Training RAN or reading? A telerehabilitation study on developmental dyslexia

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Rehabilitation procedures recommended for developmental dyslexia (DD) are still not fully defined, and only few studies directly compare different types of training. This study compared a training (Reading Trainer) working on the reading impairment with one (Run the RAN) working on the rapid automatized naming (RAN) impairment, one of the main cognitive deficits associated with DD. Two groups of DD children (N = 45) equivalent for age, sex, full IQ, and reading speed were trained either by Reading Trainer (n = 21) or by Run the RAN (n = 24); both trainings required an intensive home exercise, lasting 3 months. Both trainings showed significant improvements in reading speed and accuracy of passages and words. Bypassing the use of alphanumeric stimuli, but empowering the cognitive processes underlying reading, training RAN may be a valid tool in children with reading difficulties opening new perspectives for children with severe impairments or, even, at risk of reading difficulties.

KEYWORDS
developmental dyslexia, intervention, rapid automatized naming, reading, telerehabilitation
1  |  INTRODUCTION

The recent advances in the diagnosis of developmental dyslexia (DD; Snowling & Hulme, 2012; Galuschka & Schulte-Köme, 2016) have not been accompanied by comparable and rapid progress in the rehabilitation field, which underscores the need for conducting effective early interventions (Hulme & Snowling, 2016).

Implementing early remediation techniques faces complications due to a series of factors: high costs for the health system, long waiting lists often leading to delayed treatments, most interventions requiring some level of reading ability and therefore not deliverable in the very early phases of reading acquisition, or the extremely poor skill. Furthermore, when reduced reading fluency rather than accuracy characterizes DD, as in languages with regular orthographies (e.g., Wimmer & Goswami, 1994; Zoccolotti et al., 1999), there are still too few interventions available for improving reading speed (Tucci, Savoia, Bertolo, Vio, & Tressoldi, 2015).

The lack of timely rehabilitation and delayed or poorly effective treatments may have long-term effects on educational opportunities and vocational opportunities and success (Ghidoni & Angelini, 2011; Olofsson, Taube, & Ahl, 2015). As a result, the significant reading deficits of individuals with DD impact on daily life to such an extent that they may contribute to the high incidence of overlap with other psychological disorders (Huc-Chabrolle, Barthez, Tripi, Barthélémy, & Bonnet-Brilhault, 2010; Mammarella et al., 2016).

In the last decade, the use of “home-based” rehabilitation tools, for example, tailored online computer exercises adapted and supervised by expert clinicians, has contributed to reducing intervention costs and increasing efficiency of reading remediation (Spencer-Smith & Klingberg, 2015). Recent studies on transparent orthographies have demonstrated the effectiveness of software targeted to home rehabilitation of reading disorders in children with DD (Pecini et al., 2018; Tressoldi, Brembati, Donini, Iozzino, & Vio, 2012; Tucci et al., 2015).

Simultaneously, while most trainings focus specifically on reading (Tressoldi, Vio, Russo, Facoetti, & Iozzino, 2003), others move towards process-oriented interventions attempting to address the main cognitive deficits underlying DD (e.g., Franceschini et al., 2013). As the latter approach does not require reading, it may prove particularly suited for early rehabilitation of reading dysfunctions, especially because it is perceived as easier and more motivating for the child. Nevertheless, existing process-oriented remediation techniques for reading difficulties vary considerably in terms of the specific cognitive function trained with a certain technique (Bonacina, Cancer, Lanzi, Lorusso, & Antonietti, 2015; Gori & Facoetti, 2014), given the multifaced cognitive and linguistic components underpinning normal and impaired reading. This type of rehabilitation approach may thus miss the interactions among the several cognitive functions required by the complex task of reading.

Because there is general agreement that DD may be conceptualized as a “multifunctional deficit model” (Pennington & Bishop, 2009; van Bergen, van der Leij, & de Jong, 2014), training one cognitive function at a time may therefore overlook the complexity of the reading process. In comparison with reading accuracy, which can be

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Practitioner Points
The study contributes to the research on rehabilitation in developmental dyslexia by

- describing the characteristics of home-based procedures for reading rehabilitation;
- comparing task- versus process-oriented rehabilitation methodologies;
- showing the effects of rapid automatized naming exercises on reading decoding;
- suggesting the need to integrate different interventions according to different reading cognitive profiles.
improved by explicit exercises on grapheme–phoneme conversion rules, fluent reading depends on a complex set of cognitive processes that must work together in concert (Zoccolotti, de Jong, & Spinelli, 2016). Thus, it seems a promising perspective to devise interventions that, even without acting directly on the reading task per se, are capable of engaging the different linguistic, visual, and attentional processes involved in reading fluency and integrate these components into a multiple task resembling the complexity of reading.

Many people with dyslexia demonstrate difficulties in rapid automatized naming (RAN) tasks (for a review, see Wolf, Bowers, & Biddle, 2000; Norton & Wolf, 2012). RAN is operationally defined as the ability to name as fast as possible a large array of highly familiar visual stimuli, such as digits, letters, colours, and objects (Denckla & Rudel, 1976). In the last 40 years many studies have investigated the relationship between RAN and reading in children with different reading abilities and found that RAN is an early and significant predictor of reading across different orthographies. RAN is related to reading abilities (Di Filippo et al., 2005, 2006; Helland & Morken, 2016; Papadopoulos, Spanoudis, & Georgiou, 2016; Peterson et al., 2018; Zoccolotti, De Luca, & Spinelli, 2015) regardless of the type of stimulus to be named (Landerl et al., 2013; Papadopoulos et al., 2016; van den Bos, Zijlstra, & Spelberg, 2002). Some studies and meta-analyses suggest, however, that alphanumeric RAN stimuli are more strongly related to reading than are nonalphanumeric stimuli (Araújo, Reis, Petersson, & Faísca, 2015; Georgiou, Aro, Liao, & Parrila, 2016; Song, Georgiou, Su, & Hua, 2016). Mainly for languages with regular orthographies, RAN speed is significantly related to the acquisition of both sublexical and lexical strategies in reading (Gasperini, Brizzolara, Cristofani, Casalini, & Chilosì, 2014; Zoccolotti et al., 2013; Zoccolotti, De Luca, Marinelli, & Spinelli, 2014). RAN deficits are found in DD regardless of the presence or absence of phonological processing deficits (Brizzolara et al., 2006; Chilosì et al., 2009; Nelson, 2015; Pecini et al., 2011; Wolf et al., 2000). Together with verbal working memory and phoneme deletion, RAN speed predicts reading progress of children with dyslexia after intervention (Tilanus, Segers, & Verhoeven, 2016). Moreover, functional neuroimaging findings indicate that RAN tasks activate a fronto-parietal–temporal brain circuit that is similar to that used for reading (Cummine, Chouinard, Szepesvari, & Georgiou, 2015; Cummine, Szepesvari, Chouinard, Hanif, & Georgiou, 2014; Norton et al., 2014).

RAN may be considered as “a microcosm of reading” because like reading task it requires fast multimodal integration and several neurological and cognitive processes: saccadic movements, perceptual recognition, visual attention shifts, working memory, lexical access, and articulatory planning (Norton & Wolf, 2012). In particular, it is suggested that RAN and reading are “allies” because both tasks require time-constrained cross-modal integration of rapid lexical access to visuo-attentional scanning and recognition of serial stimuli (Araújo et al., 2011; Bexkens, van den Wildenberg, & Tijms, 2015; Di Filippo & Zoccolotti, 2012; Georgiou et al., 2016; Georgiou, Parrila, Cui, & Papadopoulos, 2013).

Despite large body of work describing the RAN–reading relationship, the few studies that have attempted rehabilitating RAN in DD have yielded mixed results (De Jong & Vrielink, 2004; Holmes, Wolf, Miller, & Donnelly, 2009; see Kirby, Georgiou, Martinussen, & Parrila, 2010 for a review). These studies used paper and pencil tools, without time constraints and were conceived without autoadaptive and intensive training algorithms. RAN training effects were compared with traditional reading interventions, which differ in more than one methodological aspect, thus making it difficult to tease out which functions directly benefited from RAN intervention.

We have recently developed a new software for telerehabilitation, Run the RAN (RANt, http://info.ridinet.it/app/run-the-ran/), that requires fast naming of serially presented pictures. Much like exercises for reading speed (Tressoldi et al., 2012), RANt decreases stimulus presentation time as a child's performance improves, leading to a progressive increase in naming speed. In order to generalize the improvements in naming speed to reading paragraphs, stimuli are not presented individually but within matrices requiring visual exploration from left to right, thus forcing the automatization of visual scanning. Moreover, in RANt, several cognitive functions required by both RAN and reading can be manipulated such as complexity of visual processing (e.g., stimulus size), visual attention load (e.g., interstimulus distance), lexical access difficulty (e.g., lexical frequency of the pictures name), and phonological planning difficulty (e.g., phonological complexity of the pictures names). The software’s parameters can thus be set to adapt the exercise to the individual cognitive functioning of the child. The program also complies with
the guidelines for neuropsychological rehabilitation (Zoccolotti, 2011) as it is an intensive training requiring daily exercises.

In the present study, the effects of RANt were compared with those obtained with another telerehabilitative software already tested on Italian children with DD, Reading Trainer (RT; Pecini et al., 2018; Tucci et al., 2015). RT is a home-based training aimed to improve reading speed by requiring participants to read aloud different narrative texts displayed on the computer screen with a preset speed that progressively increases according to reading accuracy.

The aim of the present study was to verify if the reading improvements obtained by accelerating the access to the lexical representations of serially presented, nonalphanumeric visual stimuli were comparable with those obtained by a training directly targeting text reading. We hypothesized that as soon as the main cognitive underpinnings of reading are trained with RANt, decoding speed and accuracy would improve as much as they do when phonics instructions are given or whole-word decoding is trained with reading.

2 | METHODS

2.1 | Participants

Forty-five native Italian children, attending primary school, from second to fifth grade, were selected from a larger sample of children referred for learning problems to the Department of Developmental Neuroscience of the Scientific Institute Stella Maris Foundation, Pisa, to the Neuropsychiatric Unit of the Azienda Sanitaria Locale (ASL) of Venice and to the Don Gnocchi Foundation of Milan, during 2015–2016. All children received DD diagnosis (DSM-5; American Psychiatric Association, 2013) according to the following criteria: (a) absence of adverse conditions in prenatal, perinatal, and postnatal clinical history; (b) absence of neurological abnormalities at the standard neurologic examination; (c) nonverbal intelligence in the average range, within 1 standard deviation (sd) from the population mean on the Colored Progressive Matrices (Belacchi, Scalisi, Cannoni, & Cornoldi, 2008) or on the full IQ of the Wechsler Intelligence Scale for Children, Fourth Edition (Orsini, Pezzuti, & Picone, 2012; Wechsler, 2003); (d) impaired scores (z score ≤−1.5 or ≤5 percentile rank) in aloud-reading speed for text passages (MT test; Cornoldi & Colpo, 2011, 2012), words, or nonwords (Batteria per Dislessia e Disortografia Evolutiva (DDE-2); Sartori, Job, & Tressoldi, 2007); and (e) learning difficulties present for at least 6 months and manifest during school-age years when the demands exceed the individual’s limited capacities (e.g., as in timed tests, reading or writing lengthy complex reports for a tight deadline, and excessively heavy academic loads).

For all children, the age of onset of reading problems was identifiable by parents during the anamnestic interview from the beginning of the primary school, but most of the children received a diagnosis of DD in the third grade, when the demands for those academic skills exceed the individual’s limited capacities.

Children were assigned to one type of training according to the partial randomization clinician-centered design (Korn & Baumrind, 1991). Twenty-four children were impaired at the RAN test (≤−1.5 z score; Di Filippo et al., 2005, 2006); these children were assigned to the RANt program (Coop. Anastasis, http://info.ridinet.it/app-run-the-ran). The other 21 children performed the RT intervention (Anastasis; http://info.ridinet.it/reading-trainer) because performances at the RAN task were not necessarily impaired. The two groups did not differ for class, gender, age, and full IQ. As reading speed was the primary outcome measure for both trainings, the two groups were also matched for mean speed in reading passages, words, and nonwords (see Table 1).

No other treatment was carried out during the RANt or RT trainings.

The research project was approved by the Regional Pediatric Ethical Committee (November 20, 2013; Prot. No. 13/2013). All children were carefully informed on the procedure and gave their verbal consent to participate to the study. Written informed consent was obtained from both parents/guardians of the children.
2.2  |  Materials

Children were tested twice, before and after the training.

- The MT test of reading accuracy and speed (MT-2 reading battery; Cornoldi & Colpo, 2011, 2012) was used to test passage-decoding skills. The child was requested to read aloud, within a 4-min time limit, a passage appropriate for level of education. Reading speed was measured in syllables per second (syll/s), while reading decoding accuracy in number of errors.

- In the single-word and nonword reading tests (words and nonwords lists of the DDE-2 battery; Sartori et al., 2007), the child was asked to read aloud as quickly and as accurately as possible four lists of 28 concrete and abstract words with high or low frequency (4- to 8-letter long) and three lists of 16 nonwords (5- to 9-letter long) in line with the phonotactic and phonographic rules of the Italian language. Number of errors and reading speed (seconds) were recorded.

- The RAN test and cancellation test (De Luca, Di Filippo, Judica, Spinelli, & Zoccolotti, 2005; Di Filippo et al., 2005) were used to measure speed of naming and serial stimulus processing. Stimuli were the same for the two tasks and were colours, either black and white objects or digits. Each stimulus type had two matrices. There were 10 rows of five stimuli in each matrix, for a total of 50 stimuli randomly presented. In the RAN task, the child was required to name stimuli in the matrix as quickly and as accurately as possible from left to right. In the cancellation task, the child had to cancel one of the five target stimuli as quickly and as accurately as possible, within matrices equivalent to those of the RAN. For both RAN and cancellation, time to complete the task and number of errors were measured. The cancellation condition was used alongside the Italian standardization of the RAN task, to control for visual search difficulties that could contribute to RAN and reading deficits in children with DD (Di Filippo et al., 2005, 2006).

2.3  |  Interventions procedure

Each child was tested individually. As soon as the initial evaluation was completed, each child started the intervention, either the RANt or the RT.

RANt (http://info.ridinet.it/app/run-the-ran/) is a home-based software requiring the child to name as quickly as possible timed visual nonalphanumeric stimuli (colours or pictures). Stimuli are presented in matrices, requiring left to

| TABLE 1  Mean demographic and clinical characteristics of RANt and RT groups |
|--------------------------------|----------------|----------------|----------------|----------------|
| Sample characteristics       | RANt (n = 24)  | RT (n = 21)    | Inferential statistics | p values |
| Class                        | 2              | 1              | 2              | X²(3) = 1.67 | .64 |
|                             | 3              | 4              | 6              |             | .52 |
|                             | 4              | 12             | 8              |             | .59 |
|                             | 5              | 7              | 5              |             | .59 |
| Gender                       | 10 M, 14 F     | 8 M, 13 F      | X²(1) = 0.06 | .52 |
| Age                         | 9.0 (0.88) years | 9.1 (0.92) years | t(43) = −0.25 | .80 |
| IQ                           | 102.9 (14.8)   | 103.0 (12.3)   | t(37)² = −0.03 | .97 |
| syll/s                      | 1.06 (0.27)    | 1.11 (0.38)    | t(43) = 0.54 | .59 |

Note. syll/s refers to the mean speed at reading passage, words, and nonwords.
Abbreviations: F, female; M, male; RAN, rapid automatized naming; RANt, Run the RAN; RT, Reading Trainer.

Six children (3 from RANt and 3 RT) performed the Colored Progressive Matrices.
right exploration on the computer screen. Five stimuli are repeated randomly within a matrix of 20–50 stimuli. During the exercises, the child must keep the naming speed provided automatically by the computer. When naming performance reaches at least 97% accuracy, naming speed is stressed by reducing the stimulus presentation time of about 50 ms. Stimuli presentation time is managed according to different modalities: in the antiprogressive and single-item modalities, when time expires, stimulus disappears; in the progressive and all-stimuli modalities, a red cursor moves automatically to the next stimulus (see Figure S1). The starting presentation duration for naming is defined by a self-paced matrix, where the child has to name the stimuli at his/her own speed. The naming speed targeted by the training is determined by each child according to the Italian norms of the correspondent school grade. During the exercises, the child must adhere to the naming speed provided automatically by the computer. In order to record the child’s naming speed trend, a self-paced matrix is proposed at the end of each daily session and before new stimuli categories. Finally, as the performance of the child improves, the physical characteristics of the stimuli (size and type) change. The visual discrimination of the stimuli is manipulated by figure size that may progressively decrease to reach a certain target dimension (to a minimum of 1 cm in length). Types of stimuli include colours and black-and-white pictures belonging to different libraries. Libraries contain pictures corresponding to different lexical items varying for lexical frequency, word length, and syllable structure. When a child reaches the target time for a given type of stimulus, the program introduces stimuli from the subsequent library.

Accuracy (number of errors) is recorded by a supervising adult, by pressing “Enter” for every incorrect response on the keyboard. Before each exercise, the child can preview and listen to the names of the stimuli that are going to be presented. Different stimulus presentation modalities (see Figure S1) are presented according to either a random sequence or set by the clinician.

In RANt, it is possible to manage the parameters described above manually or through self-adaptation. The parameters settable by the clinician are as follows: number of stimuli to be named, length of the training session, and the possibility to exclude some stimuli presentation modes or libraries (for details, see “Parameters Setting,” http://info.ridinet.it/app/run-the-ran/). The aim of this procedure is to “break down” the complexity of the task in order to exercise the processes that prove most difficult for a given child.

RT (http://info.ridinet.it/reading-trainer) is another home-based software aimed to improve reading decoding speed. It requires the child to read aloud different narrative texts displayed on the computer screen at a preset speed (syl/s) that progressively increases according to the reading accuracy.

The starting reading speed (syl/s) is preset for each child at about 0.2 syl/s below his/her reading speed in the MT test. For each narrative text, the syllables or the words on the computer screen are individually highlighted in red colour according to the preset speed. The reading accuracy performance (number of errors) is recorded by the adult near the child by pressing “Enter” on the keyboard whenever the child commits a decoding error. When five consecutive narrative texts are read with accuracy above the cut-off criterion (less than 3% of errors), the program automatically increases reading speed of 0.1 syl/s. Narrative texts vary for difficulty according to text length or word complexity and frequency (Gulpease index). Letter size and letter spacing are set for each child in order to make the reading task easy and pleasant (for details, see “Parameters Setting,” http://info.ridinet.it/reading-trainer).

For both RT and RANt interventions, the training lasted for 3 months with sessions administered three to five times a week lasting from 5 to 15 min dependent on each child’s abilities, attention, compliance, and grade. The total amount of training time was about 8 hr for RANt and 12 hr for RT.

Both home-based trainings were conducted under the parent/s/guardian’s supervision. Children were trained, during the first session, by modelling and role playing; child’s level of motivation and naming/reading errors were recorded. All parents/guardians were trained by the clinician on how to manage RANt/RT software, on how to explain the exercises to the child, on how to mark the errors committed during the training, and on how to motivate the child if necessary. No parent/guardian was allowed to give explicit instructions to the child during the exercises.

To ensure that treatment procedure was correct for all children and for all sessions, clinicians monitored via web exercise parameters session’s dates and duration, exercise types, and child performances (see Figure S2). All the other parameters were automatically controlled by the software algorithm. Moreover, when the software recorded some
deviations from the predefined parameters, an automatic message was sent to advise the clinician. In such a case, clinicians had a telephone interview with the parent or directly observed child’s performance during a training session in the clinic.

2.4 | Statistical analyses

The Statistical Package for Social Sciences, version 21.0 (MAC SPSS Statistics, IBM Corporation, 2012) and online statistics (https://www.psychometrica.de/effect_size.html) were used for statistical analyses. Descriptive statistics (mean, standard deviation, and frequency of occurrence) were run to explore the main data trends. Student t tests and the Mann–Whitney test were planned to verify the absence of differences between the two subgroups (RANt and RT) at the pretraining assessment.

In order to verify the training effects and the possible training by group interactions, separate mixed ANOVAs, with type of training as between-subjects factor and pretraining–posttraining as within-subjects factor, were run on both reading speed (syll/s for passage, words, and nonwords) and RAN speed measures for different types of stimuli. On the RAN speed measures, ANCOVA was used in order to covariate the pretraining RAN total score on the training effects because at the pretraining the two groups differed at RAN speed of colours.

To determine the effectiveness of RANt and RT on the outcome measures, pretraining–posttraining effect sizes differences (Cohen $d$) for each of the dependent variables were computed according to paired t-test and Mann–Whitney comparisons. Effect size of the pre-post training differences for each of the dependent variables of each group were then compared with their confidence intervals (Fritz, Morris, & Richler, 2012; Kirby & Gerlanc, 2013).

Effect sizes were interpreted according to Cohen’s reference points (Cohen, 1988): standardized mean differences were considered small when $d \leq 0.20$, medium for $d \geq 0.50$, and large for $d \geq 0.80$.

3 | RESULTS

Parametric statistics were applied on speed measures of reading and RAN as they were normally distributed within each group (skewness and kurtosis indexes <2, as suggested for clinical sample). Nonparametric comparisons were used on accuracy measures as they often overcame the cut-off for either skewness or kurtosis.

3.1 | Pretraining assessment

Given the selection criteria, mean decoding speed was significantly lower than expected from school-matched typical readers (below $−1.5$ sd), and it was impaired in reading passage (mean $z$ score $= −1.6$, sd $= 0.40$), words (mean $z$ score $= −1.98$, sd $= 2.2$), and nonwords (mean $z$ score $= −2.25$, sd $= 1.7$).

RANt and RT training groups did not significantly differ in any measures with the exception of RAN colours where the RANt group obtained worse performances than did the RT group (see Table 2). The two training groups were therefore comparable at the pretraining tests on the primary outcome measures.

In the cancellation task, mean scores across the three conditions were in the normal ranges (colours: mean $z = −0.73$, sd $= 1.26$; figure: mean $z = −0.83$, sd $= 1.28$; numbers: mean $z = −0.51$, sd $= 1.20$).

3.2 | Trainings effects

Premean and postmean reading values of the two groups and the results of mixed ANOVAs (Pre-Post training x group) are reported in Table 3.
ANOVAS on reading speed showed the main effect of the training without significant Pre–Post training × group, indicating similar improvements after RT and RANt training in reading passage, words, and nonwords (Table 3).

ANCOVA on RAN speed showed significant Preassessment–Postassessment × Group interactions for both colours and numbers as the RANt group had larger pretraining–posttraining differences than had the RT group; nevertheless, for all types of stimuli, also the pretraining total RAN significantly covaried with training effects, suggesting the effect of the pretraining performances at the RAN test on the Training × Group interaction (Table 3).

Visual inspection of Table 3, revealed larger pretraining–posttraining differences in reading passage errors in the RANt group than in the RT group; however, variability was high in both groups, and Mann–Whitney comparisons were not significant (passage: $z = -0.47, p = .64$; word: $z = -0.89, p = .37$; nonword: $z = -0.71, p = .48$).

Pretraining–posttraining effect size for each dependent variable for the two groups are reported in Table 4. In the RANt group, effect sizes of treatment were medium or large in all outcome measures with the exception of passage reading accuracy; in the RT group, medium and large effects size were found on reading outcome measures but not on RAN.

### 4 | DISCUSSION

The present study confirms previous researches on telerehabilitation of DD in regular orthography by showing that home-based software can effectively speed-up reading aloud after only a few months of teletraining that may foster automatization of the reading processes (Pecini et al., 2018; Tucci et al., 2015). Home exercises were generally well accepted by children with DD and their families, and RANt was perceived as an easy and enjoyable task not requiring the more difficult activity of reading.

The main and new result of the study is that speed and accuracy of reading improved regardless of training type, RT versus RANt. This finding suggests that it is possible to ameliorate reading by exercising RAN. Thus, RAN is a task suitable not only to predict reading efficiency (Landerl et al., 2013) but also to improve reading speed and accuracy.

In agreement with the literature on the RAN–reading relationship (Georgiou et al., 2013), it may be hypothesized that training RAN improves reading by consolidating both lexical access and visual exploration of multiple stimuli that are involved in both RAN and reading tasks.

It seems likely that the RANt efficacy found in the present study is in part attributable to the specific methodology used for the training. Previous studies attempting to improve RAN did not find significant effects on reading.
However, such studies used less intensive, paper-and-pencil, and not autoadaptive, trainings (De Jong & Vrielink, 2004), presumably limiting the effect of the RAN exercise on the automatization of the cognitive underpinnings required for fluent naming and reading. In children with DD, where visuoverbal integration needs to be accelerated

### TABLE 3
Pre-post training mean reading values after RANt and RT groups and mixed ANOVAs’ results

<table>
<thead>
<tr>
<th>Measures</th>
<th>RANt</th>
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<th>RT</th>
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<th>F (df)</th>
<th>p values</th>
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<tr>
<td></td>
<td>Premean (sd)</td>
<td>Postmean (sd)</td>
<td>Premean (sd)</td>
<td>Postmean (sd)</td>
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<td>Reading speed: syll/s</td>
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<tr>
<td>Passage</td>
<td>1.36 (0.43)</td>
<td>1.71 (0.45)</td>
<td>1.44 (0.57)</td>
<td>1.75 (0.60)</td>
<td>44.51 (1, 43)</td>
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<tr>
<td>pre-post effect</td>
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<tr>
<td>RAN–RT effect</td>
<td>0.14 (1, 43)</td>
<td>.24 (1, 43)</td>
<td>.24 (1, 43)</td>
<td>.24 (1, 43)</td>
<td>.71</td>
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<td>Factors interaction</td>
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<td>.62</td>
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<tr>
<td>Words</td>
<td>1.01 (0.32)</td>
<td>1.36 (0.46)</td>
<td>1.04 (0.41)</td>
<td>1.43 (0.45)</td>
<td>82.57 (1, 43)</td>
<td>.000</td>
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<tr>
<td>pre-post effect</td>
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<tr>
<td>RAN–RT effect</td>
<td>0.16 (1, 43)</td>
<td>.22 (1, 43)</td>
<td>.22 (1, 43)</td>
<td>.22 (1, 43)</td>
<td>.68</td>
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<td>Factors interaction</td>
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<td>.64</td>
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<tr>
<td>Nonwords</td>
<td>0.80 (.21)</td>
<td>1.01 (0.23)</td>
<td>0.84 (0.31)</td>
<td>1.05 (0.31)</td>
<td>47.45 (1, 42)</td>
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<tr>
<td>pre-post effect</td>
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<td></td>
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</tr>
<tr>
<td>RAN–RT effect</td>
<td>0.31 (1, 42)</td>
<td>0.01 (1, 42)</td>
<td>.31 (1, 42)</td>
<td>.01 (1, 42)</td>
<td>.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factors interaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.98</td>
</tr>
</tbody>
</table>

### TABLE 4
Pretraining–posttraining effect sizes differences (Cohen \(d\)) for each of the dependent variables, mean pretraining and posttraining differences (post–pre), and standard deviation (sd)

<table>
<thead>
<tr>
<th>Measures</th>
<th>RANt</th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>d _z</td>
<td>post-pre</td>
<td>sd</td>
<td>RT</td>
<td>d _z</td>
<td>post-pre</td>
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<td>Reading passage</td>
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<tr>
<td>Speed</td>
<td>0.8</td>
<td>.35</td>
<td>.25</td>
<td>0.51</td>
<td>.30</td>
<td>.39</td>
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<tr>
<td>Accuracy</td>
<td>0.26</td>
<td>-1.19</td>
<td>5.8</td>
<td>0.53</td>
<td>-1.7</td>
<td>5.8</td>
</tr>
<tr>
<td>Reading words</td>
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<tr>
<td>Speed</td>
<td>0.74</td>
<td>.35</td>
<td>.25</td>
<td>0.88</td>
<td>.38</td>
<td>.28</td>
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<tr>
<td>Accuracy</td>
<td>3.45</td>
<td>-3.53</td>
<td>5.8</td>
<td>3.62</td>
<td>-1.1</td>
<td>8.2</td>
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<td>Reading Nonwords</td>
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<tr>
<td>Speed</td>
<td>0.95</td>
<td>.21</td>
<td>.17</td>
<td>0.69</td>
<td>.21</td>
<td>.24</td>
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<tr>
<td>Accuracy</td>
<td>2.47</td>
<td>-2.41</td>
<td>7.5</td>
<td>2.3</td>
<td>-3.3</td>
<td>7.3</td>
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<tr>
<td>RAN</td>
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<td></td>
<td></td>
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<tr>
<td>Colours</td>
<td>0.81</td>
<td>1.34</td>
<td>1.14</td>
<td>0.25</td>
<td>.19</td>
<td>.82</td>
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<td>Figures</td>
<td>0.93</td>
<td>1.25</td>
<td>1.25</td>
<td>0.02</td>
<td>.02</td>
<td>.82</td>
</tr>
<tr>
<td>Numbers</td>
<td>0.67</td>
<td>.99</td>
<td>1.07</td>
<td>0.12</td>
<td>.15</td>
<td>1.26</td>
</tr>
</tbody>
</table>

Note. Large and medium effect sizes are in bold.

Abbreviations: RAN, rapid automatized naming; RANt, Run the RAN; RT, Reading Trainer; sd, standard deviation.

However, such studies used less intensive, paper-and-pencil, and not autoadaptive, trainings (De Jong & Vrielink, 2004), presumably limiting the effect of the RAN exercise on the automatization of the cognitive underpinnings required for fluent naming and reading. In children with DD, where visuoverbal integration needs to be accelerated
and automatized, intensive and repetitive trainings may be particularly effective (Dahlin, 2011; Holmes et al., 2010). These features are difficult to realize in rehabilitation programs provided in day-service settings or that are only based on paper-and-pencil exercises. Conversely, home-based telerehabilitation software allows for daily intensive trainings and clinician-managed parameter settings to increase automatization (Bavelier, Green, & Seidenberg, 2013; Klingberg et al., 2005). Another important feature of telerehabilitation is that the exercise difficulty is always closely above the child's performance, making the task not only sufficiently stimulating but also easy enough to guarantee successful achievement and exercise repetition (Wexler, Vaughn, Edmonds, & Reutebuch, 2008). Through autoadaptivity, both RT and RANt automatically modulate and online update stimuli characteristics to the child’s level online. The more the stimuli are compatible with the child’s learning progress, the more the zone of proximal development is promoted. Autoadaptivity also allows for a continuous feedback to the child and stimulates greater self-control of competency (Chacko, Uderman, Feirsen, Bedard, & Marks, 2013; Diamond & Lee, 2011; Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2009).

Despite the similar effects of the two trainings on reading, larger improvements at the RAN test were found after RANt than after RT. Nevertheless, it must be noted that at the pretraining the two groups were equivalent for reading level, which, according to the aim of the study, represents the main primary measure outcome, but they were different for performances at the RAN test performance. By covarying RAN performances at the pretraining with training effects, no significant interactions were found between the preimprovements and postimprovements at the RAN test and the type of intervention. This finding reinforces the idea that reading and rapid naming cowork for literacy learning: the automatization of rapid naming speeds up reading and vice versa (Peterson et al., 2018).

Some methodological limitations of the study should be pointed out. The enrollment of children to the two different trainings was not randomized but rather based on each functional profile. This procedure referred to as partial randomization clinician-centered design (Korn & Baumrind, 1991), allows allocating a certain child to the best appropriate training, but it increases the chance of uncontrolled covariates. Moreover, training effects were tested only immediately after the interventions, and follow-up data are not available. Thus, the findings of the present study should be confirmed through randomized controlled trials and follow-up designs. Finally, as sample size was modest and age varies across grades, future data on larger samples may verify RANt efficacy on reading across different grades.

Nevertheless, the evidence from the present study raises the interesting possibility that training RAN is an additional tool that may complement other rehabilitation techniques. It could be the case that an optimal intervention strategy would first use exercises, such as in RANt, to consolidate rapid lexical access of multiple visual stimuli, followed by exercises focused on reading, to further reinforce grapheme–phoneme conversion rules. In this way, the gains obtained in the cognitive processes underlying reading and trained by the rapid naming exercise may induce greater generalization to the reading task itself. Especially in young children at risk of reading difficulties or in children with severe dyslexia, for whom reading exercises could be too difficult and frustrating to carry out, training exercises of rapid serial naming of nonalphabetic stimuli may be more pleasant and motivating to perform than taxing literacy-based methods.

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FUNDING INFORMATION

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.