frontiers in Education

HYPOTHESIS AND THEORY
published: 05 November 2020
doi: 10.3389/feduc.2020.00153

Popularizing Visuo-Spatial Training for Reading Challenges: A Call to Experts in Support of Language and Non-language-based Cognitive Skills Strengthening

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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Education

Received: 17 March 2020
Accepted: 30 July 2020
Published: 05 November 2020

Citation:
Trebeau Crogman M and Crogman H (2020) Popularizing Visuo-Spatial Training for Reading Challenges: A Call to Experts in Support of Language and Non-language-based Cognitive Skills Strengthening. Front. Educ. 5:153. doi: 10.3389/feduc.2020.00153

We propose to researchers, educators, and professionals a discussion which contributes to a growing body of research questioning how dyslexia and reading challenges have been researched, diagnosed, and remedied. Also included is a discussion for educators and researchers including questioning the definitions of dyslexia, how educators could view dyslexia against mainstream opinions, the place of culture, language, and multisensory teaching. Two literature reviews and a pilot study are briefly described to provide the initial grounds and design to propose an alternative approach to growing our understanding and studying the connections between training non-language-based (NLB) skills and the improvement of language-based skills in students with reading disabilities. Scarce data and literature exist that effectively connect the two domains. Yet, there is some evidence that implementing NLB trainings has had transforming effects on language-based (LB) skills and effected broader benefits to students' cognitions. Findings show a lack of studies of NLB skills, study designs that ignore these skills and their developmental trajectories, and a mixed result of training effects. Suggestions are made for educators and researchers to further investigate potential effects of NLB training in reading challenged individuals within this framework.

Keywords: visuospatial abilities, dyslexia (disturbed reading and spelling), learning, education, training, non-language based, language-based competencies

INTRODUCTION

Students diagnosed with dyslexia (RD) who are enrolled in higher education seem to choose to major in STEM and typically people-oriented career fields (Gottfredson and Finucci, 1985; Adelman and Vogel, 1990; Fink, 2002; Taylor and Walter, 2003). This may be by choice to be in an environment that requires less intense use of cognitive energy to frequently read or use language-based (LB) material, or by natural ability that may lead RDs to present some unique skills in processing non-language-based (NLB) tasks (Gilger et al., 2013; Trebeau-Crogman, 2018). To investigate such a question, we must have solid data basis about NLB skills on which to build research studies and programs. However, defining NLB abilities has been a harder endeavor than expected given their range and complexity (see an example of mixed results in Duranovic et al., 2015). Generally, "non-language-based," "spatial," or "visuospatial" (VS) abilities are viewed as the processing of shapes, locations, paths, and relations among NLB entities and relations between entities and frames of reference (Hegarty and Waller, 2005). There will be mental work "to aid in manipulating, constructing, and navigating the physical world" (Newcombe and Shipley, 2015, p. 180). We see also "the ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1996, p. 3). Trebeau-Crogman (2018) specifically focused on types of VS tasks that require aptitudes in spatial relations (SR), spatial orientation, spatial visualization (SV), closure speed, perceptual speed, visual memory, and kinesthetic left-right orientation. These tasks include cognitive strategies (e.g., discriminating pattern frequencies, encoding, remembering, transforming, matching attention, or creativity), and expand to include VS dynamic versus static VS tasks and navigation as in 3D space and virtual environments (Uttal et al., 2013; Newcombe and Shipley, 2015; Gilger et al., 2016).

Thoroughly understanding how NLB skills develop and influence learning may lead STEM educators to put less emphasis on developing LB skills than would other fields. However, research shows that RDs rely heavily on their right hemisphere (typically somewhat less involved in language-based tasks) for reading rather than the left (Pugh et al., 2000; Simos et al., 2002; Shaywitz and Shaywitz, 2005, 2007; Maisog et al., 2008), a configuration that may either interfere or improve NLB skills' common right hemispheric pathways. Interference or improvement in this context is a phenomenon that is still left for researchers to understand given the lack of research at this conceptual crossroad.

Indeed, as pointed out by Lurito et al. (2000), people who process reading in this atypical right hemispheric pathway may encounter cognitive interferences by heavily recruiting these parts of the brain (e.g., dorsolateral prefrontal cortex, parietotemporal area, occipitotemporal area, anterior cingulate). Among the most important functions necessary to both LB and NLB skills, these areas are typically involved in executive and integrating functions such as: (1) reasoning and decision-making, (2) short-term and working memory, (3) stimuli tracking, attention, (4) motor planning, and (5) language, and spatial skills such as navigation (Mars and Grol, 2007; Voytek, 2013). Perhaps imposing reading practice and drills on these (NLB-serving) areas, overworks them, leaving other functions with less resources to thrive in the course of development, a trade-off that may, in the case of RDs, be a less ideal remediation solution. Diehl et al. (2014) talks about a "language-non-language trade-off." This issue is the more important if there is large overlap between LB (reading, spelling) and NLB (VS processing) cognitive structures (Kujala et al., 2001; Lorusso et al., 2006; Keller and Just, 2009; Horowitz-Kraus and Holland, 2015). The large difference in what college majors require in terms of LB/NLB skills may unevenly require more or less work on these cognitive areas for RDs, which adds to the problematic issue of how they should be best supported in their challenged learning. Gilger et al. (2013, 2016) have explored the idea of studying tailored RD-focused trainings as a foundation to understand how training and practice modifies these aforementioned regions significantly in RD's brain. The findings could lead to solutions potentially capable of transforming cognitive functioning and performance in RD.

We have, to our knowledge, no specific and comprehensive data on whether the overlap of LB and NLB functional cognitive regions, and how they are used in RDs cognitive processes, is or isn't beneficial to RD, other than the following findings:

(1) NLB regions in the brain largely overlap with LB regions (**Figure 1**), thus challenges, or at least resource trade-offs, in one area may cause challenges in the other.
(2) LB regions typically malfunction in RD, whether they are over- or underactivated (Pugh et al., 2000; Rippon and Brunswick, 2000; Simos et al., 2002; Shaywitz et al., 2003; Richlan et al., 2009, 2011). It may then be commonsense to expect the same from the specific NLB regions that overlap with them.
(3) A recent literature review of RDs' NLB skills show that they do underperform as well in some NLB skills, contrary to a commonly perceived general *NLB talent* usually attributed to RDs (Winner et al., 2001; Brosnan et al., 2002; Eden et al., 2003; Sigmundsson, 2005; Rusiak et al., 2007; Gilger et al., 2016; Trebeau-Crogman, 2018).

Based on the above summary, a discussion about whether we are or not appropriately training and supporting RDs is an important one. Naturally, the entire premise of school, education, policy, and achievement is based on the idea that training is necessary for brain development and improving performance across cognitive skills. However historically, the only type of training that has been offered to RDs are LB-focused training (**Appendix A**). Further, despite the current progress in programs which now involve "multisensory" tasks involving more NLB skills, no training is yet focused solely on supporting NLB cognitive processes whether it be separately or conjointly with LB remediation drills.

Thus, how can we begin as educators and researchers, to provide focused and tailored programs, with potentially different types of training when there are so many unknown variables about NLB learning in the present picture about RDs? Take Crogman's (2017) perspective on language in the classroom for example. The premise is that the instructor and student's languages must match to broader extents in order for optimal learning to take place. Indeed, LB skills and their correspondence between instructor and student are related to: thinking/critical thinking, pedagogy, curiosity, comprehension, sensory learning, and problem solving (Crogman, 2017 and **Figure 2**). Crogman reminds us that this is already a struggle for the common student, at least in our currently ill-fitted educational and heavily didactical practices. How much more with students whom first and foremost challenge is print language processing and comprehension. Add to that our findings that RDs also may struggle with NLB skills, and we have a recipe for extreme strain on these students' learning experience, cognitive development, and sense of comfort and achievement in the classroom. This may

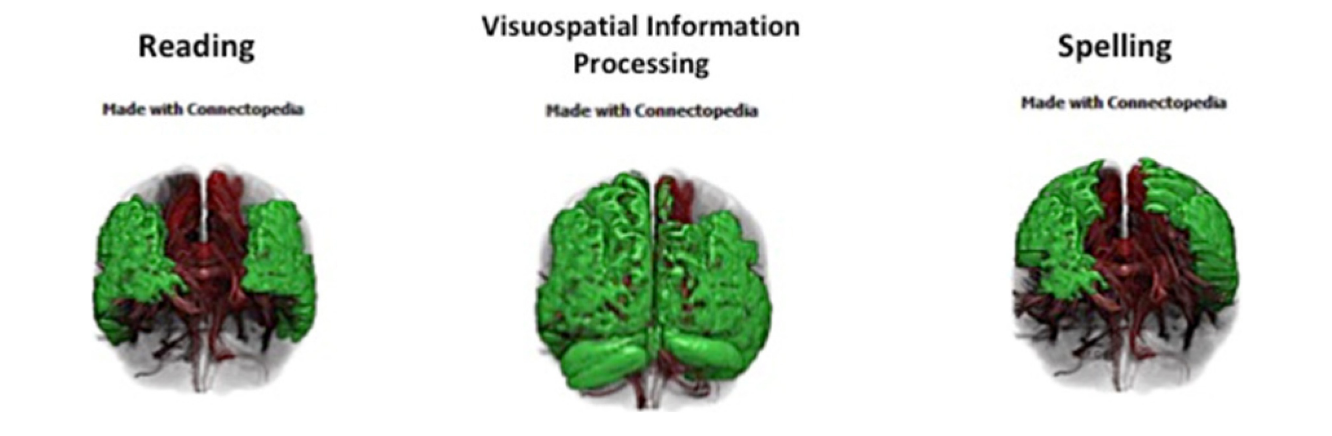


FIGURE 1 | fMRI data illustrating the surface areas activated while performing LB/NLB tasks (Ducreux, 2015).

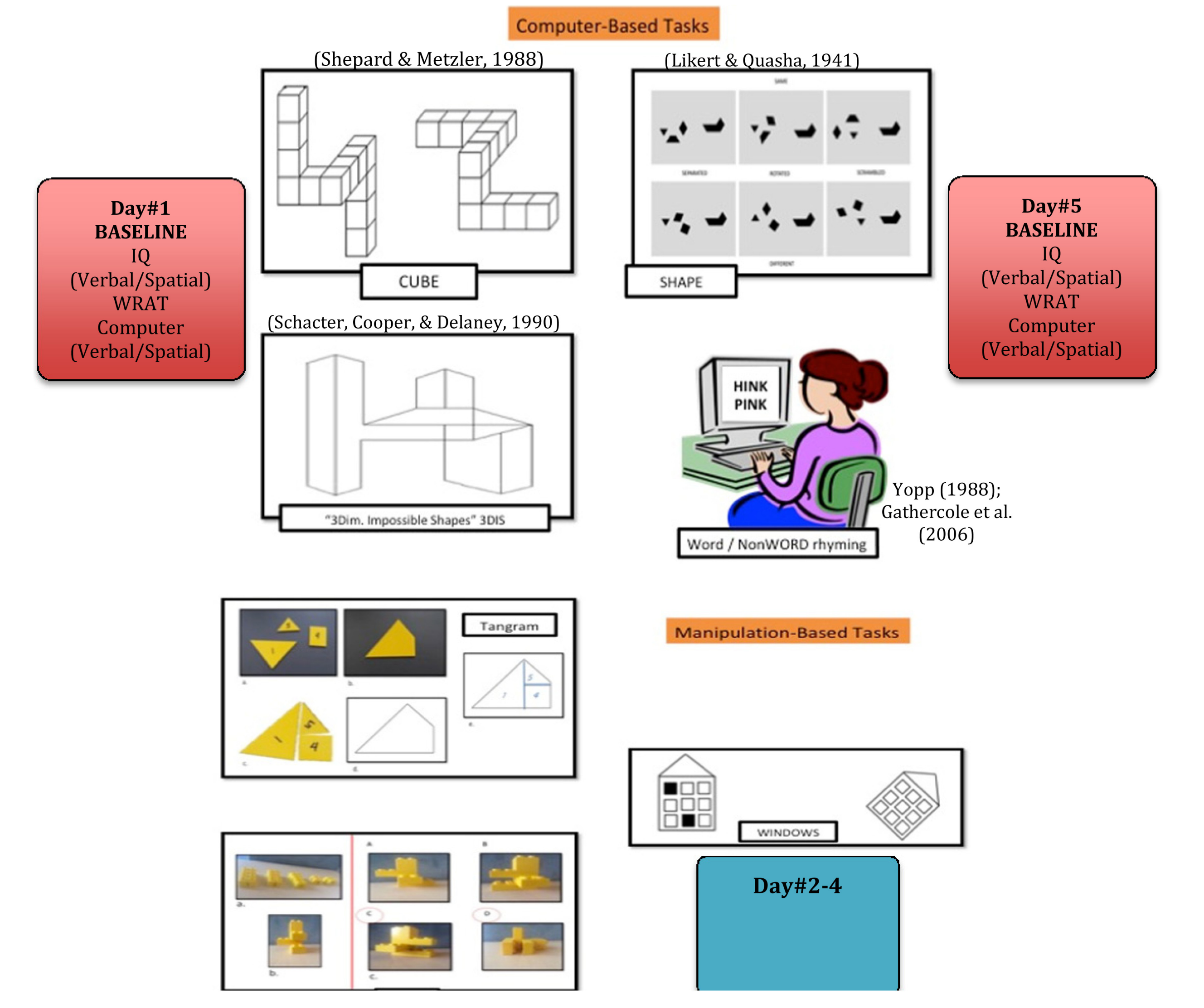


FIGURE 2 | NLB manipulative and computerized tasks.

have adverse effects felt all the way in adulthood's professional and social outcomes.

Who more than RDs could benefit from specialized and tailored empirically based training? In other words, we suggest that researchers focus their efforts on understanding how LB and NLB skills are coexisting and influencing each other in the development of reading challenged populations. This will allow proposing better solutions that may benefit struggling readers' both LB and NLB modalities in a more balanced approach than LB-only focused remediation.

Students typically falling under a certain reading skills threshold are entitled to receive tailored support (International Dyslexia Association [IDA], 2019; Munzer et al., 2020). Teacher, parents, and medical professionals can refer a student, and schools are required to develop an IEP addressing the reading skills concerns. Some equivalent support plans may be available in college (Guyer et al., 1993). However, training in NLB areas may actually equally help in their learning experience. Young RDs are usually heavily drilled and remediated in LB areas (see **Table 1**) and are neglected in their need to develop NLB skills. This suggests that the support typically proposed may not actually efficiently improve LB skills, neither the desire to choose more LB-oriented majors, perhaps because the reading challenges experienced may still be keenly felt.

Shifting the Landscape: Changing How We View RD

The goal of remediation so far has been to "normalize" the brain of RDs (Pugh et al., 2000), by intensively enforcing a LB functional cognitive shift from the right to the left hemisphere, which are more typical of LB pathways (Simos et al., 2002; Keller and Just, 2009; Breznitz et al., 2013). What we may ponder on here is if whether or not such a shift is beneficial or not beyond LB skills improvement given that it indiscriminately changes also original structures in RD brains.

Children with RD tend to develop task avoidant behaviors (Onatsu-Arvilommi and Nurmi, 2000) showing that this particular challenge significantly decreases improvement in reading skills, and that similarly, low level of reading increases task avoiding behaviors. To break this cycle, it is interesting to explore if more "dyslexic friendly" activities such as NLB-based exercises and trainings would lower the task avoiding behavior and thereby remove the barrier to improvement in cognitive processes involved in reading and NLB tasks.

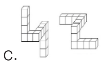
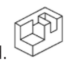
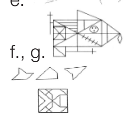
Typically, RD-focused remediation curricula are geared toward improving LB skills in RD. This is mostly stemming from a habit of remediating obvious LB challenges in RD. Nonetheless, as we showed earlier, the current most common remediation approaches move toward a multisensory-structured language programs involving NLB tasks which have been associated with improvement in LB abilities (Oakland et al., 1998; Eden and Moats, 2002; Joshi et al., 2002). This fundamentally suggests that researchers have understood the diffused and intertwined nature of brain functions, and that changes in the NLB domains may very well impact the LB domain as well (Lorusso et al., 2006; Keller and Just, 2009; Gabrieli and Norton, 2012; Franceschini et al., 2013; Horowitz-Kraus and Holland, 2015). Reinforcing that idea, Posner and Rothbart (2005) show the importance of influencing network development early in school settings. In the case of RD, their opinion seems to be that reading (phonological) interventions may not be enough since it seems to improve reading but not necessarily fluency. They recommend additional interventions that may involve VS training as well. Another issue with remediation school programs is the lack of consideration for cultural language background or even prior experience. This systemic oversight frustrates minority children (Crogman, 2017), which may result in complexifying the psychological phenomena associated with reading challenges, adding to any resistance behavior to LB approaches to reading remediation. Supporting that fact is the broad research showing that minority children are found in larger number in special education which oftentimes, has less to do with reading disorder than a misunderstanding of language patterns and culture on the part of teachers and support staff. The question then becomes, are LB-driven remediation and general curricula the only way to get RD children to read or become more functional? The answer to this question will define the approach educators can take in the future and lead to a shift in how we think, research, and create programs around students with reading challenges.

Shifting the Landscape: Effects and Benefits of Training NLB Skills in Students

Uttal et al. (2013) conducted a large metanalysis on the benefit of training students in spatial skills. Their overarching conclusion among other findings is that educational curricula reinforced in NLB skills training are very beneficial for achievement and retention. Achievement and retention in the life of struggling RD students are particularly at risk because America has among the world's highest rates of RD school dropouts (Daniel et al., 2006; Al-Lamki, 2012; Cortiella and Horowitz, 2014, p. 16–17). The authors contend additionally that the effects of these NLB-based trainings were in general both stable and transferable to other untargeted cognitive skills, sharing positive gains more widely across cognitive abilities.

Non-language-based training was also shown to be highly beneficial with special school age groups such as students with Down Syndrome, autism, ADHD, and others, showing significant and sustained improvement in academic skills (Bennett et al., 2013; Brock et al., 2018). Connections were also made between executive function skills, VS skills and school achievement, especially in at-risk populations. Improving these skills in after-school programs settings improved academic performance overall. With more regular school-aged groups, for example, Goss et al. (2007) used the Home Therapy System training to look at improvement in 3rd and 4th graders' reading skills. This training involves manipulation of VS information, and researchers demonstrated that completing this type of NLB training did improve students' LB skills. Again, there were no provision of brain imaging, but evidence that both LB and NLB processing centers are connected, and that focusing on NLB is a viable alternative or complement to currently available

TABLE 1 | Summary of Trebeau-Crogman (2018) literature review on NLB tasks tested in the last 40 years of literature.

Skill	Description	Type	Example Tasks	Studies
Spatial Visualization (SV)	Complex, multistep manipulations of spatially presented information, may involve rotations, dynamic movement, part-to-whole analysis	Paper From Board, Block Design, paper folding	b. 	Stanley et al., 1975; Pontius, 1981; Thomson, 1982; Thomson, 1982; Kamhi et al., 1988; Siegel and Ryan, 1989; Everatt, 1997; Winner et al., 2001; Brosnan et al., 2002; Helland and Asbjørnsen, 2003; Lockiewicz et al., 2014; Duranovic et al., 2015.
Spatial Relations or Rotations (SR)	Perceive an object from different positions, mentally rotate one stimulus to align it with a comparison stimulus, involves rotations and/or reflections	Shephard Metzler Cubes	c. 	Corballis et al., 1985a,b; Eden et al., 1993; Singh, 1993; Karádi et al., 2001; Winner et al., 2001; Rüsseler et al., 2005; von Károlyi and Winner, 2005; Rusiak et al., 2007; Attree et al., 2009; Wang and Yang, 2011; Olulade et al., 2012; Diehl et al., 2014; Lockiewicz et al., 2014.
Global-Holistic Processing, Closure Speed, Flexibility of Closure (FC)	Rapid identification of incomplete or distorted pictures and figures impossible in normal 3D environments	Impossible Figures (called in this paper '3DIS'), Gestalt Completion	d. 	von Károlyi, 2001; Winner et al., 2001; Brosnan et al., 2002; Von Károlyi et al., 2003; Buchholz and McKone, 2004; von Károlyi and Winner, 2005; Brunswick et al., 2010; Diehl et al., 2014.
Drawing (DW) (PR) Pattern Recognition/Recall/(TR) Target Recognition/Recall	2D drawing or reproduction of shapes or patterns Perceptual organization	Draw a man, Free drawing, pattern reproduction Matrices, Rey-Osterrieth Complex Figure Task, Hidden Figures, Block design	e.  f., g. 	Pontius, 1981; Everatt, 1997; Winner et al., 2001; Eden et al., 2003; von Károlyi and Winner, 2005; Alves and Nakano, 2014; Duranovic et al., 2015. Rudel and Denckla, 1976; Siegel and Ryan, 1989; Koenig et al., 1991; Eden et al., 1993; Everatt, 1997; Fischer and Hartnegg, 2000; Nicolson and Fawcett, 2000; von Károlyi, 2001; Winner et al., 2001; Brosnan et al., 2002; Helland and Asbjørnsen, 2003; Buchholz and McKone, 2004; Howard et al., 2006; von Károlyi and Winner, 2005; Attree et al., 2009; Brunswick et al., 2010; Facoetti et al., 2010; Collis et al., 2012; Olulade et al., 2012; Schneps et al., 2012; Alves and Nakano, 2014; Ruffino et al., 2014; Martinelli and Schembri, 2015; Wang et al., 2016.
Virtual World Navigation/3D Navigation/ Speed of	Navigating 2D-3D space	Maze, Navigating virtual environments,	h. 	Siegel and Ryan, 1989; Nicolson and Fawcett, 2000; Sigmundsson, 2005; von Károlyi and Winner, 2005; Attree et al., 2009; Mammarella et al., 2009; Brunswick et al., 2010; Wang and Yang, 2011.
Recognition (N) Other (O)	Right-left orientation, visuo-motor and visuo-constructive performance, perceptual organization	Finger recognition, Queen's head direction	i. 	Benton, 1984; Winner et al., 2001; Brunswick et al., 2010; Duranovic et al., 2015.

Some studies appear several times as they tested diverse types of skills. a. Constructs and table format exapnded from Gilger et al. (2016); b. Modified example from the Minnesota Paper From Board Test (Likert and Quasha, 1941); c. Example from Vandenberg and Kuse (1978); d. Example from Schacter et al. (1990); e. Example from Winner et al. (2001); f. Test stimulus from Osterrieth (1944) and Rey (1941); g. Example from Winner et al. (2001); h. Example from Brunswick et al. (2010); i. Illustration for one of the tasks in Brunswick et al. (2010).

LB remediation for students with reading and broader LB skills challenges.

Reading and comprehension are some of the most important challenges for RD. These two skills involve for example such subskills as reasoning and speed of processing for fluency. Mackey et al. (2011) have treated school-aged children to an NLB reasoning and speed training and showed significant improvement in speed and reasoning after the training. They pointed out that the malleability of fluid reasoning and processing in these children were enabling factors in this context. These studies did not, however, provide adult data to compare and confirm this hypothesis that the most efficient NLB training should happen at young ages to make any difference for RDs.

Benefits of NLB training were also found to be sustained in adult groups receiving training (Hötting et al., 2013). They worked with middle-age adults, demonstrating the unique benefit of spatial training with tasks resulting in improving spatial navigation (and VS skills such gestalt, spatial working memory, and so on). They showed significant neural modifications and efficiency in the group that received that training. This group on average showed lower frontal, temporal, and hippocampal activation, suggesting increased efficiency in functioning of these regions, the latter typically responsible for short and long term, as well as spatial memory (functions equally important in LB and NLB skills alike). The reduction and increased brain efficiency after such training supports the argument that NLB training is a viable solution to supporting RD populations at all ages, as some of these functions show overactivation in regions that should not and underactivations in others.

The forthcoming difficulty for researchers will lie in figuring out what of what types of NLB trainings will affect what aspects of NLB and LB cognition. For example, improving speed of processing may improve some NLB skills and some aspects of LB skills such as reading fluency and yet have no specific effect on other essential factors also involved in reading (Kail et al., 1979; Linn and Petersen, 1985; Uttal et al., 2013).

Training for RD and Effects on LB Skills

Gilger et al. (2013) were among the first to show the uniqueness of RD neurology using fMRI. Their interesting finding was that despite looking just like non-challenged readers on NLB skills, RDs had a completely unique cognitive process signature. One element that is often ignored is how different each RD individual's profile can be. For instance, I (Crogman) was diagnosed with dyslexia, and I would be little Jonny as described by Protopapas and Parrila (2018) in the sense of my singing ability. The issues I faced with dyslexia is not letter reversing, nor word pronunciation problems, but I substituted or saw words in a text that were not there and missed words that were actually in the text. Also, when asked to read my text back, I do read those missing words as if they were written on the page, not realizing that they were missing. I further mixed tenses in my writing. However, I would say that I never had a problem with reading *per se* because I knew the meaning of the words and could pronounce them. On the other hand, I did very well in science, math, and sports which demands NLB skills. Later, as an educator, I encountered a few of students with a similar issue: one particularly would reverse some words, yet his reading was without difficulties. Another student would get near perfect scores in math tests but had extreme difficulty with reading. Upon inquiry, this student could recognize certain words that allowed him to figure out how to do the problem.

RDs have consistently responded differently in LB and NLB learning processes and tests performance (Gilger et al., 2013; Trebeau-Crogman, 2018). Howard et al. (2006) gave a sequence-learning day-long NLB practice and found RDs to exhibit less learning, and at a slower pace, which was evident in their response time (RT) and accuracy in solving NLB problems. Thus, this NLB training highlighted specific RD weaknesses. However, these findings correspond to observations within the scope of non-dynamic NLB tasks, only a portion of the broad range of NLB tasks yet to be tested; this causes generalization limitations. Nicolson and Fawcett (2000) investigated RDs' NLB cerebellar learning performance using a dynamic 3D design (i.e., learning and integrating a spatial skill). Training lasted a year. Findings highlighted that RDs were still underperforming in speed and accuracy after "normalization" (reaching performance or behavioral similarity to control groups), but that their automatization cerebellar processes improved. Attree et al. (2009) tested navigational skills and memory in a 3D virtual space. Here RDs performed beyond controls. Brunswick et al. (2010) used the same type of virtual design, this time driving a vehicle and also testing self-location as well as memory. Male RDs spotted targets and reacted faster than all other groups (there was no control of these RDs' hobbies or pastimes and educational track that could influence these results). Sigmundsson (2005) used that design adding sound, in which RDs this time underperformed. These types of results show again the diversity of NLB skills and also how diverse RDs can be in their performances (Craggs et al., 2006; Diehl et al., 2014). Thus, mappings with different approaches seems to be the next step in tackling the NLB skill vs. disadvantage question in that group. What is also generally missing from these studies is a discussion of whether or not such NLB skills trainings did influence other cognitive functions such as LB skills.

Franceschini et al. (2013) experimented on improving attention in RD (spanning both LB and NLB skills), using video game training. Results showed an improvement of reading skills as well as attentional abilities, which are important in LB development.

However, the future developments expected from the line of research proposed here predicts to be quite complex. Diehl et al. (2014) worked with adolescents comparing neural correlations and overlap between LB and NLB skills by using both VS (NLB-VS) tasks and MRI imaging. They found that subjects with more reading challenges tended to perform better in NLB-VS tasks and this observation was concurred by relationships between LB and NLB pathway activations (frontostriatal [supporting procedural learning in reading, math and sensorimotor functions], and right/left hemisphere activations). They noted the interesting observation (Howard et al., 2006; Diehl et al., 2014) that we must parse out the various learning skills involved in these pathways, as certain implicit NLB learning skills (sequencing) tend to be low in RDs' performances, while visual patterns tend to be found intact in the same group. In their findings, Diehl et al. (2014)

discovered that lower reading skills predicted higher reaction time in VS mental rotation and 3D recognition tasks. This shows how complex the NLB skills issue is in connection with low reading skills and why it imports to study the matter conjointly to provide the appropriate type of NLB training support.

In conclusion, we've only partially scratched the surface of the complexity and importance of understanding NLB in RDs; that said, if RDs' NLB and LB skills processing are so unique, how must we design programs that will be appropriate their development? The answer lies in testing a maximum of NLB skills in a broad and uneven RD population in order to map out skills or lack thereof. This must come in conjunction with more fMRI studies to overlap behavioral findings with neurological imaging with the express purpose of figuring out what training RDs respond best to. For example, Eden et al. (1996) showed, using fMRI studies, that RD individuals were not only showing different types of cortical activations for regular reading pathways, but they did so as well with NLB skills such as tracking motion, a skill which serves both reading and NLB tasks.

Once this unique profile is better defined when it comes to processing NLB information, can we design remediation that will truly consider both LB and NLB strengths and weaknesses in RDs with the aim of improving LB and NLB skills alike? Such as a more comprehensive approach could provide answers to the long-drawn question of NLB skills deficit vs. talents in RD and provide the theoretical structure on which to build more adequate support for RD students.

New Directions for Investigating, Understanding, and Training RD's NLB Skills

In Trebeau-Crogman (2018), a first exploration of the benefits of NLB, and specifically VS training in the context of dyslexia was proposed; the main results are described in the following sections. We also explored current remediation programs to evaluate if they do contain any NLB components as compared to the known focus on LB drills.

Our hypotheses were that: (1) there would be lots of research on RD's NLB skills based on the general accepted claim that they are particularly gifted in these areas; (2) that the training/remediation programs in place do use integrated forms of NLB practice; and (3) that RD would perform better than nRD groups in NLB tasks.

Methodology

Reviewing the Literature

Two literature reviews were conducted spanning over 40 years (1975 to 2016) and based on databases, which for this search included EBSCO, PsycInfo, PsycArticles, Google Scholar, and a number of private websites belonging to foundations, private practice, schools, and other online resources available to the public, parents, professionals, and teachers. The bibliographies of identified articles and websites were crosschecked with database results to help ensure that no significant programs were missed. Key words included: program, remediation, dyslexia, reading disorder, reading disability, spatial, spatial ability, spatial aptitude, visual-spatial, non-language-based skills, ability, aptitude, VS learning, VS training, VS tasks, spatial, performance, rotation, visualization, VS skills, intervention, and training twice-exceptionality, giftedness, among others. We accepted and reviewed only programs that included a clear description of the tasks and procedures used to remedy/train or support struggling readers. We did not exclude books, chapters, and private or commercial websites. For the second review, the search yielded more than 300 articles, books, reports, abstracts, and other works.

Literature Review 1: Assessing the Current Format of RD Remediation Programs

Based on the process described above, we searched for literature and websites reporting programs geared toward RDs and checked for the use of NLB training tasks along LB remediation. Our search spanned the last four decades (**Table 1** and **Appendix A**), and landed about 41 programs. Results are described in the result section.

Literature Review 2: Studying NLB Skills in RD Research

A total of 48 articles were selected, with 204 RD/nRD task performance comparisons. Participants tested in these studies ranged from 4 years old to adulthood and accounted for a wide range of populations, genders, and participant backgrounds. The goal of the review in Trebeau-Crogman (2018) was to address three major issues found in the literature: the lack of RD studies establishing skill levels on NLB tasks, the lack of study of learning pathway and development of these skills in RD groups through the use of pre-post designs, the lack of such study designs in younger RD populations below adolescence (Before too much compensatory behaviors and strategies have been developed by RD individuals growing up in a text-demanding environment). **Tables 1**, **2** (see section "Results") show the disproportion of studies done on pattern recognition and SR compared to other NLB skills. More work is being done to extend this list and encourage researchers to explore the tasks less conventionally investigated.

Pilot Study

Based on the findings of the literature review and the issues highlighted, a pilot study was created to propose a model to researchers to accumulate more information and gather new data about the three questions described above.

Sample

The sample consisted of a total 74 participants retained after data cleaning. Ages ranged from 7 to 23 for RDs ($M = 11.55$), and 7 to 24 for nRDs ($M = 12.84$). The sample was split in age group of: Young (7–12), Teen (13–16), YoungAdults/Adults (17–23). Cut off for age groups were (for the Younger group) based on knowledge of VS skills changing with the advent of puberty; research has shown that pubescent teens exhibit a clear change in learning and VS abilities during and after puberty (Gilger and Ho, 1989). For the second (Teens) and third group (Young Adults), we based the cutoff on the timely transition from high school to college and passage from teenagehood to young adulthood.

TABLE 2 | Summary of empirical research reports of raw scores or accuracy, and RT results of RD vs. controls performances on VS tasks over 40 years of research.

	RD superior performance	RD lower performance	RD equal performance	Total tasks occurrences per skill
SV Spatial Visualization	2(8.0)	13(52.0)	10(40.0)	**25**
SR Spatial Relations or Rotations	3(9.0)	15(45.5)	15(45.5)	**33**
FC Global-Holistic Processing, Closure Speed, Flexibility of Closure	8(36.4)	7(31.8)	7(31.8)	**22**
DW Drawing	1(11.1)	3(33.3)	5(55.5)	**9**
PR Pattern Recognition/Recall	14(20.3)	29(42.0)	26(37.7)	**69**
TR Target Recognition/Recall	2(18.2)	6(54.5)	3(27.3)	**11**
N Virtual World Navigation/3D Navigation	4(30.8)	5(38.5)	4(30.8)	**13**
O Other	1(20.0)	3(60)	1(20.0)	**5**
Total Tasks Per Performance Level	**35(18.7)**	**81(43.3)**	**71(38.0)**	**187(100)**

The table classifies by performance levels and types of VS skill (Trebeau-Crogman, 2018). x(z): x represents the number of tasks among the 187 occurrences in the reviewed literature, and z is representative of the percentage over all skills in parentheses. Only 11 studies specifically separated RT and accuracy. In general, researchers reported mostly simple raw scores.

Participants were all volunteers; 18 years old and above were from a 4-year university, and younger participants were from regional schools, specialized centers (e.g., local dyslexia groups and tutor centers), and youth recreational centers.

Design

The study spanned a week, with pre-test of IQ and LB/NLB tasks on computer, followed by 3 days of targeted NLB training, and a post-test check (same as pre-test) to evaluate and compare the two groups' progress (**Figure 2**). Progress was evaluated looking at speed and accuracy of task completion. IQ measures consisted of four sections of the Wechsler Abbreviated Scale of Intelligence (WASI) – (Wechsler, 1999) Language-based (Vocabulary and Similarities subscales), and NLB cognitive abilities (Block Design, and Matrix Reasoning subscales). The NLB skills evaluated in this experiment were dynamic spatial reasoning in spatial rotations and relations with the Shepard-Metzler Cubes, SV, and ability to manipulate objects in space with the Minnesota Paper Form Board Shapes, and global holistic processing, closure speed and flexibility of closure, in other words, VS comprehension with the 3D Impossible Solids. The training itself contained Tangram tasks for spatial problem solving and pattern recognition, Lego Towers Match (Lego position discrimination) to investigate discrimination of changes in spatial configurations, and the Windows Test which tested spatial mental rotation.

These tasks covered 4 out of 7 general NLB types of tasks that were found in the literature review; however, Crogman and colleagues believe that this table could also be extended to inform the field, with emphasis specifically on using 3D/navigation experimental tasks, more fine art, engineering, and global holistic tasks in training designs to observe learning and improvement over time as compared to nRD groups.

RESULTS

Literature Review 1

Our review showed (**Appendix A**) that the most common remediation methods offered to RD students are LB-based or at best multisensory (or multimodal), focusing specifically on phonemic awareness for speech sound learning and phonics for letter-sound association improvement. No training has been found that specifically supports NLB skills separately or alongside regular remediation/support programs. **Table 1** reveals that over 41 of the most prominent reading intervention programs, height offer some form of hybrid LB/NLB-based practice. These are found in the form of images, shapes, drawing, sound/music, numbers, and symbols, which are presented along with words and letters. These programs are said to be completely or partially "multisensory." That being said, we found that none of these programs effectively help struggling readers to practice NLB skills either separately or in combination with LB tasks. In other words, we found no intentionality in supporting NLB cognitive processes to reinforce LB processes in RDs.

Consequently, no data is available on how NLB-focused trainings could support RDs' progress, nor if such trainings could help them also improve in the LB areas. Yet, a few attempts have been made showing that some aspects of LB skills may have improved after the implementation of NLB training (Eden et al., 1996; Demb et al., 1998; Stein, 2001; Vidyasagar, 2013); these examples are discussed in the following sections.

Literature Review 2

Results of this literature review and analysis of the findings showed (**Table 2**) that RDs performed higher than nRDs in about 18% of the NLB tasks studied, lower in about 43%, and equally in 38% of these tasks. The majority of these studies only collected point-in-time performance and did not include any pre-post training data.

Of 187 VS tasks across the 48 studies, individuals with RD demonstrated superior performance over controls on 35 comparisons (18.7%), lower performance on 81 (43.3%), and equal performance on 71 (38%). People with RD, when tested on VS performance against controls, do not typically outperform nRDs. In fact, individuals with RD perform equal to or worse than nRDs more than 81% of the time. When RDs performed better, it was on tests of global/holistic processing (rapid identification of spatial distortions) and pattern recognition (perceptual organization) over 63% of the time better than nRDs (see also Gilger et al., 2016). Notable also were the findings concerning RT and accuracy. A total of 11 studies particularly focused on reporting these two indices of performance. Here again, RDs had better RT only in four studies, they had worse RT in seven studies and worse accuracy rates in six studies; finally, RDs performed equally in three reports of RT and seven reports of accuracy across all tasks comparisons.

Pilot Study

Figures 3A,B show both mean of accuracy and means of RT differences between RD and nRDs. Results were quite mixed and revealed a number of complex aspects of RDs' aptitudes with NLB tasks. General linear models and mean comparisons were used to study the groups' performances. Note first that the majority of the data comparing the groups' differences were not statistically significant. Significance was found more so within the groups' own pre- to post-scores.

Comparing pre- and post-results, outcomes, for example, show that RD were faster in either CUBE (for Young RDs), or SHAPE tasks (for older RDs). Within RDs, Young RDs were generally faster and these differences were in majority statistically significant. As compared to their own baseline, there was positive improvement for all RDs in RT, more often in the Young RD group as well. At post-test, older RDs remained the second highest in computer accuracy scores but did not surpass their counterparts. Compared to their own baseline, Young RDs improved their accuracy, older RDs lost accuracy on computer tasks (which was surprising). Looking at means (**Figure 3**), when it comes to accuracy, the RD group improved in more tasks than the nRD group (shapes, impossible shapes, word rhyming); RD also improved in more tasks on their RT to solve NLB problems (on cubes, impossible shapes, word and non-word rhyming).

In their 3-day training, both RDs and nRDs improved in problem-solving speed, although the RD group took more time on average to solve their problems. Looking at the learning curve across training time, all groups completed their tasks increasingly faster as they practiced their VS problem-solving strategies but Young nRDs had the highest time gain. Results revealed that both RDs and nRDs improved in accuracy between books 1 and 3. The progression of accuracy was age and group dependent. Young RDs remained lower than young nRDs, and the same relation remained true in the older RD/nRD groups. However, Young RDs improved the most. These results were the same for each task across all groups. To conclude, RDs and nRDs performed significantly differently in the training. Both groups improved, but the RD group had the most accuracy improvement benefit from the training despite still lagging on performance over time.

When it comes to pre-test, training and post-test, overall, RDs had the largest score change magnitude (*or learning*) in most tasks (10 out of 13 tasks). They had also the largest change in accuracy (dropping on CUBE and SHAPE, increasing on 3DIS). Although RDs did not generally dramatically surpass nRDs either at baseline or after training, there was clearer self-improvement overall for RDs as compared to non-RDs, and also across all tasks, and as compared to their own baseline as well. Their results show them to be the group whose change magnitudes was the widest after training. RD also stood out as a group, with some of the widest changes in the training NLB scores between day one and day 3 – [given space and scope constraints see Trebeau-Crogman (2018) for detailed results].

The general conclusion of this pilot study was that RD as a group seems to have responded the most strongly to the NLB training both on NLB and LB tasks, but coming from their pre-test, they did not surpass nRDs. We can also conclude that RD and nRD did not generally statistically significantly differ after training on most measures and after receiving the NLB training. This could be a sign that the training helped RDs come to par with nRDs, or that they are not as gifted as expected, or a host of other conjectures that deserve to be thoroughly explored. Additionally, the lack of significance for this pilot study warrants more investigation of the question from other research groups now that the general design has been tested.

Finally, these result generally do not support the belief that RDs perform faster in general in NLB tasks as found in a number of previous studies specifically with mental rotation, puzzles, impossible figures (von Károlyi, 2001; Von Károlyi et al., 2003; Wang and Yang, 2011; Olulade et al., 2012; Diehl et al., 2014; Vakil et al., 2015). This in itself could be the start of a discussion on the real NLB skills performance of RD as compared to the commonly accepted attribution that RDs are "gifted" with NLB tasks. That being said, as Trebeau-Crogman (2018) points out, more must be done using training designs to see if the trends observed in the pilot study hold consistently across studies or if this lack of difference is actually group and study-dependent. The training was only 3 days long and could have used a wider range of tasks. The advantages of this pilot were that this was a novel approach to studying NLB abilities, that it tested training effects, and worked with younger children than previous studies.

Conclusion on Literature and Pilot Study Findings

Pulled together, these results show that the programs (most of which based on claimed evidence-based findings) do not consider NLB as an important part of their procedures and design (Review 1), some at best contain the use of some manipulatives but always connected to language modelalities; also, findings (Review 2) showed that research is sternly lacking on the study of NLB functions and skills in RD, which downstream creates an issue for the validity of the programs that are cerated based on the existing research; Lastly (Pilot study), findings show that there is no obvious across the board "talent" of RD with NLB tasks, but that they may respond better to training.

Thus, the question we raise here is to assess if we are indeed going in the right direction in how we label and diagnose dyslexia, if we are creating remediation programs that are indeed friendly and efficiently tailored to RD's needs, and if the real issue in improving symptoms of reading difficulty is not

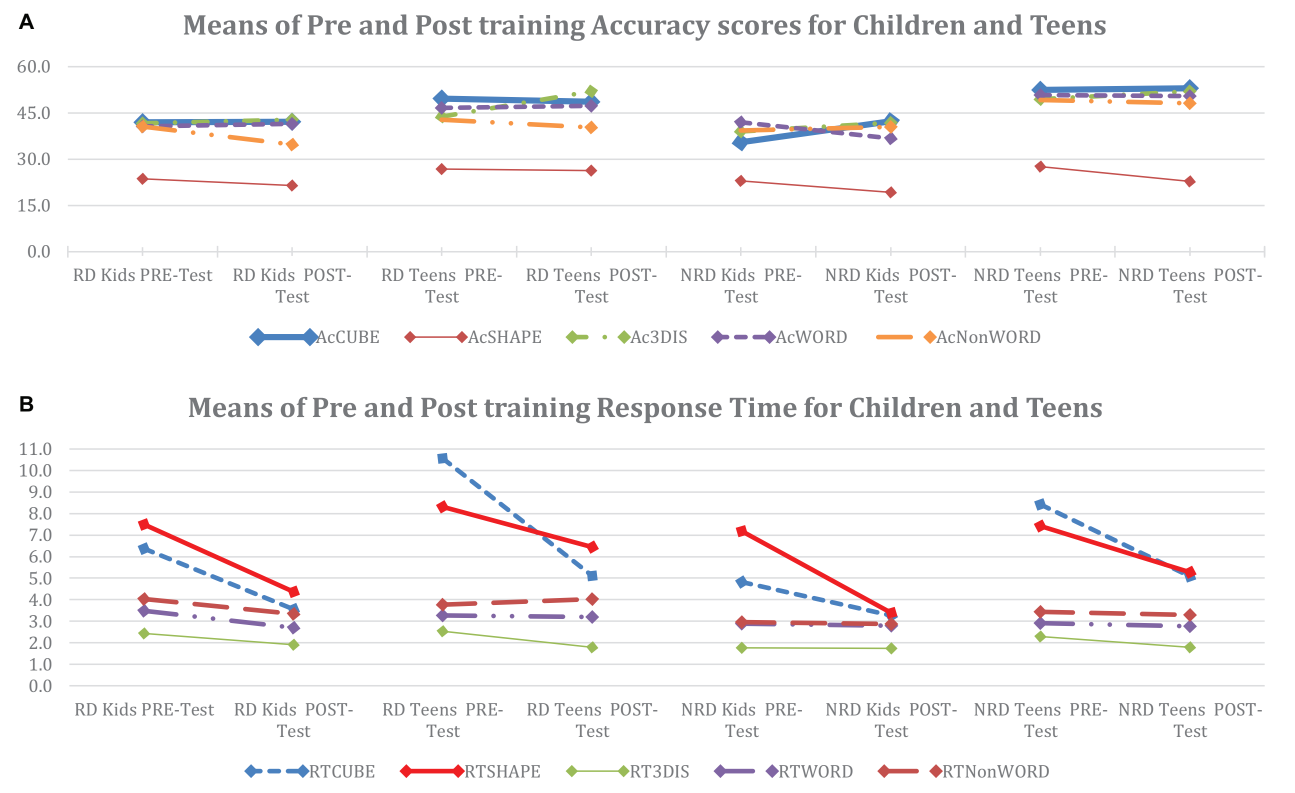


FIGURE 3 | (A,B) Pre- and post-training means of NLB and LB tasks accuracy and RT in RD and nRDs children and teens. Group mean comparisons were used as well as ANOVAs for the analyses, significance was evaluated at.

elsewhere, for example, in the way we teach and the way we support and train RDs.

DISCUSSION

In this manuscript, we have attempted to contribute to a growing opinion that dyslexia is a phenomenon that is not adequately researched (e.g., overwhelming LB-focused designs), that lacks study and consideration of whole both LB and NLB brain skills, and that is based on hasty conclusions (i.e., dyslexia is a disorder) and theories that seem to be less and less supported by solid evidence. Below is a discussion on how we propose to consider the task of reading, and how shifting our perspective can shift our research and thereby our results and support for RDs. This is combined with our general findings that (1) established that very rare "remediation" programs do consider using NLB tasks, which may be more friendly to RD brains; (2) that over the past four decades of research on dyslexia the research is weak, and the conclusions that RD are superior in NLB tasks is at best incomplete; and (3) that a process of training NLB skills should have a larger part in the dyslexia research circles as young RDs did show larger gains from the training. The pilot study by Trebeau-Crogman (2018) is a preliminary step to invite researchers to consider focusing on NLB studies in RD, with better samples and pre/post training designs.

Below we invite the reader to consider an alternative regard on dyslexia, and we conclude by making recommendations for future research.

Recommendations for Future Research

We suggest that researchers consider the following several routes of investigation.

(1) Establishing a map of all possible NLB skills. We do not currently have enough information about all possible NLB skills, nor do we have any centralized consortium or encyclopedia of these skills gathered in one area accessible to researchers. We are currently conceptualizing and building such a database which will cover known NLB skills, their known cortical and cognitive areas of functioning, tasks built by research groups that were tested and found reliable to assess these skills, as well as information about which population type/age/gender/ethnicity has been tested on these skills. Emphasis will be put on the study of struggling readers for each of these skills.

Once such mapping exists, it will become obvious where there might be areas of research left to investigate, and areas of improvement for applied researchers, especially in the context of NLB and struggling readers.

(2) Finding out how RD samples perform in these NLB skills. Once NLB skills are better studied in the general population, researchers will be able to predict where struggling readers do need specific support and match brain-based data to these tasks in order to formulate appropriate and adapted research and support tools for RD learners (and all learners in general).

(3) Designing studies that innovatively test these skills (and subskills) in RD using advanced technologies. Based on the seven basic groups of NLB skills highlighted, we invite creative researchers and educators/teachers to build technologically advanced tools to test/train/enhance these skills in struggling readers. Much emphasis should be put on gathering transparent and detailed data in order to guide empirical and concrete applications of these new research tools into mainstream educational and learning support contexts.

(4) Establishing overlaps LB/NLB skills and observing the evolution of both based on NLB trainings. We encourage researchers to focus on creating longitudinal training studies to observe not only NLB progress but corresponding/overlapping LB progress as well in order to deduce which brain processes and areas function in tandem when it comes to LB/NLB skills. This will provide significant breakthroughs both in cognitive and educational circles to better support struggling readers.

(5) Designing and proposing trainings either solely NLB based or hybrid NLB/LB. To date, we have not found trainings exclusively based on NLB support for struggling readers, nor explicit hybrid learning support programs inclusive of both LB and NLB training tasks. Thus, we insist on the intentional and purposeful application of these findings into beneficial programs for struggling readers of all ages. For starters, program builders can focus on such critical tools as question asking for learning in RD: Teaching RD students how to ask questions might just be a focus that may make more sense to RD. Thus, where they may fail to comprehend written language and use relevant vocabulary due to their lack of practice, question asking may be the tool that allows them to problem solve and circumvent their challenge. Letting RDs figure out problems on their own term may prevent forcing their neuronal pathway into a system that they may not be equipped to process. What is the connection with NLB? Through NLB trainings, a great deal of problem-solving practice can be supported, blended with such pedagogical tools as multisensory stimuli learning and teaching to power up question asking capacity. This helps build LB skills based on practicing using new vocabularies and learning to support one's position with solid arguments, for example, about how to solve an LB task. By developing appropriate tools, researchers, teachers, and educators can help RD students learn how to maintain interest in LB tasks and refocus on their areas of struggle and build LB skills. This is basically a paradigm shift where we come from NLB to create neural circuitry for LB skill building in RD.

(6) Be open for a consideration of age differences in these processes and studies, focusing specifically on developmental pathways. As indicated in Trebeau-Crogman (2018) there is a dire lack of information about the developmental trajectory of NLB skills in normal and struggling readers. We encourage researchers to focus on designs that will consider pre-K to college-aged participants and the observation of these skills in development. We must uncover possible critical periods that may be hindered in struggling readers and assess how to prevent such developmental periods to be missed before too much compensatory behaviors have been developed by RDs to survive in a LB-heavy world. This may lead to better understanding of the overlapping of LB and NLB skills as they develop and meet procedural/biological and cognitive hindrances.

Rethinking RD and Navigating the Task Spectrum

As indicated, the findings laid out above were mixed and show that more research is needed calling out educational specialists and researchers to apply better research designs and training protocols with sensitive and atypical reading challenged populations to test out if training in NLB domains influences LB abilities such as reading and spelling. The major issue with RD (i.e., dyslexia) is that it is not a well-defined set. In the literature, dyslexia is considered as a neurodevelopmental disorder, which earned it a placed in the Diagnostic and Statistical Manual. Protopapas and Parrila (2018) point out that this means that dyslexia can be legitimately viewed as a mental health problem, which comes with a broad set of ideological issues, controversies, as well as a sense of negative urgency and alarmism. This then creates a challenge about how to think about RD in terms of the task spectrum – meaning RDs' abilities between LB and NLB tasks (see **Figure 4**). Further, for a child to achieve adequate reading proficiency much tutoring and practice are required (Hutzler et al., 2004), and they tend to be diagnosed as dyslexic when they experience reading difficulty after such tutoring has occurred. Crogman (2017) has argued that much of this is due to the failure of finding/providing the right type of instruction, which plays a forgotten essential part in the development of readers' skills (Bourke, 2018; Nadelson et al., 2019). Instruction thus has not accounted for the uniqueness of children's brains or their cultural-language development. Instruction tends to force upon all children sets of rules, to get the brain to perform reading and writing tasks, which some brains just resist. This resistance is called LB disorder of phonological processing and phonemic awareness (Geiger and Lettvin, 1987). Thinking about dyslexia in the context of NLB and LB task as displayed in **Figure 4**, we can classify how RD children fare on the dyslexic spectrum as related to tasks performed.

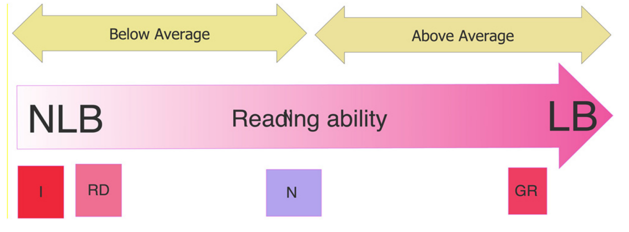


FIGURE 4 | Tasks and Dyslexia Spectrum superimposed [Illiterate (I), dyslexia (RD), normal or average reader (N), good reader (GR)].

From experience, we can speculate that children who reverse words would tend to not necessarily have a problem with most of the LB tasks. Why? Such children still understand how to pronounce the words and give meaning to the word their brain saw. Some children would reason that it's wrong because what they see does not fit the context and through experience they compensate to get to the intended choice; it stands to reason that a student with extreme reading difficulty will perform better with the NLB tasks (**Figure 4**). Letter reversal in reading and writing tends to happen only with letters that are mirror images of one another and are observed to be common among many beginning readers; for example "b/d, p/q or m/w, and letters that lack this symmetry has never been observed as reversing" (Blackburne et al., 2014). Letter and word reversals have become so strongly associated with dyslexia, yet individuals with dyslexia do not reverse letters with any greater frequency than those who do not have reading difficulties. It seems that the solution quite obviously lies in good instruction that trains the brain at such a task, which is reflected in the findings of the above result. It has been proposed that RD children continue doing this long after due to delayed development in reading rather than an issue with visual processing. Thus, causing many to suggest that the root cause of dyslexia/RD lies in the way the brain processes sounds, and that in the large majority of children, the issue is due to language processing at the phoneme (sound) level. In a recent study using fMRI, Blackburne et al. (2014) have shown that there is much more activity in the brain of adults with dyslexia than in that of children with dyslexia on reversal of letters. This is mostly due to adults being more attentive based on compensation methodologies used over the years, while children may not really be aware when they do reverse words.

A person who performs well on both will lie in the middle of the spectrum. Should it be then that, because of poor performance on LB tasks, a person be classified as RD, while a person who performs well on LB task and does poorly on NLB should be classified as another type of RD? Is difficulty in reading a manifestation of a neurological disorder? Is the brain dysfunctional? Crogman (2017, 2019) has argued that dyslexia is a result of how humans formulate language, but language was not always used by humans. Brains were not made for reading, playing chess, or for singing, but more so to manage tasks and compute how to maneuver in the environment. No brain is wired the exact same way, so different brains are differentially suited to different tasks (Refer to the widely new "Neurodiversity" conversation – a recognition that brains are simply on a spectrum without the label of disorder – see Rappolt-Schlichtmann et al., 2018). For the brain, language is just a task. Children are not born with language but only with the potential to learn it. How well a child learns language is more dependent on their environment than anything else. Take soccer for instance, it is an NLB task that all humans understand require to kick a ball around, yet, not all of them are as skilled, but we would not dare label them as having a faulty brain.

Simplifying what we mean by dyslexia would better help the classification. If we accept a working definition as difficulty in reading and writing language, then we actually have defined a spectrum from poor reader to good reader, with every brain variation in between. Some, in consequence, even reject the idea of dyslexia all together for the idea that we are simply looking at a spectrum of readers as in any other tasks (Tlemissov et al., 2020). Is dyslexia real or simply a myth in education context? In *E3S Web of Conferences* (Vol. 159, p. 09006). EDP Sciences.). A person who only reverses, inserts, or skips words could still appear for the onlooker as a good reader, but this artifact might result in their comprehension being wrong. Protopapas and Parrila (2018, 2019) argue against the notion of dyslexia as it being a neurodevelopmental disorder. Some studies have claimed to show a number of abnormalities in the brains of a few persons classified as RDs (Galaburda et al., 1985; Humphreys et al., 1990). Protopapas and Parrila (2019) contend that this study's design was flawed; it had too small a sample size and claimed evidence for participants with neurological or psychiatric conditions and impairments that were not limited to written language. Ramus et al. (2018) reported that evidence is lacking for structural differences between the brains of persons with dyslexia and typically developing readers. Many studies that claim such differences are plagued with small sample sizes, inconsistent results, fundamental methodological issues (Protopapas and Parrila, 2019), and "selective reviews of the evidence, with a marked preference for results that seem convergent" (Ramus et al., 2018). Larger studies and meta-analyses have revealed many important limitations with these brain imaging and studies designs, and it remains entirely unknown what is required for the neurodevelopment for reading skill to be unimpeded (Protopapas and Parrila, 2019). Most studies at best demonstrating theoretically trivial correlations between brains and behaviors, with no bearing on the critical issue of developmental failure.

Further, it is known that reading changes the structure of the brain (Schneps, 2014) but at possible cost (Gilger et al., 2016). For example, from a cognitive resource conflict point of view, as a group of very poor readers improved, it is at the cost of visual information (Dehaene et al., 2010). Numerous studies correlate the possibility that visual attention deficits are responsible for the reading challenges that are characteristic of dyslexia (Geiger and Lettvin, 1987; Ruffino et al., 2014). Reading is a task that requires one to focus their attention on the words as their eyes scan a sentence, while accurately shifting attention in sequence to the next. Focusing on visual details requires a trade-off with other sorts of information. RD is associated with differences in visual abilities, and these differences can be an advantage in many circumstances, such as those that occur in science, technology, engineering, and mathematics (Logan, 2009). As compared to their performance in LB, a poor reader will perform better at NLB tasks. On the RD spectrum, an extremely very good reader would be visually impaired, meaning that they would be less likely to perform well on NLB tasks (Dehaene et al., 2010). When a RD performs well at LB tasks, this might be an indicator that they might be misdiagnosed. As a child, I would perform well on both LB and NLB tasks, yet still insert words, and in writing, I would not capture everything that was in my thoughts on the paper. If being RD means "difficulty with LB tasks," then no one lies at the extreme ends of the spectrum, and our way of educating children who show this "deficit" on LB task is faulty.

Furthermore, any such conclusion that suggests that RDs have a faulty brain becomes a part of the problem on which most of the conversation and research on dyslexia is founded.

Sensory Stimuli Learning, the Game Changer

First, there is indeed harm: there is no question that poor reading is a serious problem and that it requires special attention in the form of assessment and remediation as early as possible. That being said, Protopapas and Parrila (2019) have argued, "if one wishes to demonstrate abnormality, then a completely different type of work is necessary to establish that well-specified brain properties are outside of some independently established, brain-based and brain-specific criteria." Looking at adult RDs, nearly all are functional in their NLB/LB tasks because they have learned to compensate to manage essential skills (reading, spelling, deciphering...). On the task spectrum, they would find themselves moving toward the middle, and as such brain abnormality must be determined before the onset of acquisition of skills (which is a hard problem in itself), or else whatever is found will likely be an outcome, rather than a cause of the skill level. These acquired skill sets are built through an interaction between the sense and the environment (Crogman et al., 2015; Crogman and Crogman, 2016, 2018) and such developing a tool that engage the senses would be effective to improve functionally in RDs.

Multisensory learning must be defined as learning that invokes sensory stimuli to draw out learners' curiosities and capture their attention. This is tantamount to creating a "wow factor" on which learners can *ride* to help them get over fears of performance and desire to practice skills that might have been perceived as hard before, but which, through the development of curiosity and attractive teaching multisensory methodologies as Rose (2006) develops, can help a struggling student to persevere. Through that newly found perseverance, practice may help where otherwise tedious LB-based drills may fail. Recent research has made clear that the multisensory processing of information is part of daily life, whereby the brain integrates the information from different modalities (senses) into a coherent mental perception (Ghazanfar and Schroeder, 2006; Murray et al., 2016). When the literature on dyslexia claims to support multisensory learning, it means learning through the senses and using a multisensory approach to allow children to learn simultaneously through visual, auditory, and kinesthetic activities, which are designed to secure essential phonic knowledge and skills. In the literature, reading difficulties are considered a learning problem, a fallacy, in which such students are considered having difficulties in one or more areas of reading, spelling, writing, math, listening comprehension, and expressive language. However, RD students are often shown to excel in other areas and communicate very well in spoken language.

Yet we argue that a student is still functional even though they are not versed on any of those areas. Human beings are good at compensating for their lack in one area. One hurdle RDs face is that much of the remediation approaches focus on LB, which only compounds and reinforces RDs' difficulties. It is well-known that many RD children do speak English fluently but in reading and writing they are forced to do so at a level that their brain is not ready for. This is because every individual brain behaves differently on various tasks, on the other hand, individuals' curiosities can be engaged and sustained with the right stimuli. NLB approaches are multisensory by nature and have been shown to work more effectively in engaging RD learners. Measuring improvement in reading performance, from stimuli outcome over time will demonstrate the effectiveness of sensory stimuli-based interventions.

Allowing a sense of play with the information and stimuli creates a space for questions to be born in learners (Crogman and Crogman, 2018), which leads to exploration and answers. Here we are arguing to provide more and more adapted opportunities for learners to use all their senses to engage with academic stimuli, allow them to ask the most basic questions, and be able to communicate in the level of their language ability. The Generated Question Model created by Crogman and Trebeau-Crogman (2018) allows for this type of engagement between learners and environment, and learner and teachers in their language ability. We expect in this more adapted language and brain capacity exchange, to see improvement in reading and writing with less added stress. The challenge of being stressed by the task at hand is a viable theory as to why a high rate of RDs perform better in STEM due to much of the tasks being more NLB focused.

Current multisensory approaches focus squarely on improvement in LB abilities not accounting for the differences of RD brain. No one brain is wired to read, it is a task for the brain as playing soccer. The brain gets better by practicing and tutoring. It is well observed that a majority of children that have reading difficulties overcome them by the time they are adults. Much is placed on fMRI studies to identify or confirm the existence of patterns typical to dyslexia, but most results do not yield a conclusion on which researchers can truly come to a consensus. Instead, it tells what sort of instructions would be effective in rewiring the brain. As pointed out before, common remediation approaches moving toward a multisensory-structured language program involving NLB tasks have been associated with improvement in LB abilities (see **Appendix A**). This may suggest that using purely sensory stimuli as NLB without any correlation to LB task might be a solution to educating and supporting RDs. Neurological differences drive the engine of society, to create the contrasts between hot and cold that lead to productive work (Schneps, 2014). Schneps suggests also that, "impairments in one area can lead to advantages in others, and it is these differences that drive progress in many fields, including science and math."

Figure 4 compares RD with nRD considering different prior experiences and how it may have influenced their development. Trebeau-Crogman (2018) shows that on NLB skills RD fared well as a group mostly in the complex rotation. This might be an indication that the differences observed are illusory. For any task undertaken, the brain creates specialized circuits for that specific task. This is what is activated and measured by fMRI as the task is being performed. New circuits are formed by combining parts of the brain that were originally designed to serve other functions.

Research has reported that RDs should excel in NLB tasks with sharper peripheral vision, and seeing "the bigger picture" (Geiger and Lettvin, 1987), finding the odd one out (Schneps, 2014), improved pattern recognition (Von Károlyi et al., 2003), good spatial knowledge (Franceschini et al., 2012; Zorzi et al., 2012), and picture thinkers (Geiger and Lettvin, 1987); they were also found to be effective business entrepreneurs (Logan, 2009) and highly creative (Schneps, 2014). Further, looking on how RDs perform on tasks, it is important to see how they fare against nRDs on the task spectrum.

CONCLUSION

Non-language-based training in educational settings and generally for struggling students may prove to be relevant for both LB and NLB skills alike, which RD students may struggle with, and which has been shown to impede their academic achievement. Multisensory stimuli used in learning may be one efficient method to create the proper circuitry to aid RD to be more functional. The claim of RD superior performance on NBL task is, for now, inconclusive probably for reasons that the field is not yet ready to admit, for RDs' differences might just be evidence that their circuit is wired differently. Removing dyslexia from the Diagnostic and Statistical Manual should be a discussion taken seriously and would be a first step in admitting that we still really do not understand the RD brain, and a step toward making a significant shift in how we endeavor to understanding RDs' brains. It is still left for debate what exactly of NLB skills are enhanced or impeded by the dominant use of right hemispheric functions in RD, and its potentially conflicting functions with NLB tasks. Advantages and disadvantages may also differ depending on the types of NLB skills focused on or trained, the research and training protocols used, the age/sex/background of the students tested, and a host of other parameters that seem to be missing from past and current studies. Much is left to be done in rethinking our research protocols to be better adapted to studying RD (tasks used, sample sizes, new technology). It is unknown how RDs, in their learning trajectory, can best benefit from NLB-based training and avoid passing potential sensitive NLB and LB learning periods as they develop and evolve in school settings.

DATA AVAILABILITY STATEMENT

The datasets analyzed in this manuscript are not publicly available. Requests to access the datasets should be directed to MT, mcrogman@csustan.edu.

AUTHOR CONTRIBUTIONS

MT and HC contributed equally to the making of the manuscript. MT brought expertise in dyslexia, research and data, and editing. HC brought in guidance on the theoretical and ideological direction of the manuscript, research, education, and dyslexia. Both authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2020.00153/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.