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Brief report

Improving cognitive functions in adolescents with learning difficulties: A feasibility study on the potential use of telerehabilitation during Covid-19 pandemic in Italy

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ABSTRACT

Introduction. Learning disabilities are due to genetic and/or neurobiological factors that alter brain functioning by affecting one or more cognitive processes related to learning. This study aimed to assess the efficacy of cognitive telerehabilitation in adolescents with learning disabilities to overcome the treatment problems related to the COVID-19 pandemic lockdown. Methods. Twenty-four patients diagnosed with Unspecified Learning Disability (mean ± SD age: 18.2 ± 2.9 years; 50% male) were enrolled in this study. The patients were assessed by a neuropsychological evaluation at the beginning and at the end of the program. All patients received cognitive treatment via a specific telehealth app to stimulate the cognitive skills related to learning. The treatment lasted four weeks, with a daily training (lasting up to 60 min), for five days a week. Results. Our young patients reported a statistically significant improvement in the main cognitive domains that are usually compromised in learning disabilities, including sustained and selective attention, shifting of attention, control of interference, memory and speed of information processing. Moreover, the patients showed a good usability and motivation during the training. Conclusions. Our study has shown that telerehabilitation could be a valid tool for the rehabilitation of specific cognitive skills in adolescents with learning difficulties.

1. Introduction

The COVID-19 pandemic is due to the new coronavirus SARS-CoV-2. Most patients with Covid-19 experience flu-like symptoms, although in some cases the disease may cause a multiorgan failure potentially leading to death (Guan et al., 2020). Since the first cases reported in Wuhan (China; January 2020), the virus spread rapidly all over the world, and the epidemic was declared a public health emergency of international interest by the World Health Organization. This health emergency and the consequent adaptation of the healthcare services have negatively influenced the organization of rehabilitation treatments of non-COVID-19 diseases (Xiang et al., 2020), including developmental disorders. Moreover, restrictive measures, such as isolation, quarantine, and social distancing totally changed social relationships, including those between doctors and patients.

Various studies have shown that telerehabilitation could help supporting both physical and psychosocial needs of the individuals

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living at home with an improvement of motor, cognitive, or psychological disorders (Bramanti et al., 2018; De Cola et al., 2016; Maggio et al., 2020; Zhou et al., 2020). Telerehabilitation is a field of telemedicine, consisting of systems/devices for the control of remote rehabilitation training, such as physiotherapy, speech therapy, occupational therapy, as well as assistance of patients forced to stay at home, without the physical presence of therapists or other healthcare professionals (Calabrò et al., 2020; De Cola et al., 2020; Rosso et al., 2018). In particular, tele-cognitive rehabilitation involves the recovery and/or compensation of impaired cognitive and behavioral skills to improve the quality of life of the patient in his/her family and social environment. As the use of telerehabilitation has been shown to be at least equivalent to the traditional face-to-face training, the tool may be effective in different contexts with different patients, including those suffering from developmental disorders, such as Learning Disabilities (LD) (Caso and Federico, 2020; Dayal, 2020; Sarti et al., 2020).

LD are due to genetic and/or neurobiological factors that alter brain functioning by affecting one or more cognitive processes related to learning. These problems can interfere with learning basic skills, such as reading, writing and/or calculating, and with higher cognitive skills, such as time planning, abstract reasoning, long or short term memory and attention. According to the Diagnostic and Statistical Manual of Mental Disorders 5 (DSM 5, 2015), specific LD are characterized by persistent learning difficulties of key school skills for at least 6 months, such as slow or imprecise and tiring word reading, difficulty in understanding the meaning of what is being read, in spelling, with written expression, in mastering the concept of number, numerical data or calculation and in mathematical reasoning (APA, 2015).

LD vary from individual to individual and can involve different cognitive functions: (1) processing of visual and auditory information, which can have an impact on reading, spelling, writing, and understanding or use of the language; (2) planning work and priorities, with difficulties in performing math operations and following instructions; (3) storing or retrieving information from short or long term memory; (4) spoken language and (5) awkwardness or difficulty with handwriting. In particular, individuals with LD may have problems with attention (reaction time, information processing speed, selective or distributed attention), memory (reduced memory span) and executive functions (shifting of attention, control of interfering information) (Huc-Chabrolle et al., 2010). However, they do not have intellectual disabilities or sensory impairments. Unlike DSM-V, DSM-IV-TR does not use a broad category for LD, but it includes three explicitly defined diagnostic categories: reading disorders, mathematics disorders, and disorders of written expression. There is also a residual category "LD not otherwise specified", which includes difficulties in the three areas.

The rehabilitation of these disorders, according to international guidelines, should be early, intensive and personalized (Bavelier et al., 2013; Ghidoni & Angelini, 2011; Huc-Chabrolle et al., 2010; Hulme & Snowling, 2016; Olofsson et al., 2015; Snowling & Hulme, 2012; Spencer-Smith & Klingberg, 2015; Zoccolotti et al., 2016; Wolf et al., 2000). The implementation of early interventions involves a series of complications, such as high costs for the healthcare system, long waiting lists and delayed treatments, as well as geographical/economic difficulties for subjects who are far from the rehabilitation centers (i.e. rural areas or during lockdowns). There are currently few treatments available, especially to improve the speed of reading and writing, as well as the related cognitive components (Tucci et al., 2015). In fact, the current approaches to LD focus only on specific cognitive functions (Bonacina et al., 2015; Gori & Facoetti, 2014), neglecting that learning requires complex interactions between the various cognitive abilities, given that LD are believed to be a "multifunctional deficit model" (van Bergen et al., 2014).

Lack of early rehabilitation and delayed or ineffective treatments can have long-term effects on education and career opportunities and success, causing a high incidence of overlap with other psychological disorders (Ghidoni & Angelini, 2011; Huc-Chabrolle et al., 2010; Olofsson et al., 2015). What is more, the coronavirus pandemic and the consequent social isolation may have worsened the pre-existing symptoms in young people with LD, as it did not allow them to have the necessary social experiences, and educational opportunities to improve cognitive and social skills, and overcome their deficits. This issue has been particularly important to people in late adolescence (aged 17–21 years), who were facing new challenges, such as high school exams, attending university, or starting a new job. For this reason, the use of telerehabilitation, which has proven effective to reduce intervention costs and increase the efficacy of rehabilitation programs (Spencer-Smith & Klingberg, 2015), may potentiate both cognitive and emotional skills in this patient population.

Zampolini et al. (2008) highlighted that telemedicine applied to LD allows for the continuity of care, limiting the time and economic needs of families and institutions. Recent studies on transparent spellings have shown the effectiveness of software designed to rehabilitate LD in children and young people at home (Pecini et al., 2018; Tressoldi et al., 2012; Tucci et al., 2015). There are several cognitive rehabilitation software, with different characteristics and sets of exercises, which allow the therapist to adapt the level of difficulty to the patient's performance, promoting the simultaneous activation of different cognitive domains.

Given that few studies have been carried out on adolescents, observing the effects of telerehabilitation on patients with LD, this study aimed to assess the effectiveness of cognitive telerehabilitation in adolescents with LD involving all of the three areas (i.e. reading, written expression, and calculation) to overcome the treatment problems related to the pandemic lockdown.

2. Material and methods

2.1. Recruitment of participating and study population

This feasibility study was conducted in accordance with the 1964 Helsinki Declaration. Either participants or their legal guardians provided informed consent to enter the study protocol, which was approved by the local Ethical Committee (UPME-233-20). The participants came from the same geographical area, i.e. the province of XXX to avoid cultural biases. Eighty students attending either secondary schools or University in XXX and its province were initially contacted based on the reporting by their institutions, which were previously informed about the research. About half of them provided consent to enter the study protocol, but not all of them met the inclusion criteria.

The final sample consisted of twenty-four patients: mean age ±SD: 18.2 ± 2.9 years; 50% male. All young people had a mild to moderate LD involving the three learning areas, and, according to the DSM IV, were diagnosed with unspecified LD. LD significantly interfered with the subjects' learning and quality of life. Participants lived at home with their parents. For a more detailed description of the sample, see Table 1.

Inclusion criteria were: i) A personal medical history negative for psychiatric and neurological disorders; ii) normal or correct-normal visual/hearing acuity; iii) general IQ > 80 at the Wechsler Intelligence Scale for Children IV; iv) diagnosis of "LD Not Otherwise Specified" according to DSM-IV-TR criteria.

Exclusion criteria were: i) age >25 years; ii) moderate to severe medical and psychiatric diseases that could interfere with the treatment; iii) treatment with psychoactive drugs in the last six months; iv) presence of pervasive neurodevelopmental disorders.

Inclusion and exclusion criteria were evaluated by a preliminary videoconference with the patient and, if necessary, with the parents. The videoconference was done by a neurologist and a neuropsychologist, who defined whether the subject could be enrolled in the study based on the inclusion/exclusion criteria.

2.2. Outcome measures

Each participant was evaluated by a neuropsychologist before (T0) and after the end of the training (T1). The tests administered at T0 and T1 differed concerning the stimuli presented to avoid learning bias and to encourage test/retest validity. Moreover, the assessor was blind to the aims of the study, and was different from the therapist who carried out the telerehabilitation training. The neuropsychological battery was administered using a remote videoconference. Indeed, thanks to a specific platform, the participant was submitted to standardized tests, using the "Attenzione e Concentrazione" software, developed by Di Nuovo S., Erickson (Eds) (Fig. 1). This is a useful tool for identifying and quantifying any attention and concentration deficits through an objective evaluation, which includes: Reaction time (RT), Rapidity and Accuracy (RA), Distributed Attention (DA), Digit Span Test, Stroop Test (ST), Attentive Matrices Test (AMT), Intrinsic Motivation Inventory (IMI). The System Usability Scale (SUS) was also administered (Table 2). During the assessment, the participants were not supported at home by their family members, but they were remotely guided in their training/assessment by a therapist.

2.3. Tele-cognitive treatment

All patients received the cognitive treatment via a specific telerehabilitation App to stimulate the cognitive skills related to learning. The training was intensive (i.e. a daily session lasting up to 60 min, five days a week for 4 weeks) with a series of different cognitive tasks presented in serious games, with increased feedback. The App we used was the "NeuroNation - Train your mind" (Synaptikon GmbH, Berlin, Germany), and was composed of serious games. The patients were required to download such an App on their smartphone, setting the daily time of the activity in order to have a reminder of the training protocol. All participants underwent the same treatment and the exercises varied according to the stimuli presented and/or the sequence of activities that were based on individual needs, as per the assessment at T0. The program aimed to stimulate various cognitive domains, including memory, attention, cognitive flexibility, information processing speed, working memory, and executive skills (Table 3).

The intervention used is part of the "habilitation treatments". The habilitation treatments aim to stimulate the prerequisites necessary for the promotion of reading, writing and calculation skills (Coltheart, 1978), as well as the cognitive abilities underlying these skills, such as memory, language, attention (Kavale & Forness, 1996). Furthermore, it aims to favor the development of alternative cognitive strategies through the re-education of deficient skills, also promoting the quality of life of children/adolescents. These treatments are carried out with various methodologies, both traditional and pc-based, such as in our study. In both modalities (face to face or pc-based), the intervention is based on the assessment of residual skills, the stimulation of the cognitive prerequisites, and then, the improvement of the cognitive ability of the subjects. In our study, the activities were based on recognizing previously presented images, following stimuli, reordering words, and classifying objects and paths. The App also made it possible to get weekly evaluation reports of the results obtained (Fig. 2). The therapists monitored and supervised the progress of the patients remotely through the performance reports that the App provided weekly. Moreover, a weekly online consultation was performed to better support the participants. The consultation clarified the doubts about the training or use of the App, helping to increase the involvement of program participants.

Table 1
Demographics characteristics at baseline for both groups. P-values (p) of Student T- Test.

	Male	Female	All	p-value
Participants	12	12	24	–
Age (years)	20.0 ± 3.5	18.0 ± 2.3	18.2 ± 2.9	0.20
Education	13.0 ± 2.1	12.5 ± 1.9	13.0 ± 2.0	0.28

*Quantitative variables were expressed as means ± standard deviations, categorical variables as frequencies and percentages.

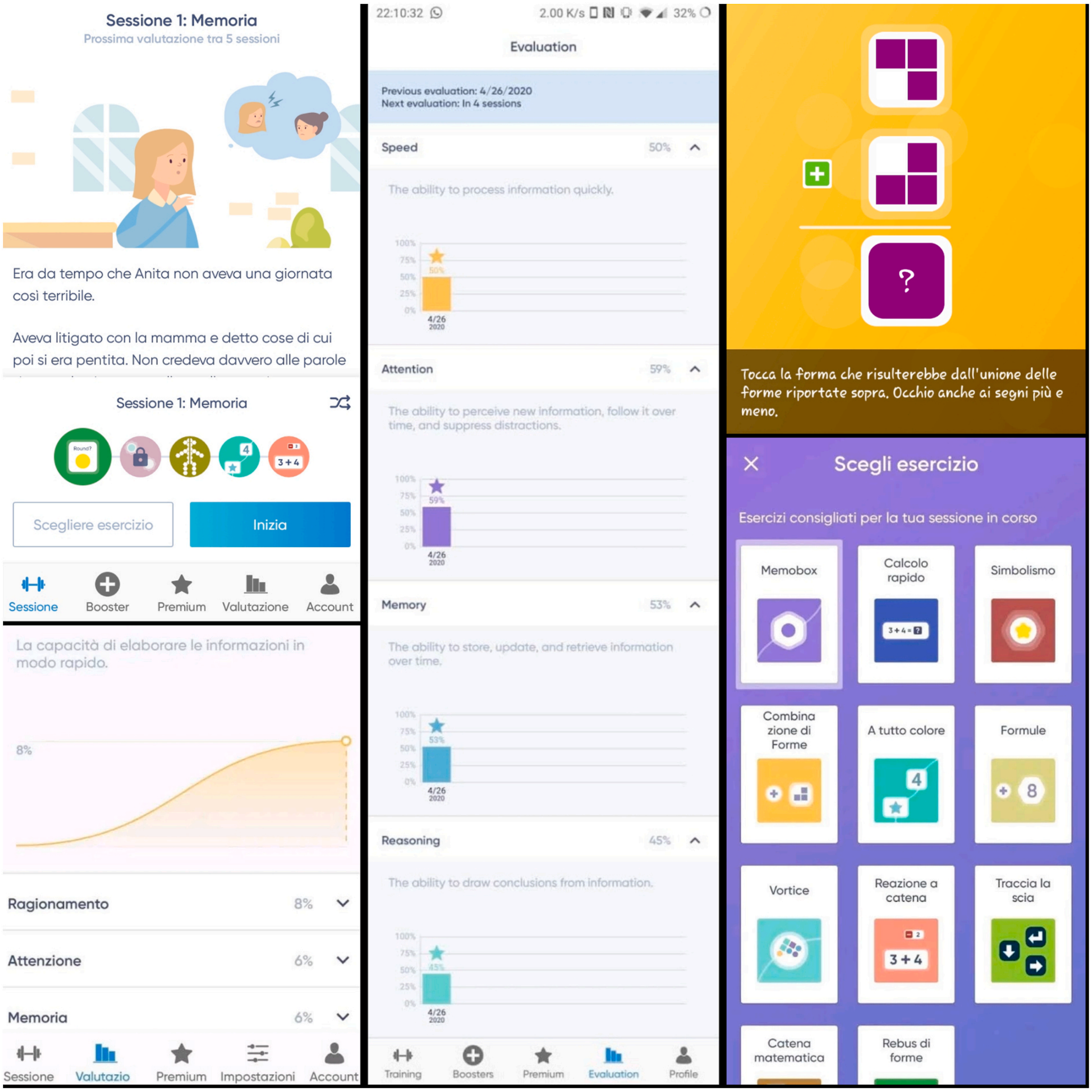

Fig. 1. Shows the original instructions (i.e. in Italian language) of some of the assessment tools (Reaction time (RT) and Rapidity/Accuracy (RA)) belonging to the "Attenzione e Concentrazione" software, developed by Di Nuovo S., Erickson (Eds).

2.4. Statistical analysis

Data were analyzed using the SPSS 16.0 version (SPSS Inc., Chicago, IL), considering a $p < 0.05$ as statistically significant. Descriptive statistics are presented as mean ± standard deviation or median ± first-third quartile, as appropriate, whereas categorical variables as frequencies and percentages. The normality of variables was analyzed using the Kolmogorov-Smirnov test. Since most of the target variables were non-normal distributed, a non-parametric analysis was performed. Thus, the Wilcoxon signed-rank test was applied to compare the scores of all tests used, comparing the baseline and the end of the study in the inter-group.

3. Results

All patients completed the training without any side effect. The participants did the exercises on their own and performed all planned training sessions.

The results of Wilcoxon signed-rank tests and the median between T0-T1 showed significant differences in all of the domains we

Table 2
Clinical assessment.

Scale/test	Description
Reaction time (RT)	RT allowed evaluating the reaction time of the subject to respond to the appearance of a stimulus. The subject had to press the spacebar on the keyboard when the target stimulus (i.e. a star) appeared, which appeared with variable times. Cut-off: >1 (error and time)
Rapidity and Accuracy (RA)	RA consists of numbers from 1 to 6 that appear on the screen, the subject must press the key corresponding to the number that turns red. Cut-off: >1 (error and time)
Distributed Attention (DA)	The subject must press a key on the keyboard when a target figure among other distracting stimuli appears on the screen, and press another key when he hears the word "SUN". Cut-off: > 3 for error; and >1 for time.
Digit Span Test	Numbers appear on the screen for a few seconds, the subject must rewrite them first in the same order of appearance, then in reverse order. **Cut-off: < 6.**
Stroop Test (ST)	The subject must press on the keyboard the key corresponding to the initial (R-G-B) of the color of some circles that appear on the screen, then he must press the initial of the ink color of names related to non-colored correspondents displayed on the screen. Cut-off: > 2 (error and time)
Attentive Matrices Test (AMT)	The subject must search in a matrix of images, 3 target stimuli presented at the top of the screen. **Cut-off: > 3 for error; and > 40 for time)**
Intrinsic Motivation Inventory (IMI)	IMI is a questionnaire that provides qualitative information on the content and level of motivation that an user experiences during an intervention. Each IMI item consists of a seven-point Likert scale, ranging from "not at all true" to "completely true", with a maximum score of 144. Higher scores mean a more positive result on motivation. IMI is composed by 7 subscale: interest/enjoyment (maximum score = 49), Perceived Competence (maximum score = 42), Effort/Importance (maximum score = 35), Pressure/Tension (maximum score = 35), Perceived Choice (maximum score = 49), Value/Usefulness (maximum score = 49), IMI Total (maximum score = 259).
System Usability Scale (SUS)	SUS is a scale that consists of 10 items, and it offers a global view of the subjective usability experience. A high score means a better usability: scores of 90 are exceptional, whereas scores between 60 and 80 are good and promising; instead, SUS scores lower than 50 indicate usability difficulties

Table 3
Cognitive rehabilitative program.

COGNITIVE DOMAIN	COGNITIVE TRAINING
ATTENTION AND SPEED OF COGNITIVE PROCESSING	The exercises consist of selecting, with immediate feedback (audio and video), some elements (colors; numbers; geometric shape; animals …) observed in the virtual screen. These elements remain visible for a variable time, established by the virtual system. The patient touches the virtual target element: this action causes a visual change with specific audio feedback (positive reinforcement); otherwise, the element disappears (negative reinforcement). In addition, there are simple or complex calculation exercises. *The difficulty level increases as the number of distractors increases and the useable execution time decreases.*
MEMORY	The exercises require observing elements of various kinds and then (in immediate and recall time) remember them (colors, numbers; environments, animals; geometric shape) or remember their position in space, with a dynamic interaction in the virtual screen of the smartphone. The patient remembers the place (the position; visuospatial memory) and the name (verbal information) of the observed element (s). *The level of difficulty increases with the increase of the number of elements to remember and with the reduction of the time to execution.*
EXECUTIVE VISUOSPATIAL FUNCTIONS REASONING	The App requires creating specific associations (eg number-color) with a dynamic interaction in a virtual environment. Furthermore, it is required to recognize shapes equal to a target stimulus, even if with a different orientation, to add shapes or to understand the relationships between objects or logical sequences proposed on the virtual screen. *The level of difficulty increases (from first to third level) with the increase of the complexity of virtual ideo-motor serious realization.*

evaluated (Table 4). Significant pre-post-treatment differences were observed in reaction time (RT), rapidity and accuracy (RA); distributed attention (DA); selective attention capacity and processing speed ability (ST); attentional shifting and sustained attention (AMT), as well as in memory (Digit Span).

Table 5 show the main effects on the user experience. The motivation during training was positive, as demonstrated by the average IMI score of 216 (SD = 21.3). In particular, patients showed a high interest/pleasure in carrying out the activity, with high perceived competence, sense of effort/importance, and value/usefulness. Participants also presented higher usability scores (SUS average: 84.0; SD: 4.3).

4. Discussion

Our study has shown that telerehabilitation could be a valid tool for the rehabilitation of specific cognitive skills in subjects with LD. In fact, our young patients reported a statistically significant improvement in the main cognitive domains that are usually compromised in these disorders, including sustained and selective attention, shifting of attention, control of interference, memory and speed of information processing. As we involved patients with unspecified LD (in which reading, mathematics, and written expression ability are compromised), at the time of the study definition we did not expect such a dramatic improvement in all of the areas considered by the rehabilitation tool.

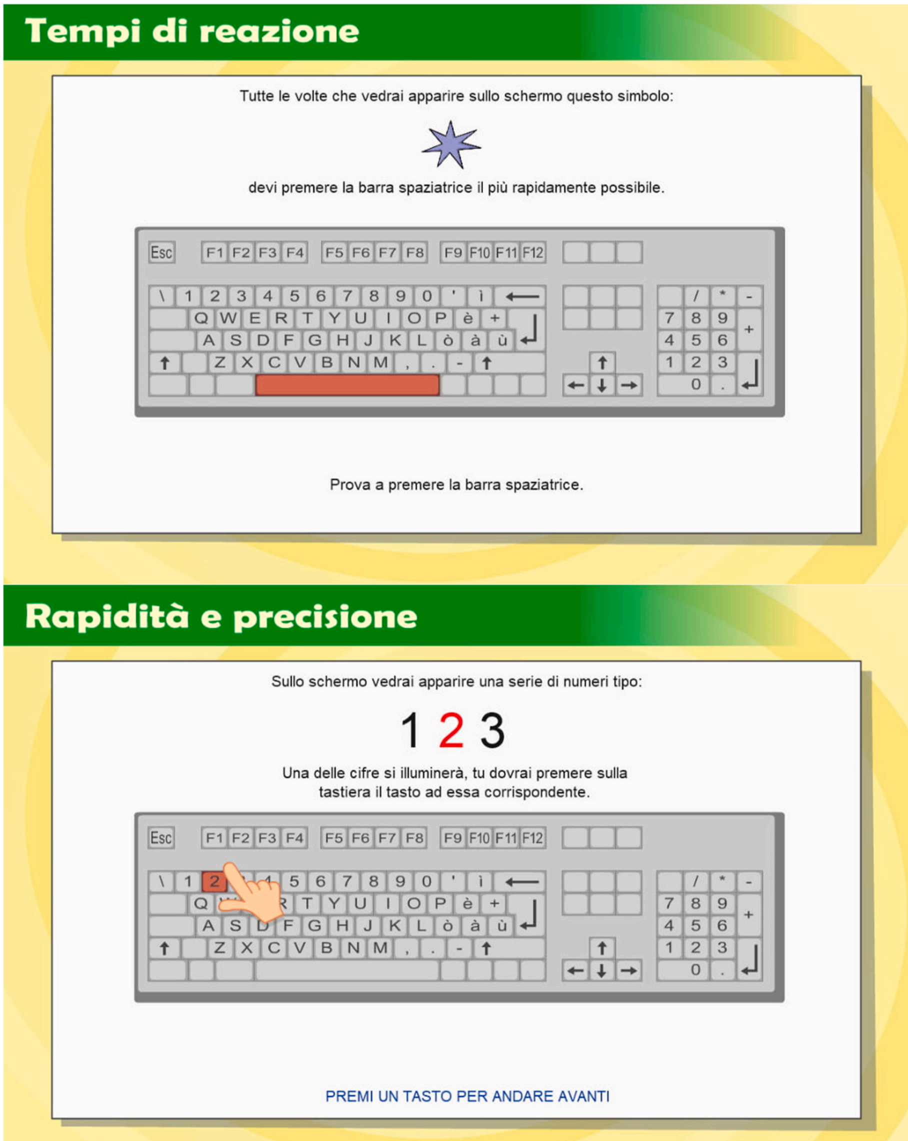

Fig. 2. The "NeuroNation" APP used for Tele-Cognitive training: on the right, the exercises available for rehabilitation; on the left, a sample report provided by the application weekly.

Table 4
p-values (p) for the clinical assessment tests. Data are reported as median (1 Quartile-3 Quartile). Significant p-values (<0.05) are highlighted.

Clinical assessment		T0	T1	p-value
RT	E	1.0 (0.0-5.0)	0.0 (0.0-0-0)	0.001
	T	0.78 (0.69-1.1)	0.5 (0.43-0.66)	**0.003**
RA	**E**	2.5 (1.0-7.0)	0 (0.0-1.0)	**0.000**
	T	1.1 (1.0 -1.4)	0.9 (0.6 -1.0)	**0.000**
DIGIT SPAN		9.0 (6.0 -10.2)	12.0 (11.0-14.0)	**0.000**
DA	**E**	4.0 (0.7-6.0)	0.0 (0.0-1.0)	**0.000**
	T	1.3 (1.2-1.8)	0.8 (0.6-1.0)	**0.000**
ST	**E**	2.5 (1.0-5.2)	0.0 (0.0-1.0)	**0.000**
	T	1.6 (1.4-2.0)	1.0 (0.8-1.2)	**0.000**
AMT	**E**	3.5 (1.7- 5.2)	0.0 (0.0-1.0)	**0.000**
	T	58.8 (48.4-67.7)	27.3 (23.4-34.6)	**0.000**

Legend: RT = Reaction time; RA = Rapidity and Accuracy; DA = Distributed Attention; ST= Stroop Test; AMT = Attentive Matrices Test; E = number of wrong answers (0-8); T = n. minutes taken to complete the task.

Table 5
Average of usability/motivation of participants.

Test/scale	Participants	
	Mean ± SD	Range
SUS	84.0 ± 4.3	72–89
IMI I/E	40.8 ± 4.0	35–48
IMI PC	38.8 ± 2.8	35–42
IMI E/I	28.8 ± 3.7	21–35
IMI P/T	28.2 ± 4.1	21–34
IMI PCh	37.4 ± 4.5	28–42
IMI V/U	42.2 ± 3.6	38–48
IMI Total	216.2 ± 21.3	178–249

Legend: System Usability Scale (SUS); SD: standard deviation; the Intrinsic Motivation Inventory (IMI): interest/enjoyment (maximum score = 49), Perceived Competence (maximum score = 42), Effort/Importance (maximum score = 35), Pressure/Tension (maximum score = 35), Perceived Choice (maximum score = 49), Value/Usefulness (maximum score = 49), IMI Total (maximum score = 259).

Because LD is a disorder with multidimensional deficits affecting cognition, for effective rehabilitation it is important to involve the different cognitive domains subtending the disease. It is known that the lack of early and effective rehabilitation can affect LD people's well-being and their professional and relational life (Ghidoni, E., & Angelini, D., 2011). In the last decade, the use of "at home" rehabilitation devices, supervised by skilled therapists, has helped improve the outcomes (with regard to reading abilities) and reduce intervention costs (Spencer-Smith & Klingberg, 2015). Moreover, recent studies have shown the effectiveness of telerehabilitation software in children with LD (Pecini et al., 2018; Tressoldi et al., 2012; Tucci et al., 2015). In particular, the tele-trainings that are aimed to involve different cognitive, linguistic, visual and attention processes subtending learning by integrating the components into a complex activity, are promising. This could be the reason why we got our amazing findings by using the simple but valuable App, whose serious games have stimulated different cognitive domains.

Telerehabilitation applied to the LD field can allow the patients to get early diagnoses and tailored treatments, with regards to children at high risk, including those housebound because of restrictions (like during Covid-19 pandemic). Tele-cognitive rehabilitation allows intensive and daily interventions without the physical presence of the therapists, in order to avoid unnecessary and potentially dangerous real-life contacts (Maggio et al., 2020). The effectiveness of telerehabilitation seems to be due to the possibility of simultaneously involving several cognitive domains, implementing remote monitoring while the subject is in a family environment (Flaugnacco et al., 2015; van Bergen et al., 2014; Zoccolotti et al., 2016). Another important feature is the presence of effective and stimulating tasks with playful aspects, which encourage motivation and a good compliance. According to this issue, our results showed a good usability and motivation during the training, as demonstrated by the promising applications in the field of neurorehabilitation (De Cola et al., 2020; Manuli et al., 2020; Norton and Wolf, 2012). Motivation is an important predictor of long-term changes for rehabilitation outcomes and quality of life (Resquìn et al., 2016). Patients who find innovative systems useless and not motivating have been shown to have more difficulty in their use and less therapeutic adherence (Grahn et al., 2000). This is more valid in the developmental age, where it is necessary to highly stimulate young people, encouraging the adherence to the therapeutic program. This is the reason why we adopted a system that automatically adjusted the interventions to the needs of the participants, and the characteristics of the stimuli were modified online according to the users' skills and preferences. In fact, the personalization of the intervention to the subject's abilities and the continuous feedback to the children/adolescents stimulates a greater self-control of the competences and promotes the zone of proximal development, encouraging and advancing individual learning (Chacko et al., 2013; Diamond and Lee, 2011; Klingberg et al., 2005; Kuusisaari 2014; Thorell et al., 2009).

The main limitation of the study is the small sample size, which could not allow extending the results to the whole population of subjects with LD. Our study should be understood as a pilot, with promising results to be confirmed. Furthermore, it was not possible to enroll a control group that performed traditional and face-to-face rehabilitation, due to the COVID-19 pandemic, and we did not find in literature a historical control group having the same clinical features of our sample (we enrolled unspecified LD, as per DSM-IV diagnosis). Thus, it was not possible to consider the real effectiveness of telerehabilitation in relation to other interventions. Moreover, although the tests contained in the "Attenzione e Concentrazione" software are validated, the tool is currently under standardization. Finally, the duration of the telerehabilitation training over time remains somewhat indefinite due to the lack of a follow-up period. Further studies should be promoted using larger samples, control groups, standardized measures and long-term follow-up to confirm our promising results.

In conclusion, this study suggests that cognitive training through telerehabilitation could be a useful approach to the rehabilitation of patients with LD. The results suggest that this approach can stimulate the improvement of patients' cognitive functioning. In addition, this innovative system could promote adolescents' health care at home to meet the needs of the patient, guaranteeing the continuity of care, and timely rehabilitative intervention, especially during lockdown periods.

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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. The Institutional Review Board of IRCCS Centro Neurolesi Bonino Pulejo (Messina, Italy) approved the study.

Informed consent: patients provided their written informed consent to study participation and data publication.

Declaration of competing interest

None of the authors have potential conflicts of interest to be disclosed.

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