Comparison of the Effect of Cognitive Rehabilitation and Neurofeedback on Sustained Attention Among Elementary School Students with Specific Learning Disorder: A Preliminary Randomized Controlled Clinical Trial

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Abstract
Specific learning disorder (SLD) can occur along with the problems of attention performance and be complicated by them. Recent studies have reported the positive effects of cognitive rehabilitation (CR) and neurofeedback (NFB) on sustained attention (SA) in SLD. Nevertheless, it has not yet been determined what kind of treatment may be the most appropriate option for this disorder in terms of the different functions of cognitive status, especially SA. This preliminary study aimed to compare CR and NFB effects on SA among elementary school students with SLD using a randomized controlled clinical trial (RCT). Fifty-three eligible students with a DSM-5 SLD diagnosis, aged 7–10, were randomly allocated in NFB ($n=18$), CR ($n=18$), and control groups ($n=17$). All the participants were evaluated for SA by performing the continuous performance test (CPT) on the studied groups at the time of their inclusion in the study and 7 weeks after it. The intervention groups took part in 20 sessions of CR and 20 sessions of NFB. Conversely, the untreated group were evaluated without any intervention.15 boys and 30 girls in 3 groups completed the study ($n=15$ per group). The mean and standard deviation of participants’ age were (8.66 ± 1.48) years, (8.40 ± 1.73) years and (8.53 ± 1.63) years in CR, NFB and untreated groups, respectively. The results showed significant differences between the groups based on the variables of the CPT test ($p<0.05$). Also, the significant effects of the variables represented the higher scores of the CR compared to the NFB group ($p<0.001$). This study provides initial evidence that CR is more effective than NFB on SA improvement among students with SLD.

Keywords Cognitive rehabilitation · Neurofeedback · Sustained attention · Specific learning disorder

Introduction
Specific learning disorder (SLD) is one of the most common neuro-developmental disorders among school-aged children (Moll et al. 2014). It involves the ongoing problems of learning the key academic skills, including reading, writing, and math. SLD prevalence among elementary school children is 5–15% in the area of education (DSM-5; American Psychiatric Association 2013). SLD students are more likely to be dropped out of school (Vogel and Reder 1989), suffer joblessness (Shapiro and Lentz 1991), and develop suicidal thoughts in comparison to other students (Daniel et al. 2006).

Sustained attention (SA) is the ability to direct attention and focus on specific stimuli for a continuous amount of time without being distracted (Oken et al. 2006; Bergera and Cassutob 2014). Learning disabilities (LD) can occur along with the problems of attention performance and be complicated by them (Sterr 2004). There is evidence that children with specific reading disorders have SA deficits (Duncan et al. 1994). Some studies have demonstrated that children with dyslexia exhibit attention deficits (Facoetti et al. 2006; Marzocchi et al. 2009). For example, Facoetti and Molteni (2000) showed that children with dyslexia have problems with focusing attention on texts and simultaneously inhibiting distractor stimuli.

In recent decades, there has been growing interest in the use of cognitive rehabilitation (CR) in the field of executive...
functioning (Rodríguez-Blanco et al. 2017) among children and adolescents with LD (Peijnenborgh et al. 2016). CR includes a collection of methods designed to increase executive functioning, such as perception, attention, comprehension, learning, memory, problem solving, and reasoning, in the related impaired persons (Galletly and Rigby 2013). There is some evidence that show CR can promote SA in LD (Gray et al. 2012) and some other diseases like cerebral palsy (CP) (Muriel et al. 2014), alzheimer (Kasper et al. 2015), and multiple sclerosis (MS) (Amato et al. 2013; De Giglio et al. 2015).

Neurofeedback (NFB) is another technique that is used today to reduce LD symptoms (Mosanezhad Jeddi and Nazari 2013). As an intervention, it can be helpful in the treatment of some disorders and relevant abnormalities by regulating electroencephalogram (EEG), functional magnetic resonance imaging (fMRI), and hemoencephalography (HEG) (Nazari et al. 2012). This treatment approach as a non-pharmacological intervention tends to alter brain activities by providing any feedback for EEG activity (Loo and Makeig 2012). It has been observed that NFB can improve SA in some disorders, such as reading disorder (Mosanezhad Jeddi and Nazari 2013) and attention-deficit/hyperactivity disorder (ADHD) by increasing and decreasing beta and theta activities, respectively.

As noted, SLD is often accompanied by impairments in neurocognitive functioning like SA deficits (Lawrence et al. 2003). Recent studies have reported CR (Gray et al. 2012; De Giglio et al. 2015) and NFB (Mosanezhad Jeddi and Nazari 2013) positive effects on SA in SLD and some other disorders. However, to date, no comprehensive studies have been done to compare CR and NFB training for children with SLD and determine the best treatment option in terms of SA as a function of cognitive status. Therefore, the primary objective of the present study was to determine CR and NFB efficacy on SA among elementary school students with SLD. Also, in this preliminary study, we tried to compare CR and NFB effects on SA among the mentioned students using a randomized controlled clinical trial.

Before the study enrolment, a psychologist screened the participants for eligibility. The inclusion criteria were having an age of 7–10 years, educational grades of 1–4 with at least 1 year of education, and no comorbidity of other neurological disorders, such as ADHD, communication disorder (CD), developmental coordination disorder (DCD), autism spectrum disorder (ASD), or other mental disorders, including anxiety disorders (ADs), mood disorders (MDs), and bipolar disorders (BDs) according to the parents and as recorded for the psychiatric cases that could be interfered with SLD diagnosis. The exclusion criteria were having abnormal mental abilities, receiving CR or NFB before entering the study, and not cooperating.

**Intervention**

**Cognitive Rehabilitation (CR)**

The three approaches of child-clinical psychology, educational psychology, and brain injury rehabilitation provide the interventions that are combined in a tripartite model called CR (Butler and Copeland 2002). A specific individualized CR training is programmatic and consists of the following interdependent components: (a) strategy acquisition, (b) massed practice of hierarchically graded exercises, and (c) cognitive-behavioral intervention. The studied students completed a modified version of attention process training (APT) program in CR, which had been designed for reinforcing the dimensions of attentional processes and developed by Sohlberg et al. (Sohlberg et al. 1999; Sohlberg and Mateer 1999). The specific exercises were selected based on 50–80% of the rule-based guidance. An activity was considered to be too complex when at least 50% of it could not be correctly performed by the participants and thus a more basic task was selected. The next level of complexity was practiced upon obtaining of 80% of accuracy. The preliminary RCT was intervened according to Butler and Copeland’s CR approach (Butler and Copeland 2002).

The mentioned program incorporated a series of attentional exercises, which were graded hierarchically. 15 metacognitive strategies in the field of education were designed in the form of a dictionary to address the general areas of preparedness, task approach, on-task behavior, and generalization. The 1st strategy might be exemplified as assisting the students to identify a special word or term by teaching them a brief breathing exercise that signaled their readiness to initiate a difficult task. The 2nd strategy dealt with completing the activities through a systematic approach besides an appropriate self-encouragement. The 3rd strategy involved the repetitive checking of one’s own work while maintaining a self-dialogue encouragement during the course of an exercise. Finally, the 4th strategy was promoted by providing

**Methodology**

**Study Design and Subjects**

To this goal, 53 consecutive students aged 7–10 years and diagnosed with SLD according to the Diagnostic and Statistical Manual of mental disorders (DSM-5 criteria) (American Psychiatric Association 2013), who had attended an LD center (Tabriz, IR Iran), were randomly divided into 3 groups: NFB (n = 18), CR (n = 18), and untreated group (n = 17).
parents and teachers with a list of their children’s strategies to ensure their applications both at home and school. Cognitive-behavioral interventions (Kendall 1991) for the children were adopted from the child-clinical psychology described in the literature, the designs of which were based on improving the children’s resistance to distraction, as well as helping them learn how to be their own coaches during the long course of a difficult activity. The mentioned interventions were done by modeling a proper internal dialogue in a clear manner. Then, the dialogue was practiced by the children in a similar way. Ultimately, they used the dialogue in a covert manner as soon as they proved to have appropriately acquired the skills. Acquisition of the cognitive skills were followed by an active distraction triggered by the therapist. Visual imagery and chunking served as the mnemonic strategies learnt by the children within the cognitive-behavioral framework as well (Sohlberg and Mateer 1989).

A 7-week training course incorporated 20 CR sessions into the program. The children and their parents were allowed to meet for 45–60 min three times a week with a 5-min break between the sessions. Moreover, an interaction was provided between the coach and children’s parents and sometimes teachers if possible. A certified CR training coach, who was completely independent from the study team, supervised the CR training program.

**Neurofeedback (NFB)**

This type of treatment was carried out through a specific system of NFB consisting of a Play Attention Interactive Learning Tool (Fletcher, NC: Unique Logic and Technology Inc.) with an impedance tracing of less than 5 kΩ to automatically control the artifacts (>120 μV). EEG was analyzed based on the two frequency bands of 4–7 and 12–15 Hz for theta and beta activities, respectively. The tulpus of both ears and head skin were cleansed with white alcohol and Nuprep gel and the electrodes were bonded using a TEN20 adhesive. The brain waves were recorded at a neroscan rate of 250 Hz. Ear-link montages were assembled during EEG registration (Demos 2005). The monopolar signal for FCz localization was based on the 10–20 international placement system with ear reference points applied in EEG recordings which were obtained during the theta/beta training sessions held every week for the participants aged 7–10 years. Six 4-min runs were conducted in each of the three theta/beta training sessions held every week for the participants to complete the treatment program within a total period of 20 sessions based on the recommended guidelines (Monastra et al. 2005). Determination of the baseline values at 30 s was managed at the beginning of each session, which was followed by an introductory period of 2–5 min for familiarizing the participants with the procedure. The EEG feedback and training periods were later enhanced with the initial duration of 120 s for each child’s learning curves. The subjects’ theta and beta activities were respectively decreased and increased through practicing and learning their different ways of figure manipulation on the computer screen. Following the alterations in the theta: beta ratios, they were able to learn how to ameliorate their attention on the six different tasks and score their own points by using an algorithm through the computer program. The participants would be rewarded if their theta and beta times of activities showed the thresholds of lower and higher than 70 and 20%, respectively.

The 20-session monitoring of the children’s NFB training and implementation fidelity was done by a trained research assistant, who administered the former via a standardized 2-week training program and the latter by filling out a standardized session checklist at end of each session.

**Measurements**

**Continuous Performance Test (CPT)**

SA was examined using a computerized, standard version of the Conner’s CPT (Version 3.0, Conners 1994). During the sequential presentation of a series of letters (1 inch in size), the subjects were instructed to press any letters on the keyboard, except for “X”. In this test, one letter appeared on the screen at a time for 250 ms. This task took approximately 14 min to be completed and inattention was assessed by the number of omission errors (i.e., the targets to which the participants did not respond), commission errors (i.e., false positives), and response times (Adams et al. 2011; López-Martín et al. 2013). Some studies have supported the acceptable validity of CPT for research objectives (Raz et al. 2014). The reliability of this research was estimated by using the Cronbach’s alpha coefficient of 0.78 for CPT.

The participants in groups were evaluated for SA using CPT. SA was administered at the baseline time and 7 weeks after beginning the study. Accordingly, the participants in the experimental groups were evaluated before and after 20 sessions of CR and 20 sessions of NFB, while the subjects in the untreated group were assessed at the baseline and after 7 weeks of inclusion in the study without any interventions. To prevent the participants from being informed of their random divisions into the three groups and grouping methods, the untreated group received an artificial NFB in a way that the conditions for performing the intervention like skin preparation and attachment to the electrodes were provided similar to the real NFB group. There was only a difference between the feedbacks provided for the other two groups. In the untreated group, no feedbacks (either audibly or visually) were provided based on the electroencephalographic data.
Statistical Analysis

Data were presented as mean ± standard deviation and frequency (percentage), respectively. All the findings were consistent when analyzed by time (pre- and post-test periods) and group (CR, NFB, and untreated groups) via repeated measures MANOVA. The independent between-group variables included the three levels of CR, NFB, and untreated groups. The independent within-group variables consisted of the two levels of pre- and post-test evaluation periods. The dependent variables were the SA variables of omission errors, commission errors, and response time. Bonferroni’s post-hoc analysis was used to compare the SA variables between the three study groups before and after the interventions. Cohen’s $F^2$ provided the small, medium, and large estimations of 0.02, 0.15, and 0.35 for the effect sizes, respectively (Cohen 1992). All statistical analyses were conducted with IBM SPSS Statistics, version 20.0 (IBM Corp 2011). $P$ values less than 0.05 were considered as statistically significant.

Results

Demographic Data

Totally, 69 SLD students participated in the study to be then screened based on the eligibility criteria (Fig. 1). Of these, 16 did not meet the eligibility criteria: 6 showed the presence of attention deficit/hyperactivity disorder and/or developmental coordination disorder using the parents and recorded in the psychiatric cases while 4 received NFB and 2 received CR before entering the study, 4 were over 11 years of age. The remaining 53 children were randomized to one of the three groups. 6 children dropped out during each pre-test period of CR and NFB training. Also, two children dropped out at the post-test in the untreated group. Therefore, 45 children completed the study: CR ($n = 15$), NFB ($n = 15$) and untreated group ($n = 15$).

The total sample included 45 individuals (15 and 30 boys and girls, respectively), while 5%, 33.3%, and 61.7% of them were 7–8, 8–9, and 9–10 years old, respectively. The mean and standard deviation of participants’ age were (8.66 ± 1.48) years, (8.40 ± 1.73) years and (8.53 ± 1.63) years in CR, NFB and untreated groups, respectively. 16 (51.7%), 26 (43.3%), 2 (3.3%), and 1 (1.7%) students enrolled in the 1st, 2nd, 3rd, and 4th grades of an elementary school, respectively.

CPT

Each variable of CPT evaluated at the pre-test and the post-test between the three groups are presented in Table 1. All the measures of omission errors, commission errors, and response time improved from the pre- to the post-test periods in both of the intervention groups, but not in the untreated group (Table 1).

Comparison of the CPT variables at the pre-test and the post-test between the three groups are presented in Table 2. The variables of SA were evaluated for the three groups based on CPT at the baseline and 7 weeks after beginning the investigation. Repeated measures MANOVA depicted
significant multivariable effects for the groups ($F^2 = 0.31$, $F = 0.001$, $F_{(6,82)} = 6.20$, $V = 0.625$), and evaluation periods ($F^2 = 0.45$, $P = 0.001$, $F_{(3,40)} = 11.18$, $V = 0.456$), as well as significant interaction effects between the groups and evaluation periods ($F^2 = 0.46$, $P = 0.001$, $F_{(6,82)} = 11.83$, $V = 0.829$).

The univariable between-group analysis displayed significant effects for the omission errors ($F^2 = 0.30$, $P = 0.001$, $F_{(2,42)} = 9.03$), commission errors ($F^2 = 0.25$, $P = 0.002$, $F_{(2,42)} = 7.08$) and response time ($F^2 = 0.27$, $P = 0.001$, $F_{(2,42)} = 8.10$) with the lower scores of CR group compared to the other groups. The univariable within-group analysis demonstrated that the omission errors ($F^2 = 0.04$, $P = 0.003$, $F_{(1,42)} = 2.06$), commission errors ($F^2 = 0.08$, $P = 0.001$, $F_{(1,42)} = 3.94$) and response time scores ($F^2 = 0.37$, $P = 0.001$, $F_{(1,42)} = 25.23$) had significantly improved from the pre-test to the post-test stages, regardless of the groups. In addition, there were significant interaction effects between the groups and evaluation periods in terms of the omission errors, $F^2 = 0.53$, $P = 0.001$, $F_{(2,42)} = 23.98$, commission errors, $F^2 = 0.43$, $P = 0.001$, $F_{(2,42)} = 15.43$, and response time, $F^2 = 0.26$, $P = 0.001$, $F_{(2,42)} = 84.92$ (Table 2).

Post-hoc comparisons using the Bonferroni’s test were indicative of significant effects for the omission errors, commission errors, and response time associated with the higher scores of the CR compared to the NFB group ($p < 0.001$) as well as those of the experimental compared to the untreated group ($p < 0.001$).

### Discussion

The data analysis revealed some SA changes caused by NFB and CR in the SLD students. For example, omission errors, commission errors, and response time in the CPT were reduced after NFB and CR training.

Different studies have indicated that children with SLD have SA deficits significantly correlated with executive functioning (Willcutt et al. 2011), while improvement of these abilities can result in enhanced academic skills among people with LD (Swanson and Jerman 2007).

Mosanezhad Jeddi and Nazari (2013) reported the successful use of NFB for continuous attention and working memory improvements leading to decreased theta and increased beta activities in reading disorders (15–18 Hz). Furthermore, some studies have reported NFB efficacy in SA improvement in ADHD (Steiner et al. 2014).

Despite these positive points regarding the useful effects of NFB on SA, a study conducted by Rostami et al. (2017) revealed that NFB had no effects on SA in patients with Traumatic Brain Injury (TBI). This contradiction is justified by the various disorders discussed in both studies. Furthermore, their study suffered from a reduced sample size.

The main results obtained from our research were suggestive of decreased omission errors, commission errors, and response time through a CR compared to an NFB program based on CPT assessment.

There are some studies evaluating CR effects on cognitive functions, such as attention in SLD people. In a randomized controlled trial study, Gray et al. (2012) assessed the effects of a computerized working memory training (WMT) program on adolescents with LD/ADHD. They compared their attentions during the pre- and post-math training and WMT periods. Finally, they showed that WMT is more effective than motor training (MT) in attention improvement. Their findings demonstrated smaller effect sizes for omission errors, commission errors, and response time associated with the higher scores of the CR compared to the NFB group ($p < 0.001$) as well as those of the experimental compared to the untreated group ($p < 0.001$).

#### Table 1

| Variable   | Groups | At the pre-test | At the post-test |
|------------|--------|----------------|-----------------|
|            |        | $M \pm SD$     | $M \pm SD$      |
| Omissions  | CR     | 2.05 ± 4.26    | 1.06 ± 1.43     |
|            | NFB    | 1.43 ± 3.25    | 0.82 ± 2.60     |
|            | Untreated | 1.16 ± 3.36   | 1.28 ± 3.93     |
| Commissions| CR     | 1.53 ± 9.73    | 1.42 ± 4.20     |
|            | NFB    | 1.35 ± 8.60    | 0.98 ± 5.40     |
|            | Untreated | 9.06 ± 1.48   | 9.85 ± 1.84     |
| Response time | CR | 34.01 ± 434.56 | 30.98 ± 332.40  |
|            | NFB    | 31.55 ± 453.73 | 29.60 ± 347.53  |
|            | Untreated | 32.23 ± 423.30 | 32.57 ± 436.21  |

$M$ mean, $SD$ standard deviation, $SA$ sustained attention, $CR$ cognitive rehabilitation, $NFB$ neurofeedback

$N = 45$

#### Table 2

|                      | Main effect | Interaction effect |
|----------------------|-------------|-------------------|
|                      | Within-group| Between-group     |                   |
|                      | $F$        | $P$               | $F$      | $P$ | Effect size, Choen’s $F^2$ |
| Omissions            | 2.06       | 0.003             | 9.03     | 0.001 | 0.30          | 23.98       | 0.001 | 0.53          |
| Commissions          | 3.94       | 0.001             | 7.08     | 0.001 | 0.25          | 15.86       | 0.001 | 0.43          |
| Response time        | 25.23      | 0.001             | 8.10     | 0.001 | 0.27          | 84.92       | 0.001 | 0.26          |

$F$ and $P$ values refer to repeated-measures MANOVA comparing groups.
errors, commission errors, and especially, response time as compared to the previous studies (Gray et al. 2012).

CR can have significant impacts on SA (Rodríguez-Blanco et al. 2017). For example, Kasper et al. (2015) reported SA improvements following CR in cases of alzheimer diseases. Some other studies supported these findings for other diseases like CP (Muriel et al. 2014) and MS (Amato et al. 2013; De Giglio et al. 2015).

Nevertheless, it was difficult to identify the underlying mechanisms for the clinical improvements of SLD students following CR in our research. In this regard, some researchers have reported functional reorganization occurring to specific brain regions following executive functions or SA via rehabilitative programs based on fMRI observations (Sastre-Garriga et al. 2011; Cerasa et al. 2013). Structural reorganization has been also evidenced following CR even after short periods of intervention (Cerasa et al. 2013). Although similar mechanisms can be hypothesized to have involved our study population, further research is required to prove any association between functional and structural modifications and CR training programs.

Anyhow, as clearly evidenced by our study, the NFB protocol did improve the students’ scores on the Conners’ CPT, while the training protocol contributed to a decrease and increase in the theta (4–8 Hz) and beta (12–15 Hz) activities, respectively. There are many different kinds of NFB protocols leading to various outcomes. NFB may be altered into a very different protocol by changing its location and frequency (Marzbani et al. 2016). Therefore, it may be more effective than CR training, but its confirmation will require future research.

Limitations

Some limitations of this investigation included non-generalizability of the interventions for the studied elementary school children involved in SLD to any other individuals like similar high school children and lack of the RCT follows-up due to having limited access to the children.

Conclusion

In this study, CR and NFB efficacy in SA improvement among the SLD students was documented. We concluded that CR was more effective on SA than on NFB improvement among the subjects. However, further research is needed to corroborate CR effects on SLD children. Future studies should include larger sample sizes, various participants with different educational levels, more sessions, and longer follow-up periods based on varied protocols.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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