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Authors

Crogman, Maryam T

Gilger, Jeffrey

Hoeft, Fumiko

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Twice-Exceptional

*Supporting and Educating Bright and
Creative Students with Learning Difficulties*

EDITED BY

SCOTT BARRY KAUFMAN

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Visuo-Spatial Skills in Atypical Readers

Myths, Research, and Potential

MARYAM TREBEAU CROGMAN, JEFFREY GILGER,
AND FUMIKO HOEFT ■

OVERVIEW

Atypical learners including those with developmental dyslexia (also called decoding-based reading disability [RD]) and twice exceptionality (2e), where 2e refers to having an RD co-occurring with giftedness, often exhibit a wide variety of cognitive profiles. Following a medical historical tradition of a symptom-cure perspective, however, these individuals have typically been addressed by focusing more on *disabilities* than on *abilities* and on specifically salient behavioral outcomes such as improvement in reading-related challenges. While data on non-linguistic skills remain relatively unconsidered in general definitions of RD, we argue that these abilities may be an important part of the RD and 2e-RD picture. To develop such an argument, we start by providing an overview of current definitions of RD (Lyon, Shaywitz, & Shaywitz, 2003) and 2e (Foley Nicpon, Allmon, Sieck, & Stinson, 2011), and summarize the past 40 years of research on how non-verbal visual-spatial (VS) reasoning is expressed in people with RD. While results generally suggest that RD individuals as a group do not exhibit overall superior VS abilities, there appear to be specific types of VS skills that RD individuals show strengths in, but more rigorous and systematic research is needed. We also note that regardless of the data on VS skills in heterogeneous RD samples, there is a subset of RD individuals who could be classified as 2e-RD and who often demonstrate superiority in the VS domain. The special needs of these 2e-RD individuals needs to be better addressed with an extended focus beyond their reading challenges.

This chapter aims to highlight the need for a different theoretical and applied approach to how nonverbal VS skills in RD populations are considered; it also suggests the need for shifting the methodological approach of researchers when it comes to assessing those skills. The goal is to contribute to a change in the educational and clinical infrastructures that support and enhance nonverbal skills in these populations. Recommendations are made for future research in order to characterize the VS aspects of the RD profile and what, if any, links there are between the neurological underpinnings of 2e-RD and what may be unique VS processing mechanisms in RD and 2e-RD populations. We also make recommendations on how to translate such research into mainstream education and other venues catering to these groups. Researchers, educators, and parents are invited to focus on what may be processing and learning “uniqueness” or cognitive differences in RD and 2e-RDs when it comes to nonverbal VS skills and are invited to seek answers as to how to best support these learners.

INTRODUCTION

Reading Disorder

Developmental dyslexia or decoding-based RD is one of a set of specific learning disorders recognized by educational and medical professionals. According to Lyon et al. (2003, p. 2), it is

A specific learning disability that is neurobiological in origin . . . characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities . . . typically resulting from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge.

Prevalence estimates of RD in the school-age population run around 7% to 10%, with approximately 1.5 boys to every girl where the ratio may be higher as with greater severity (Boyle et al., 2011; Goswami, 2006; Hawke, Olson, Willcutt, Wadsworth, & DeFries, 2009; Shaywitz & Shaywitz, 2005; Willcutt & Pennington, 2000).

The consensus of brain imaging studies is that people with RD show an under-activation during phonological reading tasks in parts of the reading circuit (left parietotemporal and occipitotemporal regions). There may also be a developmentally inappropriate over activation of the right and left inferior frontal regions (Cao, Bitan, & Booth, 2008; Hoeft et al., 2007; Richlan, Kronbichler, & Wimmer, 2009, 2011). For example, research has shown that normal reading activation profiles change with age, with a natural shift to reliance on left hemisphere processing,

yet in RD samples (especially at younger ages) there remains a relative overactivation of the right hemisphere (Frye, Wu, Liederman, & McGraw Fisher, 2010; Hoeft et al., 2011). Appropriate and intensive remediation can change these atypical neurological patterns and “normalize” the reading circuit with more appropriate activation of brain regions and a more typical pattern of hemispheric reliance (Keller & Just, 2009; Simos et al., 2002).

In general, RD is defined on the basis of a reading problem. In practice, however, we see that individuals with RD often exhibit a wide variety of cognitive profiles. In addition to the reading problem, other symptoms such as delays in oral language and motor development, auditory processing deficits, and secondary academic problems are common, as are certain co-occurring conditions such as attention deficit hyperactivity disorder (Chaix et al., 2007; Greven, Harlaar, Dale, & Plomin, 2011; King, Lombardino, Crandell, & Leonard, 2003; Ramus, 2003; see Fugate, this volume). There are also data indicating that individuals with RD may show nonlinguistic behavioral or sensory deficits, such as those related to visual-orthographic processing, cognitive-temporal sequencing, and functioning of the parvo-magnocellular visual system (Fawcett & Nicolson, 1994; Howard, Howard, Japikse, & Eden, 2006; Schneps, Brockmole, Sonnert, & Pomplun, 2012; Skottun, 2005; Stein, 2001). However, the contribution that these nonlinguistic or sensory deficits may make to the etiology of the reading issue is unclear, and more research is needed (Goswami, 2006, 2015). Thus people with RD constitute a very diverse group, with developmental challenges and etiologies that require multidisciplinary approaches to support and research.

RD and Giftedness

Further complicating the RD profile is the potential for reading deficits to occur alongside cognitive strengths or talents. The presence of cognitive gifts/talents such as high ability to process verbal (Berninger & Abbott, 2013) or nonverbal information (Gilger, Tavalage, & Olulade, 2013) may mask RD traits, complicate RD diagnoses, or, more positively, help individuals with RD to compensate for their reading weaknesses (Silverman, 2009; van Viersen, Kroesbergen, Slot, & de Bree, 2016). In educational settings, it is common to label children who have a learning or cognitive disability but also learning or cognitive gifts/talents as twice exceptional (2e; Foley-Nicpon, 2013; Kalbfleisch, 2012; Nielsen & Higgings, 2005). Many different disorders can co-occur with a superior ability (e.g., Treffert, 2009), but this chapter focuses on one of the most common forms of 2e, 2e-RD. The superior component of the 2e-RD condition can take many forms, such as measurable verbal IQ or performance IQ, special talents in math or art, extreme memory skill, and other (Kay, 2000; Nielsen, 2002; Nielsen et al., 2005).

Twice exceptionality rates vary greatly across studies, and some of the best estimates have placed the prevalence of 2e in K–12th grade in heterogeneous special education or gifted populations at around 3% to 5% (with some as low as 1% and as high as 36%; Foley-Nicpon et al., 2011; Ruban & Reis, 2005). Given that

reading/language-related disabilities are the most common of the specific learning disorders (Cortiella, & Horowitz, 2014), it is not surprising that a majority of these 2e children will have reading impairments as part of their profile. While the reading-related deficits may be the focus of remediation in children with 2e-RD, best practices suggest that a thorough treatment plan should attend to the entire profile of student strengths and weaknesses (Berninger et al., 2013; Jones, 1986; Kalbfleisch, 2012; Kappers, 1991; LaFrance, 1997; Paulesu et al., 2001; Snowling, 2000; Snowling, Bishop, & Stothard, 2000).

Neural Systems of RD

The disease model of RD has, understandably, dominated the neurobiological studies, and researchers have tended to focus on the left hemisphere language-based systems or the classic reading circuit: left hemisphere inferior frontal, inferior temporo-occipital, and temporo-parietal areas (Linkersdörfer, Lonnemann, Lindberg, Hasselhorn, & Fiebach, 2012; Richlan et al., 2009, 2011; Vandermosten, Hoeft, & Norton, 2016). Research, however, shows that individuals with RD often have broader differences in brain functions and structures not limited to the left hemisphere, with behavioral consequences we do not fully understand (Diehl et al., 2014; Eckert, 2004; Gilger & Hynd, 2008; Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopoulos, 1990; Galaburda, LoTurco Ramus, Fitch, & Rosen, 2006; Gilger & Kaplan, 2001; Linkersdörfer et al., 2012; Maisog, Einbinder, Flowers, Turkeltaub, & Eden, 2008; Olulade, Gilger, Talavage, Hynd, & McAteer, 2012; Richlan et al., 2009, 2011). In addition to the reading pathway of the left hemisphere, the brains of people with RD show structural and/or functional differences in the right hemisphere, subcortical and cerebellar regions (Eckert, 2004; Gilger & Kaplan, 2001; Galaburda et al., 2006; Galaburda, 1992; Hynd et al., 1990; Lindell, 2006; Linkersdörfer et al., 2012; Maisog et al., 2008; Pugh et al., 2000; Richlan et al., 2009, 2011; Temple et al., 2003). While the processing of language-related information is not constrained to the left hemisphere, these other regions where RD differences have been found are known to be important for other functions as well, such as processing visuo-spatial information, social, affective, and musical information. Again, we know little about how these other neurological differences in RD individuals manifest in behavior or what factor they may play in response to remediation; nor do we understand how reading remediation might in turn influence the development of these associated skills.

Considering the Nonverbal Profiles of Individuals with RD

We must keep in mind that despite similarities in behavioral and cognitive characteristics, each individual in the general RD population is different. Thus categorizing individuals, though helpful in many respects, can also become a limitation to the full consideration of skills and challenges encountered by these individuals.

Indeed, science has truly advanced our understanding of the causes and expression of RD. The relatively neglected questions deal with why and how the brains of people with RD may be unique in other ways and how that uniqueness may manifest itself in behavior.

Twice exceptional-RD individuals, as mentioned earlier, likely constitute a sub-population within the RD group. But some have proposed that 2e-RD is more than a subgroup and that RD individuals *in general* show a tendency to excel in certain VS skills as part of their RD profile, perhaps reflecting a unique neurology present at birth (Eide & Eide, 2011; Galaburda, 1992; Geschwind & Behan, 1982; Geschwind & Galaburda, 1987; von Károlyi, Winner, Gray, & Sherman, 2003). Skills in the nonverbal and VS domain are, in fact, those most often represented in 2e populations, including savants and gifted children with specific learning disorders (Treffert, 2009). Seminal research initiated discussions on how the neurology of RD could be linked to special skills in the nonverbal domain (Galaburda, 1992; Geschwind et al., 1982; Geschwind et al., 1987). Geschwind and colleagues hypothesized that pathological or atypical prenatal development of the left hemisphere, and secondary right hemisphere neurological compensation and development, could lead to both the language-related weaknesses *and* non-verbal strengths simultaneously.

Partly based on these early hypotheses about RD and 2e-RD neurology and partly because of subsequent research and additional anecdotal reports, some authors have suggested that we destigmatize individuals with RD by moving away from a purely deficit perspective and emphasizing their possibly inherent strengths such as VS abilities. For example, some have suggested that people with RD are gifted in nonverbal areas and/or the status of being RD is a gift in itself (e.g., Davis, 2010; Eide, 2013; Kaufman, 2015; West, 1997). Because individuals with RD may be talented in the nonverbal areas, they may therefore excel at careers or avocations related to these special aptitudes (e.g., West, 1997).

Indeed, there are data suggesting that people with RD tend to adopt and perform well in VS-oriented professions or professions involving more mathematical and artistic skills than verbal skills (Cowen, 2004; Eide & Eide, 2011; Logan & Martin, 2012; Steffert, 1998; Taylor & Walter, 2003; West, 1997, 2009; Wolff & Lunberg, 2002). There are also some reports that people with RD do better than non-RD groups on the processing of complex visual forms (e.g., Diehl et al., 2014; Von Károlyi et al., 2003). Our experience with people that have RD is that they often do “think differently” and in creative ways (see Daniels & Freeman, this volume), but the precise ways they do so have yet to be empirically resolved. As we detail in this chapter, research over the past 40 years is inconsistent on this question. Some studies report better performance in RD samples, while many do not. The best conclusion at this time seems to be that there are large individual differences, with some being gifted or talented and others not.

We suggest that it is important to take a more individual differences approach rather than categorizing individuals into RD or 2e-RD groupings and stopping there. The end result may be a better way to consider innovative perspectives,

aimed at supporting individuals in all their dimensions, rather than further refinement of labels and limiting boxes (Gilger & Hynd, 2008; Rose, 2016).

MYTH OR REALITY: ARE PERSONS WITH RD SUPERIOR IN VS THINKING?

Quality data on what may be a dyslexic advantage in nonverbal and creative domains is limited. While only a few studies have provided career assessment data, a number of studies have addressed the aptitude question, which we detail next.

Careers

While the literature does show an elevated rate of individuals with RD in non-verbal careers (fine arts, astronomy, etc.; Hickman & Brens, 2014; Schneps et al., 2011), these findings are largely anecdotal reports or self-report surveys, and there is a paucity of experimental studies of good design in this area (Taylor et al., 2003; Wolff et al., 2002). In contrast, other reports (Fink, 2002; Finucci, Gottfredson, & Childs, 1985; Gottfredson, Finucci, & Childs, 1984) show that people with RD choose fields that are considered more “verbal” (nursing, business, law). It has been proposed that many RD individuals have strong oral language skills and that some of these “verbal” professions may require certain creative thinking abilities characteristic to people with RD (Fink, 2002; Finucci et al., 1985; Gottfredson et al., 1984). Thus, whether in positions that appear nonverbal or verbal, the argument is that people with RD choose careers based on a set of unique abilities that they possess more often than people without RD. It is possible, however, that career choice is more a matter of preferences or practice based on compensations for reading-related weaknesses or *within-person relative strengths* (and not necessarily that their nonreading skills are in the gifted domain).

For example, Wolff and Lunberg (2002) suggest that career choice is more a function of compensation and practice. They worked with art students and through both interviews and tests concluded that art students were more often likely to report issues with phonological skills than non-art students. They reported that art students tended to choose this field more often when they are RD because of their challenges with reading. In the same vein, Hickman and colleagues (2014) interviewed and observed art teachers with severe dyslexia to find out what coping strategies they had employed in their teaching and to see if those strategies could be used as tools to help students with RD. One conclusion was that these teachers had not only a hyper-awareness about VS information but were also very socially attuned and particularly empathetic to struggling students due to their own experiences.

In other domains such as the sciences, few reports are available, and sometimes they are contradictory (e.g., people with RD are wired for and choose more scientific careers [Schneps et al., 2011] versus they choose careers that are

more “people oriented” [Taylor, et al., 2003]). For example, Schneps and colleagues observed astronomy students with RD and professional astrophysicists and discovered that they were better at detecting signals and had unique visual strategies to solve problems. They posited that many struggling individuals with RD may find success in careers that build on the type of strengths they naturally possess; however, the authors suggested that these abilities may not be manifested without proper training and guidance (see also Gilger et al., 2016; Gilger et al., 2013). Thus Schneps and colleagues imply that a special potential ability for these types of skills is inherent to the RD profile, but these abilities need to be trained.

Finally, Taylor and Walter (2003) did a simple comparison between the occupations of adults with and without RD and found that people with RD were more often in “people-oriented” professions such as nursing or business rather than science. They stressed the possibility of a pattern of career choice correlated with having RD. Logan (2009) found similar results with some nuances as to the type of business venture, for example people with RD were more often entrepreneurs than corporate managers, and used strategies such as delegation for tasks that involved verbal demands. In the same vein, Finucci and colleagues (1985) tracked boys with RD into adulthood to assess their career choices and found the majority to be employed in the business area with differences correlated to the degree of their original reading deficits as young children.

The variety of the reports and the lack of consensus on what people with RD choose as careers is a testimony to the confusion that still exists around inherent RD abilities and that representation in careers. An important remaining question is if the career choices made are reactionary to reading weaknesses and compensation over time, reflect the practice of relative strengths, or are due to some innate ability or brain-behavior skill set that is linked to being RD. It is valuable to address this question to adequately support individuals with RD from birth through their adult life.

Visuo-Spatial Ability

There are many more studies on VS aptitude in people with RD than there are regarding RD careers. Before summarizing this research, we must point out that despite a general belief that RD may exhibit superiority in VS skills, a large body of research has looked at VS *deficits* and VS associations with RD. For example, Facoetti and colleagues (2010) have shown connections between visuo-spatial attention and auditory processing deficits in families at risk for RD, and the work of Valdois and colleagues (2004) and Vidyasagar and Pammer (2003) demonstrates that visuo-spatial attention issues may be a predictor dyslexia. There is also a body of work looking at the role that specific neurological visual system may contribute to the RD profile (e.g., Eden, Stein, & Wood, 1993; Facoetti et al., 2009; Goswami, 2012; Gould & Glencorss, 1990; Howard et al., 2006; Koenig, Kosslyn, & Wolff, 1991; Schneps et al., 2012; Stein, 2001). While phonological decoding

problems are considered the hallmark of RD, there are multiple factors that contribute the expression of the disorder, and this research suggests a multi-deficit view of dyslexia, including connections to VS abilities.

Before beginning our review of VS skills it is noteworthy that a significant amount of research has focused on the more basic or primary aspects of visual processing or perceptual skills in RDs, and this work is not part of our review here. These studies have considered such behaviors as peripheral visual abilities, visual memory, motion perception, the analysis of variable spatial frequencies, and functions of the parvo-magnocellular system in RD subjects (see Eden, Stein, & Wood, 1993; Facoetti et al., 2009; Goswami, 2012; Gould & Glencorss, 1990; Howard et al., 2006; Koenig et al., 1991; Schneps et al., 2012; Stein, 2001). While studies of these more basic visual abilities or perceptual processes are important, they do not represent the type of skill most often studied and considered as an RD gift or as an explanation for the overrepresentation of successful RDs in artistic, nonverbal reasoning, or creative fields. These skills do, however, likely influence the more dynamic spatial reasoning or processes we review.

Our aim in the following sections is to review the literature on experiments assessing VS abilities in RD samples. We emphasize dynamic and complex spatial visualization, reasoning, rotation, nonverbal holistic processing, and nonverbal creativity. These abilities have been well researched and linked to the effects of genes, hormones, gender, age, and training (Cohen, Kosslyn, Breiter, & DiGirolamo, 1996; Jung & Haier, 2007; Linn & Peterson, 1985; Moore & Johnson, 2008; Newcombe & Dubas, 1987; Uttal et al., 2013). They are also correlated with nonverbal IQ (and to a lesser extent verbal IQ; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004). Other studies have also found relationships between VS skills and performance in math, engineering, music, and art, as well as interpersonal communication styles (e.g., Stieff, Dixon, Ryu, Kumi, & Hegarty, 2014; Winner Casey, DaSilva, & Hayes, 1991). The term *visual-spatial* (VS) skill or ability is a broad term that includes a plethora of separate yet related behaviors, and it is assessed in a number of different ways. Lohman (1996) defines VS ability as “the ability to generate, retain, retrieve, and transform well-structured visual images,” and he included several subfactors that comprise VS in general: spatial relations, spatial orientation, and spatial visualization, inclusive of tasks requiring encoding, remembering, transforming, and matching and cognitive activities involving closure speed, perceptual speed, visual memory, and kinesthetic left-right orientation. For the purpose of this chapter we use Lohman’s definition and include additional VS skills categories such as dynamic versus static VS tasks, navigation in 3D space and the processing of virtual environments, and so on (Newcombe & Shipley, 2015; Uttal et al., 2013). Additionally, we incorporate abilities that involve recognizing pattern frequencies, memory, attention, or creativity as they relate to processing of information in space. Note that these separate VS skills are not uncorrelated, and the list is not necessarily exhaustive.

Literature Review

We reviewed the literature for the past 37 years, 1978–2015. Like Gilger and colleagues (2016), we reviewed only those studies that included a control (non-RD comparison) group. A total of 43 articles were found to meet our selection criteria. Collapsing the VS measures of these 43 we found 192 (partially overlapping and repeated) tests comparisons between individuals with and without RD (non-RD).¹ Participants tested in these studies ranged from four years old to adulthood and accounted for a wide range of populations, genders, and participant backgrounds. Databases searched included HEBSCO, PsychInfo and PsychArticles, and Google Scholar. The bibliographies of identified articles were crosschecked with database results to help ensure that no significant articles were missed. Key words searched alone or in combination were: dyslexia, reading disorder, RD, spatial, spatial ability, spatial aptitude, VS talent, nonverbal skill, ability or aptitude, VS learning, VS training, VS tasks, spatial, performance, rotation, visualization, VS skills, intervention, training. Accepted publications had to include comparisons of RD to non-RD samples, or at least present adequate data to deduce how subjects with RD performed relative to a population norm. Excluded from this review are books, chapters, conference presentations, single subject case studies and anecdotal reports, and publications with a primary focus other than dynamic and complex VS skills as defined previously (e.g., peripheral abilities, visual attention, etc.).

Table 14.1 provides descriptions of the seven main categories of VS skills we focused on. Brief descriptions of each of the 43 studies are shown in Table 14.2. Finally, summary statistics for each of the seven categories of VS are provided in Table 14.3. Table 14.3 allows the reader to see at a glance the overall average performance of individuals with RD compared to non-RD controls on the 192 VS task comparisons found in the review. It is important to remember that when we speak of RD “superiority” on certain tasks, we do not necessarily mean “gifted” performance but rather superior performance relative to controls. Gifted performance would require levels in the exceptional range, say, 1.5 to 2 standard deviations above the population mean on a standardized test (Stephens & Karnes, 2000). The reader is free to examine the studies in Table 14.2 on his or her own; *however, our conclusion is that rarely did RD groups achieve a high enough level of mean performance to classify as gifted.*

Out of the 192 VS tasks recorded across 43 studies, individuals with RD relative to non-RDs demonstrated superior performance on 30 (16%) comparisons, lower performance on 70 (36%), and equal performance on 92 (48%). These findings clearly show that people with RD do not typically outperform their non-RD counterparts, and, in fact, individuals with RD perform equal to or worse than non-RD

1. Some papers included more than one VS test that was used to make RD/non-RD statistical comparisons. There were 192 useable statistical comparisons for VS skills in these 43 articles.

Table 14.1. VISUO-SPATIAL SKILLS AND CONSTRUCTS^a

Task Category	Task Type	Example	Illustration	Associated Literature Assessed
Spatial Visualization	Complex, multistep manipulations of spatially presented information, may involve rotations, dynamic movement, part-to-whole analysis	Paper from board, block design, paper folding		Thomson (1982); Kamhi, Catts, Mauer, Apel, & Gentry (1988); Siegel & Ryan (1989); Everatt (1997); Winner et al. (2001); Brosnan et al. (2002); Helland & Asbjørnsen (2003); Duranovic, Dedecic, & Gavrić (2014); Lockiewicz, Bogdanowicz, & Bogdanowicz (2014).
	Perceive an object from different positions, mentally rotate one stimulus to align it with a comparison stimulus, involves rotations and/or reflections	Shepard Metzler cubes		Stanley, Kaplan et al. (1975); Pontius (1981); Thomson (1982); Corballis, Macadie, & Beale (1985); Eden, Stein, & Wood (1993); Singh (1993); Karádi, Kovács, Szepesi, Szabó, & Kállai (2001); Winner et al. (2001); Rüsseler, Scholz, Jordan, & Quaiser-Pohl (2005); von Károlyi & Winner (2005); Rusiak et al. (2007); Attree, Turner, & Cowell (2009); Wang & Yang, (2011); Olulade, Gilger, Talavage, Hynd, & McAteer (2012); Diehl et al. (2014); Lockiewicz, Bogdanowicz, & Bogdanowicz (2014).
Global-holistic processing, closure speed, flexibility of closure	Rapid identification of incomplete or distorted pictures and figures impossible in normal 3D environments	Impossible figures, Gestalt completion		von Károlyi (2001); Winner et al. (2001); Brosnan et al. (2002); von Károlyi et al. (2003); von Károlyi & Winner (2005); Brunswick et al. (2010); Diehl et al. (2014).
Drawing	2D drawing or reproduction of shapes or patterns	Draw a man, free drawing, pattern reproduction		Pontius (1981); Everatt (1997); Winner et al. (2001); Eden, Wood, & Stein, (2003); von Károlyi et al. (2005); Alves & Nakano (2014); Duranovic et al. (2014).

Pattern Recognition/ Recall / Target Recognition	Perceptual organization	Matrices, Rey- Osterrieth Complex Figure Task, hidden figures, block design	f, g	Siegel & Ryan (1989); Koenig, Kosslyn, & Wolff (1991); Eden, Stein, & Wood, (1993); Everatt (1997); Fischer & Hartnegg (2000); Nicolson & Fawcett (2000); von Karolyi (2001); Winner et al. (2001); Brosnan et al. (2002); Helland & Asbjørnsen (2003); Howard, Howard, Japikse, & Eden (2006); von Karolyi et al. (2005); Attree et al. (2009); Brunswick et al. (2010); Olulade et al. (2012); Schneps, Brockmole, Sonnent, & Pomplun (2012); Alves & Nakano (2014); Ruffino, Gori, Boccardi, Molteni, & Facoetti (2014); Martinelli & Schembri (2015).
Virtual world navigation / 3D navigation / speed of recognition	Navigating 2D–3D space	Maze, navigating virtual environments,	h	Siegel & Ryan (1989); Winner et al. (2001); Nicolson & Fawcett (2000); Sigmundsson (2005); von Karolyi et al. (2005); Attree et al. (2009); Mammarella et al. (2009); Brunswick et al. (2010); Wang & Yang (2011).
Other	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. (2014).

NOTE: Some studies appear several times as they tested diverse types of skills. ^aConstructs and table format borrowed from Gilger, Allen, and Castillo (2016). ^bModified example from the Minnesota Paper From Board Test (Likert & Quasha, 1941). ^cExample from Vandenberg and Kuse (1978) based off of the Shepard-Metzler Cubes Mental Rotation Tasks (1988). ^dExample from Schacter, Cooper, and Delaney (1990). ^eExample from Winner et al. (2001). ^fTest stimulus from Osterrieth (1944) and Rey (1941). ^gExample from Winner et al. (2001). ^hExample from Brunswick et al. (2010). ⁱIllustration for one of the tasks in Brunswick et al. (2010).

Table 14.2. STUDIES FEATURING RD PERFORMANCES COMPARED TO CONTROLS^a

Authors	Sample and Age Group	Tools & Tasks	Higher Performance	Lower Performance	Equal Performance
van Bergen et al. (2014)	212: 100 at risk w/o RD 44 RDs, 68 controls (Age 4 and 4 years later)	Block design, patterns (copying patterns), object assembly (jigsaw puzzle), picture completion (adding missing parts), analogies (assembling pieces in small trays by shape, color, size)		PR (block design)	
				PR (patterns), PR (analogies)	
				SV (object assembly)	
				SV (picture completion)	
Kamhi et al. (1988)	30, 10 RDs (6–8)	Minnesota Paper Form Board, paper folding		SV (Minnesota Paper), SV (paper folding)	
Siegel & Ryan (1989)	641, 200 RDs (6–14) Grouped as 6–8, 9–14: PDG, CDG, RDG	Block design, object assembly, picture completion, picture arrangement, mazes, PIQ			PDG: SV (block design in PIQ) 6–8 PR (object assembly) 6–8 PR (picture completion) 6–8 CDG: SV (Block design in PIQ) 6–8 / 9–14 PR (object assembly) 6–8 PR (picture completion) 6–8 PR (picture arrangement) 6–8 RDG: SV (block design in PIQ) 6–8 / 9–14 PR (object assembly) 9–14 PR (picture completion) 9–14 PR (picture arrangement) 6–8

(continued)

Table 14.2. CONTINUED

Authors	Sample and Age Group	Tools & Tasks	Higher Performance	Lower Performance	Equal Performance
Pontius (1981)	356 children: 104 RDs (8–15)	Bender Gestalt Rotation task, drawing		SR (mental rotation) DW (drawing a person)	SR (mental rotation)
Thomson (1982)	83 RDs (8–16)	British Ability Scales: Letter-like form rotation, visualization of cubes, block Design (level), block design (power), recall of design			SR (letter rotation) SV (blocks level), SV (blocks power) SV (cubes)
Benton (1984)	Multiple studies with children and adults	Show right left limbs, finger recognition		O (right-left orientation) O (finger recognition)	
Singh (1993)	40, 20 RDs (8–11)	Mental rotation		SR (mental rotation)	
Fischer & Hartnegg (2000)	85 RDs (8–15)	Practice on pattern orientation to detect targets in visual field			PR (pattern detection after training)
Karádi et al. (2001)	55, 27 RDs (8–9)	Angled drawing recognition		SR (mental rotation)	
Duranovic, Dedeic, & Gavrić (2015)	80, 40 RDs (9–11)	Mental rotation, paper folding, Rey-Osterrieth complex figures, electric grid task, drawing memory	SV (paper folding)	PR (Rey-Osterrieth complex figure, recall) DW (drawing memory long term but results nonsignificant)	SR (mental rotation) PR (Rey O. complex figure copy) PR (electric grid) DW (drawing memory short term)
Mammarella et al. (2009)	39, 22 RDs (9–12)	Outdoor spatial description surveys and route description		N (outdoor spatial description surveys and route description)	

Alves & Nakano (2014)	26, 13 RDs (9–11)	Raven matrices, figural creativity	DW (creative drawing), PR (Raven matrices)
Eden, Stein, & Wood (1993)	17 (10–13)	Complex figures, judgment of lines	SR (judgment of lines) PR (complex figures)
Eden, Wood, & Stein (2003)	93, 26 poor readers (10–12)	Clock drawing, handedness (Edinburg test), visuospatial skills (WTSC block design test)	DW (clock drawing)
Wang & Yang (2011)	120, 60 RDs (10–12)	Columns (cover) a ball (target), must rotate 3D figures to find a ball	SR, N (rotation response time) SR, N (rotation accuracy)
Corballis, Macadie, & Beale (1985)	20, 10 RDs (11–13)	Rotation of letters, discriminating Bs from Ds	SR (left hemisphere advantage for unrotated letter recognition in space) SR (accuracy)
Corballis, Macadie, Croft, & Beale (1985)	20, 10RDs (11–13)	Recognizing rotated letters F, G, and R.	SR (1/accuracy letter recognition, more errors with G; results nonsignificant) SR (letter recognition accuracy and speed of F and–R) (2/speed of recognition (rotated and unrotated) but results nonsignificant)

(continued)

Table 14.2. CONTINUED

Authors	Sample and Age Group	Tools & Tasks	Higher Performance	Lower Performance	Equal Performance
Vakil, Lowe, Goldfus (2015) – <i>Practice study</i>	53, 23 RDs (11–13)	ToH puzzle (SV), pattern skill learning task (PR)	PR (pattern skill learning task, RT after practice) SV (time by first move after picture)	SV (time per moves)	PR (pattern skill learning task, learning rate) SV (number of moves to find solution, RT)
Helland & Asbjørnsen (2003)	39 RDs (12–13)	Aston Index (visual-sequential memory tasks pictures and symbols), WISC (block design, object assembly)	PR (visual-sequential tasks for the subgroup with math skills)	PR (visual-sequential tasks) for the mathematics-impaired subgroup PR (block design), SV (object assembly)	PR (visual-sequential tasks for RD subgroup with language and math impairments)
Attree, Turner, & Cowell (2009)	42, 21 RDs (12–14)	BAS pattern construction and design recall tasks, virtuality “pseudo-real life test”	PR (spatial recognition memory); N (real-world, target recognition)	PR (BAS but results nonsignificant)	SR (global rotation)
Martinelli & Schembri (2015)	36, 16 RDs (12–13)	Hidden shapes, sections, jigsaws, wallpaper and right angles (Smith & Lord, 2002).	PR (Raven matrices -progressive) PR (jigsaw) PR (wallpaper but results nonsignificant) PR (right angles)	PR (hidden figures, sections)	

von Károlyi, Winner, Gray, & Sherman (2003)	64, 29 RDs (13–18)	S1 and S2: Impossible Figures test	S1 and S2: FC (Impossible Figures, in RT)	S1 and S2: FC (Impossible Figures in accuracy but results nonsignificant)
Nicolson & Fawcett (2000)	S1: 21, 13 RDs, (13–15). S2: 22, 11 RDs, (15–16)	PacMan maze practice		S1 and S2: PR (automatization “strength” after training)
Diehl et al. (2014)	53 RDs; 27 did the fMRI (13–22)	fMRI, mental rotation (accuracy and RT), Impossible Figures (accuracy, RT), Navon task (accuracy, RT)	FC (Impossible Figures RT out of scanner)	FC (Impossible Figures accuracy) FC (Navon accuracy) SR (mental rotation RT)
von Károlyi (2001)	40 RDs (15–18)	Computerized global task (Impossible Figures), feature oriented task (Celtic Matching Task)	FC (Impossible Figures for RT not at expense of accuracy)	FC (Impossible Figures for accuracy)
Winner et al. (2001)	S1: 60, 21 RDs (15–24). S2: 37, 15 RDs (grades 9–12). S3: 63, 40 RDs	S1: Vandenberg Test of Mental Rotation, Rey–Osterrieth Figure, hidden figures. S2: all above + Archimedes’ screw, pyramid puzzle, drawing, K-Bit matrices. S3: Gestalt Completion Test, spatial orientation, card orientation, boat test, form board test, figural flexibility (storage task), closure speed, reference memory (maze test)	SR (mental rotation, card rotation (in S3)) SV (Archimedes screw) SV (form board in S3 if untimed) PR (Rey complex figure in S2 but results nonsignificant) PR (K-bit matrices in S2), O (storage test) N (spatial reference memory in maze test)	PR (Rey complex figure) PR (hidden figure) SV (Archimedes screw) SV (form board) SR (mental rotation) O (storage test), FC (Gestalt completion) DW (drawing hands)

(continued)

Table 14.2. CONTINUED

Authors	Sample and Age Group	Tools & Tasks	Higher Performance	Lower Performance	Equal Performance
Koenig, Kosslyn, & Wolff (1991)	12 RDs males (16–18)	Memorizing shape or letters patterns in a grid		PR (letter patterns)	PR (shapes pattern)
Everatt (1997)	36 (18–55)	Spatial reasoning, Ravens matrices, drawing	DW (creative drawing)	SV (spatial reasoning) PR (matrices but results nonsignificant)	
Sigmundsson (2005)	23, 10 RDs (18–23)	Simulator car driving while pushing buttons (condition 1) or a voice-activated microphone (condition 2) immediately when a road sign appears		N (RT)	
Brosnan et al. (2002)	S1: 18, 9 RDs. (Mean age 34); S2: 60, 30 (14) RDs. S3: 30, 15 RDs (18–29)	S1: Group Embedded figure test GEFT (for inhibition), ToH task (planning); S2: Group Embedded figure test GEFT (for inhibition); S3: spatial span, spatial recognition, matching complex figures, pattern recognition		S1&2: FC (Group Embedded figure test)	S1: SV (ToH ball task) S3: PR (spatial span), PR (spatial recognition), PR (matching complex figures), PR (pattern recognition)

von Károlyi & Winner (2005)	S1: 60, 21 RDs (young adults). S2: 37, 15 RDs (college). S3: 63, 40 RDs. (highschool); S4 & 5: 64, 29 RDs (Middle and Highschool)	S1: Vandenberg mental rotation test, Rey Osterrieth and hidden figures. S2: S1 + K-Bit, drawing task, 3D puzzle, Archimedes' screw; S3: spatial orientation (card rotation, Vandenberg TMR, boat test), mental visualization (Form Board Task), figural flexibility (storage task), closure speed (Gestalt completion test), spatial memory (Morris maze); S4 and 5: Impossible Figures task.	S4 and S5: FC: Impossible Figures	SR: (Vandenberg test of mental rotation (RD females)) PR (K-Bit matrices) S3: SR (card rotation) SR (boat test when timed) FC (storage test when timed) N (Morris maze)	PR (Rey-Osterrieth complex figure) PR (hidden figures); SV (Archimedes' screw); DW (drawing ability); S3: SR (boat test when untimed); FC (storage test when untimed) FC (Gestalt completion)
Howard, Howard, Japikse, & Eden (2006)	23, 11 RDs (20)	Alternating serial RT and spatial context learning, computer screens letters and shapes series	PR (pattern recognition in spatial context learning)	PR (pattern recognition in sequence learning)	
Barnes, Hinkley, Masters, & Boubert (2007)	60, 30 RDs (20-30)	Detecting motion in rotated or linear static images on screen, identifying if image presented corresponds to the previous screen picture		SV (perception of static spatial movement organization)	

(continued)

Table 14.2. CONTINUED

Authors	Sample and Age Group	Tools & Tasks	Higher Performance	Lower Performance	Equal Performance
Rusiak et al. (2007)	28, 16 RDs (19, 20)	S1 and S2: Letters oriented differently, press key when stimuli appears		S1 and S2: SR (letters mental rotation RT)	S2: SR (mental rotation of shapes)
Brunswick, Martin, & Marzano (2010)	41, 20 RDs (college students)	WAIS PIQ (picture completion, block design, object assembly), Rey Osterrieth complex figure, ambiguous figure test, visuospatial knowledge: queen's head direction, Herman virtuality environment, Gollin incomplete figure test	PR (PIQ picture completion) PR (object assembly) FC (ambiguous figure) for RDs men; PR (Rey-Osterrieth complex figures)	PR (PIQ block design)	
Stothers & Klein (2010)	49 RDs (college-age and adults)	Gestalt closure, block design	PR (pattern reproduction) O (recalling image direction) N (navigating) N (recreating virtual environment)		FC (Gestalt closure), PR (block design)

Olulade et al. (2012)	21, 9 RDs (18–25)	fMRI 3D rotation task	PR (WASI PIQ) SR (MRI Rotate response time but the result was non significant)	SR (MRI rotate % accuracy, results nonsignificant) SR (MRI non-rotate % accuracy and RT, results nonsignificant)
Schneps, Brockmole, Sonnert, & Pomplun (2012)	29, 10 RDs (college age)	S1: object search in sets, S2: finding objects in real- world scenes, S3: finding objects in low-pass filtered scenes	S3: TR (object search in low- pass filtered scene)	S1: TR (object search in set) S2: TR (object search in real-world scene)
Lockiewicz, Bogdanowicz, & Bogdanowicz (2014)	180 high school up to 30, 93 RDs	The APIS-Z Battery visuo-spatial subtests (2, 7), Urban-Jellen Test for Creative Thinking– Drawing Production, Polish adaptation		SV (test2 square) SR (test7 cube)

^aDetailed by age range, year, tasks used, and level of performance by type of visuo-spatial skill tested.

NOTE: RD = reading disorder. SV = spatial visualization; PDG = phonetics deficit group; CDG = comprehension deficit group; RDG = rate deficit group; PIQ = performance IQ; PR = pattern recognition/recall; N = navigation; TR = target recognition/recall; FRT = Figure Rotation Test; EFT = Embedded Figures Test; SR = spatial relations or rotations; DW = drawing; BAS = British Ability Scales; O = other; WISC = Wechsler Intelligence Scale for Children; ToH = Tower of Hanoi; RT = response time; S1 = Study#1; S2 = Study#2; S3 = Study#3; S4 = Study#4; fMRI: functional magnetic resonance imaging; FC = flexibility of closure; GEFT = Group Embedded Figures Test; K-BIT = Kaufman Brief Intelligence Test; TMR = Test of Mental rotation; MRI = magnetic resonance imaging; WASI = Wechsler Abbreviated Scale of Intelligence; APIS-Z = Test Battery from Matczak, et al. (1995).

Table 14.3. SUMMARY OF EMPIRICAL RESEARCH RESULTS ON RD PERFORMANCE VERSUS. CONTROLS ON VS TASKS^a

Tasks Types	Superior		Lower		Equal		Total Tasks
	Performance (%)		Performance (%)		Performance (%)		
<i>Spatial visualization</i>	2 (8.0)		13 (52.0)		10 (40.4)		25
<i>Spatial relations or rotations</i>	3 (10.0)		14 (46.7)		13 (43.3)		30
<i>Global-holistic processing, closure speed, flexibility of closure</i>	5 (31.2)		5 (31.2)		7 (43.7)		16
<i>Drawing</i>	1 (11.1)		3 (33.3)		5 (55.5)		9
<i>Pattern recognition/recall</i>	13 (15.3)		25 (29.4)		47 (55.3)		85
<i>Target recognition/recall</i>	1 (12.5)		2 (25.0)		5 (62.5)		8
<i>Virtual world navigation/ 3D navigation</i>	4 (30.8)		5 (38.5)		4 (30.8)		13
<i>Other</i>	1 (20.0)		3 (60.0)		1 (20.0)		5
Total Tasks per Performance Level	30 (15.6)		70 (36.4)		92 (47.9)		192

NOTE: The table classifies by performance levels and types of visuo-spatial skill. Units = number of tasks among the 192 occurrences reported in the reviewed literature and representative percentages over all skills in parentheses).^a

counterparts 84% of the time. Where individuals with RD did do better, the data suggest that this is most likely to occur on tests of global/holistic processing and virtual world navigation (over 30% of the time better than non-RDs). A similar conclusion was made by Gilger and colleagues (2016).

Summary

In this review, we have assessed VS abilities from a purely functional point of view, without looking at the connections to deficits and to the development of RD. At this point in time, a majority of the experimental VS data suggest that there is no generalized advantage across individuals with RD when it comes to VS abilities, and there is more often equality or disadvantage in individuals with RD for a variety of subskills related to the VS domain, particularly those that require complex dynamic thinking. This finding may support in part the multiple-deficit theory described earlier and it also reifies that the RD population is not homogenous in terms of skills and potential. We also found an exception to the equal or underperformance results in the domains of global/holistic and virtual world navigation (see also Gilger et al., 2016). This domain is worthy of further attention. Finally, there were a number of gaps in the literature, such as a lack of studies specifically on 2e-RD children, and there was a tendency for certain VS tasks to be commonly studied and others only minimally.

In terms of careers, people with RD were found to be slightly overrepresented in artistic, scientific, as well as “people-oriented” professions (nursing, business). However, these data come largely from self-reports, observations, interviews, and surveys and not always from peer reviewed research. This in itself warrants more concrete nationally driven studies to allow for drawing definitive conclusions. Furthermore, none of the career studies are longitudinal thus preventing conclusions about the etiology of career trajectory (i.e., choice driven by weakness avoidance, practice, or inherent strengths).

DISCUSSION ON KEY ISSUES

Given the results of our review, it is unclear that there is an ontological or naturally occurring “RD advantage” per se (see Davis, 2010, and West, 1997, for contrary views) across a gamut of VS skills or in career choice for people with RD. Similarly, at this point there is little or no empirical support that individuals with RD are more likely to be especially talented at complex spatial reasoning, although there is some very preliminary data that 2e-RDs may be overrepresented in the 2e population (see the Conclusions section for caveats). There is, for instance, reason to expect a higher frequency of RD co-occurring with giftedness given the high rate of RD compared to other specific learning disorders, and there is also some preliminary data (see Gilger et al., 2008) to suggest that prevalence of 2e-RD

individuals may be roughly eight times higher than we would expect if the two exceptionalities co-occurred just by chance.

In spite of our general conclusions based on the data reviewed, we feel there is still more to be learned in this area, and we next highlight next some of the remaining questions that need to be addressed. Specifically, we identify needs in four areas of research and practice: a consideration of learning versus aptitude, age and development questions, the range of behavioral assessments used, and the behavior-process distinction. While we address each of these areas separately, they are interrelated.

The Phenomenon of Learning

We can distinguish learning measures from measures of discrete aptitude or ability, and there is a need to examine VS abilities in the framework of learning processes rather than single point in time behavioral performance. Aptitude is a measure of performance given the subject's knowledge and capacity at a certain point in time, whereas learning is a measure of response over time given certain experiences. Using reading as an analogue, RD is not just an unusual lower aptitude to read per se as it is a difficulty with *learning* and retaining skills relevant to reading. This learning-ability distinction has been well studied for the linguistic aspects of RD but has not been studied for the VS aspects of the RD condition. Our review suggests that the VS studies available have only assessed aptitude at a single point in time or, at best, a secondary look at the effects of practice as a result of pre- and posttesting (e.g., Fischer & Hartnegg, 2000, Table 14.2; Nicolson & Fawcett, 2000). There is, however, one interesting 3D practice study in our review using a virtual reality task created by Nicolson and Fawcett (2000), which did look at training and learning of VS information over time. The authors concluded that practice helped RD participants to gain a normal level of automatization catching up to their counterparts. However, they still lagged behind controls' skills after a year. Such studies are rare but point to the fact that training, even implicit training, specifically in VS could be an important asset in the support of students with RD. This study, however, dealt with basic automatization of simple VS tracking, and it did not include measures of complex or dynamic VS reasoning. Indeed, prior research has shown clearly that training and experience in more dynamic spatial areas can have significant effects in non-RD samples (Uttal et al., 2013); thus testing how training is responded to by RD samples is called for.

Key research questions on the horizon include (a) do individuals with RD possess a learning difference for VS skills, irrespective of ability? and (b) do they respond differently than normal readers to training or experience in VS areas? This requires short- or long-term longitudinal studies, perhaps with training on such skills over time. Research that includes this reformulation will be important in the future, and combining behavioral learning and brain imaging

technologies has the potential to bring additional information about RD brain processing. Teachers can play a fundamental role in collaboration with researchers to address these questions in the future, perhaps by combining curricula and research in programs or tasks that may assess these learning abilities in order to inform the field in more organic environments outside of the research lab.

Age and Developmental Trajectory

Age is another variable that has not been well considered in the research to date. The vast majority of the work on VS skills in RD samples has been on adults. There is to date no substantial information on VS skill in individuals with RD at ages less than four years and minimal research on preteens. Thus, if no RD/non-RD difference is found, we are unsure that it may not have been found in younger ages and before the person's neurology has been changed by experience, reading interventions, normal maturation (e.g., puberty), or lack of appropriate stimulation/practice. Similarly, if differences are found in older samples, we cannot be certain of their etiology: these could be inherent differences or differences acquired through choice or practice (e.g., Winner et al., 2001).

Age and experiential effects are correlated, and they may be particularly important to consider for several reasons. First, as noted, spatial skills can be affected by experience or practice (Uttal et al., 2013). People subjected to, or with more access to VS practice would, on average, do better than their contrasting cohort. If there is a differential amount of experience across RD and non-RD groups, this may mask (or enhance) VS ability differences. Second, studies have hinted that RD individuals, relative to those without RD, have a prolonged developmental period where they rely more on the right hemisphere for reading (Keller & Just, 2009; Shaywitz & Shaywitz, 2005; Simos et al., 2002). This right hemisphere reliance is thought to help those with RD to compensate for left hemisphere deficits. Gilger and colleagues (2013) suggested that, as people with RD get older, continuing to rely on these right hemisphere areas to solve reading-related problems may cause permanent neurological changes, and the possibility that any inherent right hemisphere advantage, if it exists, for above-average spatial thinking could be lost (see also McBride-Chang et al., 2011). This illustrates further the call to take a developmental perspective when looking at nonverbal skills in 2e-RD and RD children.

Because of the complicating factors of age, and the comparative lack of research on younger age groups, we propose that the neurology and behavior of persons with RD, along with the neurological changes from childhood to adulthood, be given more careful consideration, particularly in the VS learning and ability domains. More specifically, it is important to assess VS skills in the *very young* and later compare this data to that in older children to get at the question of causation, the developmental trajectories of VS abilities, and their relationships with reading.

Differentiating Cognitive Skills

Some studies have focused on basic visual perceptual skills using tasks (e.g., Table 14.1) tapping into cognitive processes that require *simpler* levels of spatial analysis such as recall or recognition of simple patterns in the visual field, detecting collections of similar objects, and so on (Alves & Nakano, 2014; Duranovic, Dedeic, & Gavrić, 2015; Ruffino, Gori, Boccardi, Molteni, & Facoetti, 2014). Others have looked at tasks requiring higher level thinking, creativity or dynamic nonverbal cognition such as rotating objects in the mind, or identifying rapidly Impossible Figures in space (Diehl et al., 2014; Gilger et al., 2013; Olulade et al., 2012; Winner et al., 2001). Although some of these skills rely on related neurocognitive components, they often represent different behaviors and processing systems and should be considered clearly so as not to encourage the combining of skills into overly generalized conclusions about VS aptitude. Understanding these nuances will help fine-tune our comprehension about individual differences in RDs' VS skills and could provide a window into their unique neurology beyond the nonverbal abilities.

Second, the differentiation must also be at the level of the *type of performance*. For example, some tasks look at accuracy (Franceschini et al., 2013), while others look at speed of response (Diehl et al., 2014; von Károlyi et al., 2003). Individuals with RD have sometimes been found to perform differently than controls for one of these indices while underperforming in the other. Accuracy and speed of response speak both to very different cognitive processing of VS information and can be informative as to where deficits or strengths lie. This adds a level of complexity (Diehl et al., 2014) to the interpretation of VS tasks performance and learning. Including both accuracy and timing will be important in future work. Considering both indexes combined, say through a signal detection methodology (Abdi, 2007), allows us to disentangle strategy and task approach from “true” ability.

Finally, our review and that by Gilger and colleagues (2016) suggests that out of all the VS tests used on RD samples, the speed of solving Impossible Figures may be one measure that shows a somewhat reliable difference in favor of RD participants. This task has been used mostly on computer screens, and could be explored at other levels such as 3D or manipulatives, to gather more precise data on that apparent superior performance and what it means for people with RD. Further, while virtual reality methods are fairly new to the field, they may represent another type of task worthy of further study in RD samples, and some interesting work by a few authors has reported that RD differences may exist with a marked advantage of RD performance (see Attree, Turner, & Cowell, 2009; Wang & Yang, 2011; and others in Table 14.2). These methods may allow us to track more accurately RD VS abilities and learning by facilitating access to real-time behaviors, allowing to track timing, accuracy, and type of tasks that are best responded to. Using such technologies also matches more closely the interactive and cyber world in which individuals with RD live (Shams & Seitz, 2008).

Observable Behavior versus Underlying Neural Process

Educators and researchers have long known that different strategies can be used to arrive at the same answer. These different strategies are presumably reflected in different neural processes, such as reliance on different cognitive processes and hence brain networks. Studying these processes are important because it gives us information about mechanism and may hint at ways we can support these students. Individuals with or at risk of RD have been widely shown to present very atypical neurocognitive profiles as detailed by Pugh and colleagues (2011) looking at their basic verbal circuitry, their compensatory behaviors, and unique anatomical patterns. They also make the suggestion that exploring talent will be beneficial to better serve this population (Pugh & McCardle, 2011, pp. 43–56).

As reviewed here, there are a number of papers that look at VS behavior in RD samples. But there are very few published studies that examine VS neurology in RD samples. For example, Olulade and colleagues showed that the VS behavioral performance of individuals with RD may be similar to that of controls, even though the neurological processing used to solve VS problems can be quite different (Olulade et al., 2012). Other work also compared the functional neurology of RD and 2e-RD samples while performing a VS task (Gilger, Tavalage, & Olulade, 2013). These were the first brain imaging studies on adults with RD and the only study of 2e-RD adults using complex VS tasks. Subsequent work by Deihl and colleagues (2014) supported the central conclusion that people with RD process VS information in neurologically different ways than those who do not have RD, and they also showed that those with RD were faster (not more accurate) on tests of holistic processing. Additional work by Craggs and colleagues (2006) and Gilger, Bayda, Olulade, Altman, and O'Boyle (2017) also shows that there may be neuro-anatomical differences in RD and 2e-RD subjects compared to controls that may underlie the VS brain processing differences observed.

Our review highlights an existing imbalance in the use of modern methodologies to study nonverbal skills in RD samples, with the majority of past research studies (except for the several listed here) focusing on psychometric behavioral performance without a consideration of neurology. While deficits in phonological processing may be the hallmark symptom and one of the major risk factors of reading-related problems in RD, such a focus might be expanded to include VS processing, which may yield important insights.² The neurology work this far also reminds us that similar behavior does not mean the same neurological processes are at work.

2. Gilger and colleagues (2006, 2012, 2016, 2017), further proposed that the unique neurological signature observed in individuals with RD and 2e could be a residual sign of the same developmental neurology that leads to dyslexia (e.g., Geschwind, 1985), although it may have been modified with age and compensation for reading weaknesses (Birch & Chase, 2004). This neurological profile may set certain people up not only to deal with spatial information differently but to be better able to learn VS-related skills (e.g. Schneps, et al., 2011, 2012); especially if the necessary learning experiences occur at an early age.

CONCLUSION: TYING IT TOGETHER FOR PARENTS AND EDUCATORS

While the conclusion of our review points to a lack of VS talents in RD individuals overall, the reader should bear in mind that this is limited to experimental data based on commonly used spatial tests. We again emphasize that there may be other ways of assessment that may better detect RD-non-RD differences. Future research, for example, may consider nonverbal tests that better measure creativity or fluidity of thought than typical measures that have been used in the past. Our own personal experience suggests that many people with RD take a less linear approach to problem-solving and this may in turn lend itself to unique solutions, or the same solution through different paths (see also Daniels & Freeman, this volume). Preliminary neurological research, in fact, supports the idea of dyslexics having different ways of solving problems compared to nondyslexics whether or not the behavioral outcome is the same (Diehl et al., 2014; Gilger et al., 2013; Olulade et al., 2012).

Research has an important role in addressing the needs of special populations. Progress can only be made if on the back-end of programs catering to atypical learners there exists a strong research base that is well translated and its recommendations carefully applied. Catering better to RD and 2e-RD populations, however, will take the efforts of all. Parents, educators, and researchers are the driving force.

Parents can be keen observers of true abilities and potentials, and they are the strongest advocates for more funding and better services. They can also be allied to researchers by facilitating accessibility to their children and their experience. Being a correctly informed parent is therefore critical. Similarly, educators can facilitate our understanding by channeling their observations up to academic research centers, staying abreast on the latest research, and requesting that crucial information be better distilled to their professional circles and educational programs.

Finally, researchers can help by

- extending the current research to cover the gaps we have highlighted
- focusing on a more multifaceted strength/deficits apprehension of the RD verbal and nonverbal skills problem (i.e., multifactorial liability models) and designing studies adapted to this type of models
- advocate for more comprehensive approaches to studying people with RD that focuses on individual differences across the profile of skills as much as we have focused on common deficits thus far

An empirical lack of a VS advantage in RDs does not mean that there exist no strengths or advantages at all. Until additional research is performed utilizing different types of assessments, we cannot recommend a specific type of program that could cater to more targeted strengths of RD and 2e-RD groups. Studies are also

unavailable that address how people with RD *learn* VS information, as opposed to the plethora of data on how they are learning verbal material. Yet, having a knowledge base of how learning takes place is the very foundation of teaching and supporting intellectual development and nonverbal abilities. We also found that we know very little about the developmental trajectory of VS skills in RD populations from birth to adulthood. There are too few studies investigating these skills at young ages, as the majority of studies have focused on adults and adolescents. It is thus difficult to tell parents or teachers, for example, how to support these potential skills at home or at school, although some common activities can be suggested (e.g., building games, drawing, playing with blocks, etc.).

Our review also briefly highlighted that the methodological approach to studying VS cognitive processes in RD could be modified. We have technologies readily available allowing us to observe cognitive processing in real time such as functional magnetic resonance imaging and others, yet we mainly focus on a limited number of VS skills (e.g., spatial rotation) using paper and pencil, or basic computer tasks. Additionally, such important factors as speed and accuracy of execution and complexity of the skills (static/dynamic) have often been lumped together. These aspects need to be broken down, and they need to be explored within the context of a wider variety of progressive methodologies and nuances and with a wider age range.

We hope in this chapter to have established a clearer picture of the need to understand better what specifically constitutes nonverbal strengths in individuals with RD beyond their difficulty to learn how to read and spell. Twice exceptional individuals with RD are a subgroup presenting with specific needs and a unique profile that further emphasizes the need to look beyond deficits. In the case of 2e-RD, future research will dictate whether 2e-RD and RD by itself represent groups with specific abilities when it comes to learning and processing VS information and if these abilities should be supported better in early childhood educational curricula. Additional data may help change views and considerations pertaining to treating and educating these special groups, shifting the ideology that the RD brain has to be “normalized” to the view that it should also be strengthened in areas of relative strengths (Keller & Just, 2009; Simos et al., 2002). Such findings have the potential to influence many aspects surrounding the development of RDs and 2e-RDs.

Knowing the basis of nonverbal abilities can be the subject of remediation recommendations, and this can translate into special education, tutoring, tailored class activities, games at home, and so forth. Having a better understanding will also bolster parental support in that they may understand better how to direct their child’s activities and attention; it will also indicate where to focus efforts in their advocacy with schools, districts, and healthcare providers. We invite researchers and practitioners to consider how to integrate these findings and suggestions into their work, as well as to maintain a feedback loop in order to assess in real time the progress of the newest findings as applied to the development and support of RDs and 2e-RDs.

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