.

Taking all these considerations into account, a computerized training program which combines a traditional remediation approach (sublexical treatment) with rhythm processing training was designed and implemented. A rhythmic accompaniment provides readers a structure which helps them to organize temporal cues of speech sounds. Rhythm therefore should assume the role of an aid in rapid auditory processing which can support word decoding ability.

1.2 A Computerized Training Program: The Rhythmic Reading Training (RRT)

RRT is a child-friendly computerized reading program addressed to Italian students with DD aged 8–14 [22]. The software was developed using Unity as the game engine and therefore both a Windows and a Mac version of the software are available.

Concerning the content of the application, the training program is composed of three categories of exercises designed to improve reading skills, which can be selected from a user-friendly menu screen: “Syllables”, “Merging” and “Words and Pseudo-words”. Each category of exercises is aimed at training a specific reading ability. The section “Syllables” trains syllable recognition. The section “Merging” involves merging syllables for creating words. The goal of the section “Words and Pseudo-words” is to train word, pseudo-word and small phrases decoding.

All reading exercises include a rhythmical accompaniment with gradually increasing speed. Participants are taught to read the verbal stimuli (i.e., syllables, words, pseudo-words, phrases) presented on the screen in synchrony with the rhythmic accompaniment. The first time an exercise is presented, the stimulus (or the part of the stimulus) which has to be read is indicated by a visual cue (consisting in highlighting the target grapheme in red) synchronized with musical rhythm, so to allow trainees to understand clearly in which manner they had to read the verbal materials.

The software allows the trainer to modulate the speed of presentation of the verbal stimuli in the exercises depending on the reading level of each participant. In order to make the speed setting easier, the velocity is expressed in terms of syllables per second (in RRT, 1 syllable per second is equivalent to 60 beats per minute), which is the most common measure used in clinical setting for assessing reading speed. Also, the complexity of the verbal stimuli presented is gradually increasing along with speed modulation. The complexity is modulated by increasing the number of stimuli presented on the screen (and thus manipulating visual crowding), decreasing letter font size, removing the visual cue (so that children have to rely only on the auditory aid for maintaining reading speed) or introducing concurrent tasks, such as the detection of a specific verbal target while reading.

The software provides the possibility to adapt the exercises presentation to the specific characteristics of each participant. That is the reason why the software can target a quite wide range of participants' age and levels of reading impairment.

In order to provide a distractors-free environment, all the exercises were designed for having an extremely simple and clear setting, so that children could focus only on the task presented. The font chosen for the verbal stimuli is Helvetica, coloured in black (red when the letters are highlighted by the visual cue) on a white background. Finally, the easy-to-use interface and the intuitive settings of the software makes it extremely clear and easy to managed by any trainer, even a non expert one.

2 Evaluating RRT's Efficacy: Preliminary Studies

2.1 An Application of RRT in the School Setting

In order to evaluate the efficacy of RRT as a treatment for DD, a test-training-retest experimental design was applied. We measured possible changes in reading skills of a group of children with DD between the beginning (pre phase) and the end of the intervention period (post phase). Reading improvements were compared to the ones of a control group of children with DD. Reading skills of the control group were monitored before and after a period of the same length of the intervention during which no specific activity addressed to improve reading skills was carried out.

Twenty-eight students aged 11–14 (mean age = 12.07 yrs., SD = 1.14) with DD participated in the study. They attended a junior high school in Lecco (Lombardy, Northern Italy) and had been previously diagnosed with DD on the basis of standard inclusion and exclusion criteria (ICD-10: World Health Organization, 1992) and of the ordinary diagnosis procedure followed in the Italian context.

Two subgroups of the same size matched for gender, school grade and level of reading impairment were then created and randomly assigned either to the intervention or the control condition.

Reading and rhythmic perception skills were assessed before and after the intervention or control period. The assessment of reading skills was carried out using two different batteries of tests.

- "Prova di lettura di parole e non parole" (Word and pseudo-word reading test) [23], in which speed and accuracy scores were computed for single word (4 lists of 30 words each with different lengths and frequency of use) and pseudo-word reading (2 lists of 30 pseudo-words each with different lengths).
- "Nuove prove di lettura MT per la scuola media inferiore" (New MT reading tests for junior high school) [24], a set of tests providing accuracy and speed scores in reading aloud age-normed texts.

Both batteries are the most commonly used in Italy to assess reading abilities in students with DD. In both batteries z-scores for reading accuracy and reading speed were computed from raw scores (respectively, the number of errors and the reading time expressed in seconds). A decrease in speed and accuracy measures corresponds to an improvement of the reading performance.

Rhythm perception ability was assessed through the rhythm reproduction task [25], which consists in the request to reproduce a set of rhythmic patterns of increasing complexity performed by the examiner. Scores are computed by counting the number of errors in the reproduction of rhythmic patterns.

Participants assigned to the intervention condition took part in the training program for 9 biweekly sessions of 30 min in length each, resulting in a total of 4.5 h of intervention. Training sessions were individual and were managed by the same researcher in a quite room of the school. During the training session the child sat in front of the computer and performed the proposed reading exercises under the supervision of the researcher. The number of exercises performed in each session varied according to the difficulty and the speed of the exercises. All the tasks were repeated at least three times at gradually increasing speed. The researcher managed to set up the speed in which stimuli had been presented according to the student's performance in each exercise. The student had to fulfil at least a reading accuracy of 95 % of the verbal stimuli in each exercise in order to speed up and/or proceed to the next exercise.

A mixed factorial ANOVA was carried out in order to evaluate the effect of RRT on reading accuracy and reading speed. Condition (intervention vs. control) was considered as the independent between-subject variable and phase (pre vs. post) as the independent within-subject variable.

RTT improved participants' reading skills. Both reading speed and accuracy mean z-scores increased after the intervention and these gains were significantly higher in the intervention than in the control condition. Significant interaction effects were found in short pseudo-words reading speed ($F(1,26) = 4.411$, $p < .05$, $\eta^2 = .145$), long pseudo-words reading speed ($F(1,26) = 7.493$, $p < .05$, $\eta^2 = .224$), high-frequency long words reading accuracy ($F(1,26) = 5.387$, $p < .05$, $\eta^2 = .172$) and text reading accuracy ($F(1,26) = 10.020$, $p < .005$, $\eta^2 = .278$). In particular, the time required to read short pseudo-words and long pseudo-words decreased after the intervention respectively of 0.51 and 0.75 z-scores on average. Regarding accuracy, the numbers of reading errors was reduced of 0.39 z-scores for high-frequency long words and of 2.37 z-scores for text on average.

Concerning the rhythm reproduction task, no significant difference between the control and the intervention condition was found. After both the control and the intervention period participants performed the test slightly better: a decrease of 0.93 ($SD = 2.81$) mistakes on average after the control period and a decrease of 2.00 ($SD = 2.04$) mistakes on average after the intervention period were found.

2.2 An Application of RTT in the Rehabilitation Setting

The second study was carried out in a clinical setting. Participants were recruited among patients of the neuropsychiatry unit of the IRCCS "Don Gnocchi" in Milan, Italy. The main objective of the study was to test the efficacy of RRT in an actual rehabilitation setting and on a specific sample of participants, namely, children with a diagnosis of DD in comorbidity with other specific learning disabilities. The same experimental design of the first study was applied but – due to difficulties in recruiting in the same setting a control group of children with DD matched for age, IQ and level of reading

impairment – it was decided to involve all the participants in the intervention condition and to measure possible improvements in reading skills between the pre and post phase. Seven students aged 9–11 (mean age = 9.77 yrs., SD = 0.71) with DD in comorbidity with at least one other specific learning disability (i.e., dyscalculia, dysgraphia or dysorthography) participated in the study. All of them were meant to start a speech-therapy intervention aimed at training their impaired learning abilities, as commonly offered to children with specific learning disabilities in Italian neuropsychiatry units. Regarding the pre and post assessments, besides reading and rhythm perception, a set of cognitive functions were also tested: visual sustained attention, auditory selective attention, verbal working memory and other auditory perception abilities.

Participants took part in the training program for 20 biweekly sessions of 20 min in length each, resulting in a total of 6.7 h of intervention. After each RRT session, children took also part in a traditional speech-therapy intervention session, during which other learning domains (e.g., mathematics, graphomotor skills, etc.) except reading were specifically trained for other 20 min. While RRT sessions were managed by a researcher using the same modality of the first study, traditional intervention was carried out by a speech-therapist belonging to the neuropsychiatric unit.

Because of the small sample size and the lack of a control group, it was not possible to carry out any statistical analysis. We compared the performances in the assessed skills before and after the participation in the intervention and found out the following improvements: pseudo-words and text reading speed increased after the intervention respectively of 0.22 and 0.19 z-scores on average; visual sustained attention increased of 0.66 z-scores on average; verbal working memory improved of 0.29 z-scores on average.

3 Discussion and Conclusions

The aim of the present article was to present an innovative computerized rehabilitation program for DD and to show preliminary results about its application in two different settings.

Previous research suggested that musical abilities play a role in reading and that musical training might improve reading skills. However, the musical intervention programs which have been tested so far included a variety of music activities (such as listening, singing, tapping, playing an instrument, etc.) which involved solely auditory and timing processing (e.g., pitch discrimination, reproduction of rhythmic patterns, etc.). The intervention approach that we are presenting, instead, combines a specific reading training, aimed at enhancing grapheme-phoneme connections, and music intervention, providing a simultaneous stimulation of the shared mechanisms between music and language. For implementing that, IT appeared to be the best choice: it provides multimodal (visual and auditory) stimulation as well as the perfect synchronisation of the concurrent presentation of sounds and visual stimuli and allows the trainer to have control over timing and difficulty of the stimulus presentation. Furthermore, the potentiality of music for boosting motivation and provide an enjoyable rehabilitation setting is well known and it is exploited in the training.

The results of the two preliminary studies reported suggest that RRT is effective in improving both reading speed and accuracy [26] and, thanks to the computerized version of the training, RRT can be easily applied in school and clinical rehabilitation settings.

In particular, significant improvements after the RRT were found on both short and long pseudo-words reading speed, as well as in high-frequency long words and in text reading accuracy. These results suggest that RRT is efficient in boosting accuracy in reading the kind of materials to which students are usually exposed to (namely, high frequently used words and text) and in enhancing speed when the grapheme-phoneme conversion mechanism is required, such as in pseudo-word reading. The effect of the training program seems to be specific on reading skills, since no significant improvement in rhythm reproduction was found.

Considering the duration of the intervention (4.5 h of intervention during a 5-week period), far shorter than traditional remediation treatments of DD, the fact that significant improvements of reading skills were found is promising. Regarding the clinical setting application, we found that besides improvements in short-words and text reading speed, also visual sustained attention and verbal memory were enhanced by RRT.

Results suggest that a combination of reading and rhythmic training could be an effective treatment for dyslexia and that the characteristic of the intervention can easily be adapted to different settings (i.e., scholastic and clinical settings).

However, the limited number of participants and the absence of a control group in the second study call for caution in evaluating the outcomes of the intervention. Another limitation of both of the studies is the use of the same battery of tests for both pre and post phase assessments, especially since the assessment sessions were only 5/10 weeks apart; this choice was the best for having a precise comparison of reading abilities.

Further research seems to be necessary to validate the effectiveness of RRT. In particular, it would be crucial to study the role of the rhythmic component in reading improvement. Although the hypothesis of a positive effect of music training on the impaired auditory perception and timing processing of children with DD is supported by experimental evidence, a comparison between RRT and traditional remediation treatments of DD would enable to understand the role of music in reading enhancement. Furthermore, a follow-up assessment should be carried out for evaluating the maintenance of reading improvements.

In conclusion, the combination of music and reading training allowed by the computerized version of RRT seems to be a promising rehabilitation strategy for improving reading skills in students with DD. Besides the effect on reading, this innovative treatment approach involves also an active engagement with music, which provides an enjoyable and pleasant experience for subjects with DD. Furthermore, the use of IT allows, for the reasons mentioned above, the training to be easily implemented also in home settings in a standardized and reliable way.

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