Beyond a Reading Disability: Examining the Full Spectrum of Abilities/Disabilities of the Unique Dyslexic Brain

A report by The Dyslexia Foundation (TDF), summarizing a November 2015 brief symposium of the same title

Introduction

The hallmark of dyslexia is a reading problem. Decades of research have focused on the expression and etiology of reading problems and the development of reading-related skills in the dyslexic individual. However, research, case studies, and anecdotal reports suggest that we should consider the broader range of abilities in these individuals, which might also be reflected in differences in "the dyslexic brain". These other abilities include sporadic reports of giftedness or talents in the nonverbal/spatial domains; elevated rates of dyslexics in careers such as art, theater, physics, and engineering; visual-spatial processing differences on some neurocognitive tests; diffuse differences in brain structure; and differences in brain function for tasks not related to reading.

In short, the dyslexic difference could encompass more than a reading problem, such as differences in auditory and visual perception and processing, as well as conceptualization ability, or the manner in which information is integrated. Unfortunately, there is little research investigating this, and even that has received scant attention, either because it was poorly done or because it did not fit into either a linguistic or disability-focused model.

In an April, 2003, meeting convened by TDF on the topic of Talents and Dyslexia, after much discussion, several questions in need of research were proffered regarding adults with dyslexia: (1) Problem solving: How do high-achieving, successful dyslexics approach and solve novel tasks or problems (compared to non-dyslexics) – specifically in auditory and visual discrimination and conceptualization. (2) Possible subgroup: Do these individuals constitute a subgroup within dyslexics? If so what social, psychological, and neurocognitive factors distinguish them, within dyslexics and compared to non-dyslexics? Do the differentiating abilities share a common etiology with the reading deficit or are they attributable to social support, self-selected practice and/or some inherent drive; and might experiences (self-selected or not) be multipliers of some inborn or latent abilities that may or may not develop without these experiences? (3) Genetic or neurological differences: If they exist, are dyslexics with these unusual or unexpected abilities genetically or neurologically distinct from more "typical" dyslexics? (4) Definition and assessment: Finally, how might we define and assess these special skills, especially when they appear to involve non-verbal or non-verbalizable abilities, for some of which tests do not currently exist? Do we need to create innovative behavioral and neurological approaches to study these abilities?

Despite the fact that these questions for future research were developed and shared in 2003, the issues remain understudied. Therefore, on November 13-15, 2015, TDF hosted a second meeting, to revisit the general question and to consider what currently available research and technology could tell us about the neurocognitive differences in dyslexics beyond reading-related skills. It is important also to take a developmental perspective about a possible broader behavioral phenotype, considering the full spectrum of abilities in children with or at risk for dyslexia, and how studying these issues could contribute to overall knowledge about dyslexia and the brain. Conference participants included cognitive and neuroscientists, educators, and practitioners (listed in the appendix).

COMPTON

Don Compton of the Florida Center for Reading Research at Florida State University noted that there are numerous media figures who are dyslexic or believe that they are, but that there is a contrast between media and scientific views: the scientific community is conflicted, with some purporting to support the notion of dyslexics being by definition creative, intuitive, or gifted in some area, while others advise caution. The majority of peer reviewed literature on dyslexia or reading disability (RD) examines deficits/disability, yet if scientists and clinicians plan to profile both strengths and weaknesses, they need to be looking at assessments of such attributes as creativity and giftedness as well as reading, spelling, and writing difficulties.

To determine whether all or most dyslexics really are over-represented on the higher ends of the distributions in these areas, or whether only famous dyslexics happen to be there, researchers need to examine a multiple-distribution perspective. It will be important to know whether the double-exceptionality claimed popularly now is **individually-based**, in which case the co-occurrence would be very low in the population (i.e., at chance rate), or population-based in which case the co-occurrence would be relatively high (i.e., above the rate of chance. If the co-occurrence were population based, then it would seem reasonable that the group could be distinguished by a definable set of cognitive and affective skills or neurocircuits. Compton outlined possible models of this “double exceptionality” or “comorbidity” that could be tested:

1. Chance – There are be two distributions, dyslexia and one that is something else. The potential to be in both is chance, and there is no relation between the two.
2. Comorbidity – There is a correlation between the skills under examination. However, while correlated, they may not have same underlying etiology.

3. Comorbid with three disorders – Now there are more possibilities: there could be a distinct etiology for condition A, for condition B, or for the AB group.

While models 1 and 2 are clear, Compton illustrated 3 with the example of attention deficit hyperactivity disorder (ADHD) and reading disability (RD). The base rate for each is at or above 5% in the population (see American Psychiatric Association, 1994; Shaywitz et al., 1990). The two also co-occur significantly more frequently than expected by chance; i.e., the rate of RD in samples selected for ADHD typically falls between 25-40% (e.g., August & Garfinkel, 1990; Semrud-Clikeman et al., 1992), whereas 15-35% of those with RD also meet criteria for ADHD (Gilger et al., 1992; Shaywitz et al., 1995). In addition, this comorbidity is found in both clinical and community samples, indicating that it is not a selection artifact. Do they have separate etiologies? Shaywitz et al. (1995), address whether RD+ADHD represents separate phenotype from either group separately? Thus three distinguishable profiles are possible, however the RD+ADHD looks like the RD group on reading related measures and the ADHD group on attention related measures as described in model 3 (and illustrated in Figure 2).

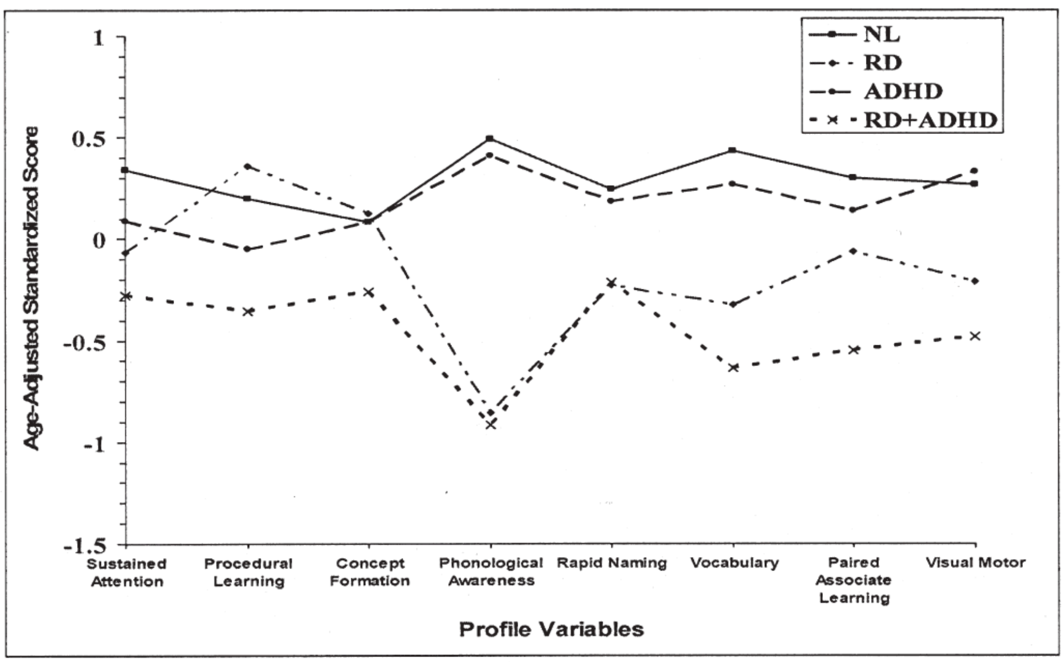


FIGURE 2. Cognitive profiles of typical achievers (NL), only reading disabilities (RD), only attention-deficit/hyperactivity disorder (ADHD), and both RD and ADHD.

In looking at individuals with these "double exceptionalities" or "comorbidities", the field seems to be cherry picking cases without thinking about negative cases where, e.g., an individual is dyslexic but has not achieved at same level of success as those famous dyslexics; thus we are guilty of poor sampling. There are several threats to accurately estimating comorbidity rates, which are based on population co-occurrence rates and are thus affected by sampling procedures. Subjects with more than one disorder are more likely to be part of a clinical sample (Berkson, 1946), which can artificially increase rates. Clinical samples are not a random sampling of those with that condition in the population. Further, if two disorders have non-overlapping sets of risk factors, but both sets of risk factors tend to be more common in certain strata of the population, then the entire sample may show significant comorbidity. Finally, it is possible that comorbid cases are more common than would be expected by chance because of symptom overlap. How samples are selected is thus extremely important in order to not give biased results.

What is needed are population studies. No one thinks all dyslexics are the same and so should all become famous. If we include careful measurement of these cognitive and affective variables, we could use latent class analyses to find classes of dyslexics where this double exceptionality exists and that may represent a common etiology. However, if we study only those creative dyslexic examples, the distribution will mislead us. A very interesting thing about these famous dyslexics – regardless of how they were diagnosed -- is that they all had trouble in school for some reason. Studying distributions, and using clear inclusion criteria when studying selected samples, can be enlightening and help us sort our science from anecdote. While the types of data needed are not simple to obtain, such studies are formidable but not impossible.

WINNER

Ellen Winner directs the Arts and Mind Lab in the Boston College Psychology Department (www.ellenwinner.com). The question she posed was whether dyslexia and visual-spatial talents are correlated. She began by pointing to studies showing that individuals in visual-spatial fields have a higher than average incidence of reading problems. Steffert (1998) and Winner , Casey, DaSilva, & Hayes (1991) reported this for visual artists, who report more reading problems, and who make more non-phonologically based spelling errors than do non-artists. Bloom (1985) reported this in mathematicians when he noted that none of the 20 world-class mathematicians he studied had read prior to schooling, and six had had reading difficulties. Colangelo, Assouline, Kerr, Huesman, & Johnson (1993) reported this in inventors when he noted that all of the 34 inventors he studied reported difficulties in reading and verbal areas. Finally, Sowell (1997) found that 72% of 43 late talking children he studied had family members in spatial professions, 60% had engineers as first or second degree relatives, and 73% of the children themselves excelled at visuo-spatial puzzles. However, it was noted in the discussion that others had failed to replicate this finding, and Sowell's sample may have been skewed towards high functioning late talkers.

Winner contrasted two explanations for the co-occurrence of visual-spatial talents and dyslexia. On the one hand, this co-occurrence could be due to heightened visual spatial talents among individuals with dyslexia compared to those without dyslexia, consistent with the “pathology of superiority” hypothesis proposed by Geschwind and Galaburda (1987). But on the other hand, this co-occurrence could be due to individuals with visual spatial talents and dyslexia simply being more likely to go into spatial fields than individuals with visual spatial talents but no dyslexia -- since the latter can also go into verbal fields. She referred to this explanation as the “default” hypothesis.

To test the pathology of superiority hypothesis, Winner and colleagues administered a variety of spatial tasks to students with and without dyslexia (Winner et al., 2001; von Karolyi, 2001; von Karolyi, Winner, Gray, & Sherman, 2003). Surprisingly, on all but one task, students with dyslexia were either no different from, or were worse than those without dyslexia. The area in which those with dyslexia showed superiority was in how quickly they could discriminate possible from impossible figures (presented as line drawings). Dyslexics performed this task no more accurately, but significantly faster than the non-dyslexics. This task requires global processing of the drawing rather than local part-by-part processing. She replicated this in two studies, and Kenneth Pugh’s lab also replicated this finding and reported this at the conference (Diehl et al., 2014).

Winner concluded that the case for the pathology of superiority in dyslexia is a very mixed one since on so many tasks the dyslexics showed no superiority. However, she called for further replications of the impossible figure finding using other global processing tasks in order to support the hypothesis that dyslexics have superior global visual processing.

GILGER

Jeff Gilger, of the University of California-Merced, noted that one key aspect of the Geschwind-Galaburda Hypothesis (Geschwind & Behan, 1982; Geschwind & Galaburda, 1987) as it has been used to guide research has been to examine whether dyslexics were specifically talented or gifted. There has been an emphasis on a medical or disease-oriented model, and on the left hemisphere model of language and reading in the brain, but dyslexic brains are not just different in the left hemispheres, they are more globally different, including differences present at birth (Gilger & Kaplan, 2001; Gilger & Hynd, 2008; Richlan, Kronbichler, & Wimmer, 2011; Eckert, 2004).

Gilger summarized the nature and manifestations of reading disability (RD) – a language-based disorder primarily affecting phonological awareness and processing, of neurological origin, in part neurodevelopmental (with disorganized neural pathways, atypical cortical cell connections, gross and fine structural formations that differ from controls), and in part genetic (with specific risk genes, although polygenic in nature, with replicated linkages to specific genes or chromosomal sites). In a forthcoming paper (Gilger, Allen, & Castillo, in review), Gilger and colleagues review the literature since 1979 on spatial skills and reading. In a summary of findings across the 21 peer reviewed papers (which involved 57 total tests) included in this systematic review, they found that 72% of spatial tests revealed no difference in spatial skills for RD vs. non-RD individuals, while on 11% of tests those with RD performed better and on 17% they performed worse than those without RD. The only possibly reliable RD- non-RD difference they found was in impossible figures.

Gilger reported on two other studies (Gilger, Talavage, & Olulade, 2013; Olulade, Gilger, Talavage, Hynd, & McAteer, 2012). One compared groups of reading-disabled (RD), non-verbally-gifted(G),non-verbally-gifted-RD(GRD), and matched control(C) adults on a number of reading-related and spatial visualization tasks, both in and outside of an fMRI protocol (Gilger et al., 2013). The results demonstrated that GRD adults resemble non-gifted RD adults in performance on paper-and-pencil reading, math and spatial tests, and in patterns of functional activation during reading and spatial processing. Another study (Olulade, 2012) demonstrated that RD neurology for spatial processing is different than that of controls, although behaviorally, RDs and controls were quite similar. Based on these studies and others, Gilger suggested that the data are consistent with what may be a shared etiology of RD and spatial aptitude potential in GRD individuals that responds to a lifespan interaction with reading compensation effects modifying how the adult brain processes text and spatial information. There is much to learn about the diffusely atypical RD brain, and Gilger called for broad behavioral and brain imaging studies that look beyond reading-related abilities.

Gilger also reported on some preliminary work with small samples of younger children with and without RD (age 7 and up) that revealed evidence that training can improve spatial performance for both groups. However, while accuracy improves minimally, response time improves at to a greater degree and at a much greater slope for the RD subjects. Clearly a larger sample is needed, and the study should be replicated in older students, but has at least generated ideas. If the effect is substantiated, the study should be replicated to included imaging of connectivity changes that occur due to training. Hypothetically a child is born with risk/potential due to neurology and genetics. This has “primed” certain people to be at risk for RD *and* for the development of better than normal learning capacity in the spatial domain. Gilger posited that there may be a sensitive period for the full development of this capacity to learn, and emphasized the need to examine these issues early in life and across time developmentally. There may be a risk for these primed brains to develop one skill over another in response to the environment. Thus if we intervene on reading alone, and those brain areas we affect for reading interact with other brain regions – those primed for spatial skills, that region may be recruited for the reading tasks; however, if we intervened on both reading and spatial skills at the same time in development, maybe they would not lose that potential. Perhaps then we should think about more holistic treatments for young children.

PUGH

Ken Pugh, Haskins Laboratories, discussed the value that brain mapping can add to our understanding of dyslexia and reading development. Studying the brain with our current neuroimaging techniques can mediate levels of analysis between gene and behavioral phenotype, contribute to better computational models, and help us delve more deeply into individual differences in component processes of behavior. Neuroimaging also has shown potential for early detection of biomarkers that might predict atypical cognitive development as well as provide some unique insights into why some tests correlate and others don't (Pugh et al., 2013).

Pugh pointed out the varied accounts of RD, including deficits in phonological representations, language, visual and/or auditory sensorimotor perception, access and retrieval, attention, procedural learning, and combinations of these. To study students with reading disabilities (RD), he advocates a multifactorial design that embraces the heterogeneity attested by these multiple accounts. This makes having the necessary power even more challenging, yet that very heterogeneity is useful in motivating neuroimaging, as each pathway or theory is a brain theory.

Both structural and functional neuroimaging have revealed insights regarding differences between those with typical reading ability and RD, at various ages (from child through adult), showing that individuals with RD fail to organize areas of the left hemisphere (temporoparietal, occipitotemporal) cortical regions into a coherent reading circuit (Pugh, Mencl, Shaywitz, et al., 2000; Pugh & McCardle, 2009). These insights include unstable and reduced activation, reduced functional connectivity (Pugh, Mencl, Jenner, et al., 2000), problems in learning and in consolidation of new learning (Pugh et al., 2008), reduced grey/white matter volume, and abnormal neurochemistry (Pugh et al., 2014).

Most of what we know about brain and RD is correlative. All these correlative markers talk about deficit. Pugh and colleagues have shown across several studies that learning to read fluently depends on ability to make speech tissue supramodal. Skilled reading causes systems to reorganize; reading is "parasitic" on oral language, so the brain must learn to use the machinery of talking and listening in literacy, making extensive demands on neuroplasticity. Researchers can predict how well someone reads by examining their activation pattern. Pugh and colleagues studied 68 7-year-old children, with followup two years later, gathering both behavioral (broad reading composite score) and neuroimaging. They found what Pugh terms "noisy circuits", an overlap of speech and print. Their finding was that what is important is not whether the brain activates for either language or reading but where the activation converges. The higher convergence was in the left inferior frontal gyrus (IFG), the better reading was two years late; higher convergence in the right IFG predicted lower reading ability at followup (Preston et al., in press, Psychological Science). There appears to be a developmental shift such that the language-dominant hemisphere needs to organize the system; the right hemisphere seems to be being used as compensation or should be quieted, and that's not happening. He emphasized that the data is descriptive only; his team is trying to examine the early perception-production dynamic to discover what drives the shift.

If you image children ages 4-7 years, annually, Pugh said, you would see individual differences in this overlap or convergence, over time, starting small and getting bigger, and the bigger it is the better reading will be. Pugh and colleagues are conducting such studies in several languages (contrastive orthographies) and in low risk students, searching for a better causal model. In preschool children, critical factors seem to be those that control perception and production dynamics and the ability to reorganize. In order to be plastic enough, the brain needs to be highly organized and "penetrable". How does it become penetrable? An in press paper (Rueckl et al., 2015) reports a study of skilled readers in Chinese, English, Spanish and Hebrew, which indicates that this reorganization that children need to move forward to fluent reading seems to be universal (common to many or all languages). The essential point is that fluent reading depends on the capacity of brain systems to reorganize such that print stimuli can leverage speech/language networks that have evolved for language processing (Preston et al., in press). And this reorganization appears to depend critically on early oral language skills.

While most work has focused on processing deficits, especially in the phonological domain there is some evidence for deficits in statistical learning and consolidation in these children. For example, Howard and colleagues (Howard, Howard, Japikse, & Eden, 2005) examined serial reaction time task among dyslexic and non-dyslexic college students. Dyslexics were impaired in sequence learning but better in spatial context learning; the sequence learning correlated significantly with word reading, but negatively with spatial context learning. Pugh felt that this could be taken to suggest that the brain is suboptimally organized in the ways that are needed for detecting regularities relevant to learning to link orthographic codes with phonologic codes, noting however that this simple task is especially vulnerable to deficits in procedural learning abilities. That sequence learning is impacted but visuospatial learning appears to be a related strength is intriguing.

There is also a good deal of anecdotal support for the claim that individuals with dyslexia might have better visuospatial processing skills than controls, but there are a limited number of controlled studies. One such study by Winner and colleagues investigated visuospatial processing in the so-called impossible figures task which entails viewing a two-D geometric drawing and making a judgment as to whether is possible or impossible as a three-D object (Winner et al., 2001). In two studies, their findings indicated a possible tradeoff, reporting that children with dyslexia appear to have better configural (global) processing than controls (von Károlyi et al., 2003; von Károlyi, 2001).

Diehl et al. (2014) in the Haskins group replicated work by Winner and colleagues with the impossible figures task. The key finding was that reaction time for impossible figures correlated with Woodcock-Johnson reading scores; performance outcomes thus replicating previous studies. Good and poor readers were the same in accuracy but the poorer readers were faster. The study then mapped the brain basis of performing each of these tasks during fMRI scanning. Lower reading skill was related to better visuospatial processing in the figures task (a tradeoff of sorts) behaviorally. On neuroimaging data, group analysis of dyslexic vs. non-impaired readers showed an interaction between group and task and revealed patterns of both cortical and subcortical activation that Diehl et al. interpreted as revealing a neural tradeoff in processing. The fusiform gyrus and other regions of the known reading network represent tissue that responds only to print only for good readers, and on the impossible figures task, good readers show activation of the right hemisphere, which works hard. Those with dyslexia appear to have less laterality/asymmetry, so that there is less left hemisphere tissue dedicated to reading. For those who are typically developing, the figures (which they find more difficult) are associated with more widespread activation patterns, and for those with dyslexia, print (which they find more difficult has a more widespread brain pattern; thus at the neural level better skill is associated with a more circumscribed brain activity. In short, the brain data reinforce quite clearly that claim from behavioral analysis that dyslexics appear to perform this nonreading visuospatial task with greater efficiency than controls. In this regard, the dyslexic brain patterns do not appear to be a source of deficit.

Pugh emphasized that replications of this imaging study are needed, and there are clearly interesting questions to address. Is the tradeoff they noted a consequence of reading experience or a predisposition in children with dyslexia? The adolescents studied were 16 years old, and had spent more or less time reading, posing a possible experiential confound. However, this may also be a preexisting tendency in dyslexia to be particularly adept at this kid of visuospatial processing and it is possible that early wiring of the dyslexic brain makes fine grained processing difficult but global configural processing a relative strength.. Pugh and colleagues are examining this issue is a new longitudinal study which includes pre readers, in which they will be able to examine the impact of spatial ability prior to formal literacy instruction.

O'BOYLE

Michael O'Boyle, Texas Tech University, discussed similarities/differences between dyslexia and math giftedness and provided an overview of the characteristics of the mathematically gifted brain. The issue of mathematical giftedness, he pointed out, is controversial, and has been presented in the popular media. O'Boyle discussed Geschwind and Galaburda (1984), their theory of "pathology of superiority", and work by Benbow (1986) on mathematically gifted (MG) children (i.e., those scoring in the top half of 1% of those ever taking the SAT Math exam). Benbow found several physiological correlates of the MG including a set of characteristics similar to those reported in dyslexics: more likely to be male, left handed, and to have autoimmune disorders like allergies and migraines.

In a dichotic listening study, O'Boyle and Benbow (1990) found MG adolescents to be equally able to report syllables presented to either ear rather than the usual right-ear, left hemisphere advantage; O'Boyle and colleagues reported a similar sort of bilateralism for the MG in a concurrent finger-tapping task, finding slower tapping rates for both hands when engaged in reading a paragraph out loud, rather than the usual asymmetric slowing of only the right hand (O'Boyle, Gill, Benbow, & Alexander, 1994), and on a chimeric face task where left-side smiles, right-side-neutral face composites were uniformly judged to be happier by the MG, suggesting greater reliance on their right hemispheres during information processing (O'Boyle, Benbow & Alexander, 1995).

His work has also demonstrated greater interhemispheric cooperation and exchange of information between brain regions (Singh & O'Boyle, 2004) in the MG, and his neuroimaging studies have identified enhanced right hemisphere development/activation in the MG that results in a special form of bilateralism; he also notes the MG have enhanced interhemispheric communication and cooperation, with increased gray/white matter ratio; heightened brain activity indicative of greater processing power and highly developed attentional and executive functions. Morphological differences reflecting greater brain maturation compared to average-ability math peers have also been reported by others (Desco et al., 2011; Geake & Hansen, 2005; Navas et al., 2013; O'Boyle et al., 2005; Prescott, Gavrilescu, Cunnington, O'Boyle, & Egan, 2010). O'Boyle is currently studying additional aspects of brain morphology including cortical thickness, volume, surface areas and other characteristics in a large sample of individuals psychometrically tested in science, math, creativity and other cognitive domains in order to determine any correlations.

He recommends that future work focus on a highly segmented evaluation of the corpus callosum size and shape, resting state and default mode network analyses of the MG brain, biomarkers of glial cell connectivity, and behavioral genetic studies designed to identify unique SNIPS that are correlated with patterns of brain activation and predictive of MG. In relating this to dyslexia, O'Boyle commented that once the brain is organized in a different way, it may have a propensity to be better at some things than at others. For dyslexia, perhaps researchers can predict where these individuals may excel (e.g., math, music and art) and what underlying cerebral organization may be responsible.

CUTTING

Laurie Cutting, Vanderbilt University, discussed her team's recent work on executive function (EF) and how that work could inform the discussion on fundamental issues regarding a "dyslexic difference", such as whether dyslexics approach and solve novel tasks or problems differently from non-dyslexics. If there is a dyslexic difference, what are the social, psychological and neurocognitive factors that distinguish dyslexics, and how might we define, assess, and study that difference? A key question is whether there is something different about dyslexics who compensate (or recover) well, and what insights that might lend to this issue.

Cutting discussed the construct of reading in the context of the simple view of reading, using the Scarborough reading rope (Scarborough, 2001), with her own addition of executive function (EF) to the model, which may serve to integrate the subprocesses in each of the two major strands as well as the "rope" overall (Cutting et al., 2015). Cutting also discussed the neurobiology of word level processing and intervention response. We know how to do successful reading intervention; studies have indicated that intervention response is related to language skills and attention issues, and that the brain changes as reading gets better. But we also know that not all children respond. In general, in studies of pre- and post-intervention activation, as reading improves you see more left hemisphere activation. Treatment resistors don't show those changes. In a meta-analysis, Barquero, Davis, & Cutting (2014, PLOS One) found indications that, in addition to the expected areas, there are other brain areas that increase activation after intervention – the left thalamus, right insula/inferior frontal gyrus, left inferior frontal gyrus, right posterior cingulate, and left middle occipital gyrus. In addition, Cutting noted that there are a few studies that suggest that the brains of those who respond vs. those who do not may have neurobiological differences before intervention begins, which can predict response (e.g., Hoeft et al., 2011; Rezaie et al., 2011a, 2011b).

Cutting and colleagues are currently in the process of examining the neurobiology and behavioral characteristics of responders and non-responders. Preliminary findings are suggesting that there are connectivity differences between those who responded to the intervention versus those that did not, with one of the findings suggesting that responders show more coordination between domain general and specialized skill regions than non-responders.

As to whether there is a subset within dyslexics who have particularly good domain general/EF abilities, Cutting suggested that perhaps there are richer connections to/from these domain general areas in responders, and that these could be linked to some of the strengths that have been reportedly observed.

Cutting and colleagues have also been studying the relationship between lower level (word recognition) and higher level (comprehension) processes in reading and their neurological correlates, in order to examine the strengths/weaknesses in various subcomponents of reading (Swett et al., in press). They have found brain regions shared by passages and words – this may mean that those regions perform the same function in support of reading, or that they have different functions for word vs.

reading comprehension. Cutting and her team concluded that domain general and semantic processing hubs have distinguishable functional connectivity patterns for word- vs. comprehension-level processing, a finding which points to a flexible network of processes within reading "hub" regions, and that domain general connections may predict responsiveness to intervention.

WASHINGTON

Julie Washington, Georgia State University, outlined the under-identification of dyslexia/reading disability (RD) among linguistically diverse students. In 2012-13, approximately 13% of all public school children in the US received special education services, and of those 35% had specific learning disabilities (SLD; NCES, 2012-2013; Condition of Education). In addition, we know from the National Assessment of Educational Progress (NAEP) that the percentages of minority students who do not read or do not read well is higher than the overall percentage of the national student population (NAEP, 2015). However, racial, ethnic and language minority students are less likely than similar white, English-speaking children to be identified as having disabilities and are therefore disproportionately underrepresented in special education (Morgan et al., 2015). This is at least partially due to the wording of the IDEA 2004 reauthorization, which contains exclusionary criteria that children are not to be diagnosed as learning disabled (LD) if their learning problems primarily result from environmental, cultural, or economic disadvantage (IDEA, 2004). While such etiologies are generally unprovable, they offer a way to exclude children from special education.

A project on world varieties of English, which includes African American English (AAE), rural AAE, historical AAE, Ozark English, Southeast American enclave dialects, and many others (Kortmann & Lunkenheimer, 2013), indicates that AAE is the most rapidly diverging of these dialects. Thus, serious consideration of how the differences between this spoken dialect and the English that students are learning to read and write needs to be taken into account in assessment and instruction.

Washington and her colleagues at the Georgia LD Research Hub are conducting a large research study examining the contribution of general verbal ability, dialectal variation, cognitive abilities, and poverty to RD, to distinguish RD children with underlying LD from those with RD due to other factors, and to explore the effects of general verbal ability and spoken dialect on essential components of reading acquisition. They have seen that those who have denser dialect use are more likely to have reading problems and are least likely to code switch, and that more of them are low SES. This research team is working with what is known about reading and dialect and examining interactions with general verbal ability to look for causal effects. At the same time, they worry about the high achieving students in these classes, who are never recognized or labeled as gifted, and about the lack of differentiated instruction for them which will likely cause them to regress to the mean, thus losing any “gifts” they may have.

Using a comprehensive battery of measures including language, reading, and dialect, as well as measures of SES and sophisticated statistical methods (including confirmatory factor models and mixture models), they are examining the impact of language variation and dialect on acquiring basic skills, independent of confounds such as SES, amount of language experience, and comorbid conditions.

One major challenge has been that the instruments used to identify dialect usage are not useful for characterizing that usage; thus the team is examining the psychometric properties of these instruments as part of their research. Code-switching seems to be a key issue. Using computational modeling, Brown et al. (2015) demonstrated that when the model was presented with two codes (AAE and Mainstream American English (MAE) that did not match in pronunciation and orthography it took the model significantly more trials to achieve mastery of basic word reading skills. The model was designed to simulate the cognitive load experienced by African American children who must learn to reconcile two codes that often differ in subtle ways in order to decode and derive meaning from text.

Their large sample (over 1700 students) is entirely African American; many live in concentrated, dense poverty, but the team is also including a group of middle income students attending charter schools. Washington and colleagues are just ending their three year data collection effort.

Students for whom data has been analyzed to date were all low SES, and IQ was not a factor. There also was a subgroup who seemed unable to benefit from even intensive intervention. Washington and colleagues are using a step-wise model to find where dialect makes this process break down. Their current findings, in brief, have been that knowledge of both MAE and AAE makes the difficulties presented by English spelling-sound correspondences even more difficult, but the effects can be reduced if context cues are included that signal which dialect to use. The effects are also modulated by other protective and risk factors (e.g., verbal ability, language experience). In their modeling to date, they have determined that the two dialects (AAE and MAE) are equally difficult to learn, but sequence matters: a model trained on MAE does learn AAE, but a model trained on AAE learns MAE faster. Possible explanations for this are that the AAE model has words with deleted phonemes; adding them for MAE is easy to learn. The MAE model, however, has to learn that some phonemes are not pronounced in AAE; learning rules for deleting them is more difficult. (It was noted that Jason Zevin is doing similar modeling with English Language Learning students).

African American students are also underrepresented in the area of giftedness (Ford, 1998; Naglieri & Ford, 2003). In 2006, it was estimated that 55% of the US public school population was Euro-American, and 67% of all gifted students in the US were Euro-American. While 17% of the entire population was African American, only 9% of gifted students were African American (US Department of Education, 2008). Measurement is a problem, complicated by poverty and linguistic factors – African American students earn lower scores on standardized tests, putting a roadblock in the way of referral for giftedness assessment (Naglieri & Ford, 2003), despite there being no standard or universal definition of giftedness (Ford, 2008). Are the assessments bad, or are they not measuring the right areas? Many think that giftedness is represented by verbal talents, but these are not the aspects of language that are not measured on currently existing instruments.

African American students are underrepresented, under-nominated, and unrecognized among gifted students and in special education. While poor teaching and similar environmental variables may not create dyslexia, in this population they do obscure diagnosis. Both dyslexia and giftedness identification are complicated by poverty and dialect. Unless they learn to code switch, African Americans don't use MAE when they read. Parents who do not code switch, when reading aloud change the output to dialect – even when reading a standard text. Reading modifies a neural system; for African American (and other dialect-speaking students) there is an opportunity to have students not only learn to read but also to begin to use the standard dialect orally. They can do this once trained, as long as text is easy, but when they have to focus on more complex text, that can exhaust available resources, and they default to dialect. Approaches that support or scaffold their reading and code-switching will be important, as will teachers' understanding of the importance of these approaches.

VISCOMI

Joe Viscomi, of Greplytix, described new ways to deal with sparse (incomplete), high dimensional data. He demonstrated using data flow graphs rather than models, a way to use descriptive language that allows flexibility in how we use data. The approach he described is not purpose built, and is not a rigid neural network; rather, the system is used to build models by visually defining the structure of how you want to consider your data. He explained that this approach separates data from function, allowing you to manipulate data at a layer of abstraction so that you can do more in less time with less work, using a graph model to partition data and find relations within your data.

Such an approach would enable the user to take naïve structures and consider how to intervene. The approach is flexible enough to use across different laboratories, thus providing a way to pool data despite the fact that different research teams did not use the same measures of a skill. It also enables researchers to compare texts – such as texts in two different dialects. It can flatten 3D space into two dimensions without loss of fidelity, and should therefore be useful with neuroimaging data.

Viscomi explained that this approach can expedite getting data into a useable form. The system can be used to test theories in a way that allows us to test two hypotheses with the same data set. The tree structures produced would tell us if data fits, and would indicate over- and under-fitting, showing error measures and biases. The system looks for the most efficient structure, and does it in the fewest steps.

One problem noted in the artificial intelligence literature on learning is that it does not mimic how children learn. It is generally set up so that it would require giving children a million trials and always telling them right or wrong each time. It is difficult to input direct instruction from a teacher, but with Viscomi's approach, if you have a large enough data set, and you have enough occurrences of a teacher giving an instruction to enough students, it is possible to show the changes in the students' profiles as a result and to sequence those. There is a feedback mechanism that can be built into the model. Viscomi explained that where a lot of people go wrong is in making absolute feature selections – they explicitly select them, and that's almost always wrong because it introduces a set of biases. A good model should be able to go the other way, so this approach pulls out the biases.

There was discussion on how to automatically identify something. Identity functions are important; this tells you if you can compress data. Models must be rerun to get consistency over time, which in turn helps constrain the data and eliminate more complex analyses that might have been done. In addition, it is possible to build several small models and combine them to see what they do globally.

GENERAL DISCUSSION

The overarching question addressed in this meeting was what the "dyslexia difference" is and how might we best investigate it. Reports of giftedness or talents in the nonverbal/spatial domains as suggested by elevated rates of dyslexia among those with careers in art, music, theater, physics and engineering, differences in visual-spatial processing on some neurocognitive tests in those with dyslexia, as well as differences in brain structure and function in those with dyslexia for tasks not related to reading have circulated. These reports have attracted significant attention as support for the idea that dyslexia is associated with specific special talents. It is now time to find out whether these reports can be confirmed by rigorously conducted scientific studies. While the group acknowledged that not everything in the popular literature will be able to be incorporated into the science, there are some aspects that could be identified and studied.

Generally there appear to be two broad classes of claims in the popular literature about those with dyslexia – that it is associated with (1) entrepreneurial success and (2) creativity. Both are somewhat difficult to quantify and therefore to study; however, the group felt that progress could be made in these areas, and a large part of the general discussion focused on ways to capture and quantify these characteristics. More specifically, if searching for etiology and a connection between dyslexia and "something", and searching for origins and mechanisms, some specificity is needed. Is there a specific area that enables people to be, for example, good actors or to run airlines? Are there neural mechanisms, perhaps biases to process information in certain ways? Is there a neural mechanism for a certain kind of motivation? If so, studies should examine both individuals with and without dyslexia who exhibit these abilities. Twin models in particular demonstrate a potentially viable approach to these questions. All of the models noted by Compton (Chance: that two conditions co-occur by chance, with no relation between them; Comorbidity: that there is a correlation but it is unclear whether two conditions share etiology; or More Complex Comorbidity: either a distinct etiology for conditions A and B, or a shared one for the AB group) are testable with twin models. Such work could begin with extant data sets and researchers could request 2-3 measures that could be included in new/future longitudinal datasets.

Although there are several existing datasets that could be used to test different hypotheses/relationships, clearly new studies that are specifically designed to tackle the question of whether dyslexia is associated with specific talents. Suggested areas for future research spanned from behaviorally- focused studies to neurobiological and genetic approaches. Both population studies and studies of selected samples with careful measurement of cognitive and affective variables are needed. Furthermore, even in selected samples, having clear inclusion criteria is important: some famous dyslexics are self-diagnosed, and those with diagnoses may have been diagnosed using differing criteria.

In the final discussion, major topics included of course brain, language, and intervention, as well as specifically reading and dyslexia. The following briefly summarizes thoughts raised in those discussion and concludes with some initial recommendations for future research.

Brain

In discussing power vs. efficiency, it was noted that if a task is subject to a lot of practice and can be fine-tuned over time, we will see efficiency. If given novel tasks that individuals cannot practice, then you'll see differences, as the tasks are less amenable to algorithmic strategizing. One point raised for consideration is that there is some clear evidence that this is non-monotonic. Researchers often find hypo-activation in in reading circuits for dyslexic as compared to typically developing readers; when tasks are repeated, both groups get faster and more accurate. At an early point in learning, better performance gives a richer BOLD signal, then at a later state when approaching asymptote, there is reduced signal, so it can appear to be opposite of what one might expect to see. It was likened to riding a bicycle: if you are good to start with, there is a ceiling effect and you will not get to see the learning taking place. There is no theory to date that can handle data on the special abilities some dyslexics seem to demonstrate, because none have been defined to handle strengths; they were developed to account for deficits, noise, and instability, not efficiency.

One place to start is with clusters of abilities where dyslexics seem to have better abilities, and reverse engineer which areas of brain could give them that boost, and see if we can find that in controlled conditions and see it in the scanner. Study what they can do – in all areas, not just reading, design paradigms that tap these various areas, and then translate them into neuroimaging studies. Resting state scans would also be interesting – what are they doing that is not task reliant? What's the default network? Many dyslexics have balanced profiles, but some have real differences. Some may also be well-functioning individuals on the autism spectrum; this would be more apparent if we were not using word reading but using comprehension tasks.

The comment was made that hyperconnectivity to unexpected areas could be associated with giftedness, as these individuals are able to coordinate and integrate various areas. Could a link between dyslexia and math giftedness be that hyperconnectivity, with one being well orchestrated and the other less well organized? Perhaps then irrelevant or poorly organized hyperconnections interfere with preplanning of purposeful action.

It would also be worthwhile to examine connectivity changes across time, as Posner, Tang, and others have shown they could grow white matter through training (Kelly & Garavan, 2005; Schlaug, Jäncke, Huang, Staiger, & Steinmets, 1995; Scholz, Klein, Behrens, & Johansen-Berg, 2009). Perhaps gaining a cognitive restorative effect is a next step. Several emerging papers show that treating reading can result in changes in both gray and white matter. Connectivity, however defined, is where the phenotype is; hypo- and hyper-activation profiles seem to vary but a more stable phenotype is how the brain adapts to experience on the fly, so that it will be important to study adaptive learning.

There was much discussion about pooling data, and being able to get some scale. However, it is easier to do scale for structural data because all have the same data. With functional maps, researchers tend to use different tasks so it becomes difficult to identify a common circuit that reflects core processes in reading that are not specific to the task. Researchers are looking for a latent structure that underpins all of them; if that could be done, fMRI data could be pooled. If you could do that you could pool fMRI data across studies even with different tasks.

Language Issues

Language is the underpinning of reading. Studying all children who have reading difficulties will be important, as we cannot yet identify well those children in disadvantaged settings or who speak dialects or who are learning a second language which is also the language of instruction. Many may in fact be gifted or have special areas of ability, but these like their possible LD, go unrecognized.

In the discussion of AAE dialect, it was suggested that, because Bayesian models say a lot about how we build concepts and how those are influenced by priors, they should be used in addition to the computational models already in use. One could potentially see a different branching of concepts in AAE vs. SAE using them, and it could allow modeling of the semantic network in different ways. In addition, the new approach to visualizing data graphically presented by Viscomi might be employed, to examine the theories underlying various models.

If the two dialects (AAE and SAE) are separate architectures, there will be a translation requirement to go from one to the other, and that takes time, but what if, for example, "hole" and "hold" are in the same node in an identical network or are side by side and interact sometimes? Are they separate systems or different systems that interact? There may be a difference between the coding and the semantic structure. Some researchers are already modeling the availability of the semantic network in a way that is correct for AAE speakers – as they learn SAE, are they restructuring the semantic network? As one reads SAE, there is more feedback the supports SAE – the idea that a speaker translates the difference between the two dialects more like the difference between two languages. One concern is that there may be a critical or sensitive period – a time frame within which to get students to be able to code switch or after which they will recode the Standard English they are reading to dialect as they read aloud. There are also prosodic differences that should be studied, and it will be important to take advantage of neuroimaging technology to study dialect speakers – the differences that exist but also learning as it happens, as has been proposed more generally for response to reading interventions. The importance of using Standard English in schools and preschools was highlighted based on work by Washington and Patton Terry (REFS). The question was raised as to how we capture strengths in AAE speakers who don't code switch, and the need for measures was highlighted.

We should be conscious of the liability of putting very young children in very structured code programs at the expense of language and other areas that can have ramifications for the development of language and background knowledge. We must remember reading is a language -skill and that students need the other parts of language to go with it. In some low SES schools, researchers are seeing focused reading skill development but with no real experience reading. It is important to develop the culture of reading along with the skills. Think of Scarborough's (2003) reading rope – if students get the strands but never weave them together (have no practice using those their skills), the skills are not contextualized. Good readers read. Anyone who develops a skill and gets good at it does so through practicing that skill. Students need to use the skills we give them, so we need to have them read and we need to read to them; teachers should still be reading to students as well as teaching them to read.

Does the brain of a child growing up in poverty look more like an RD brain or a typically developing reading brain, or is it different from both? We know poverty has a negative impact on child development (Raver, Blair, & Willoughby, 2013), and a recent paper by Johnson, Riis, and Noble (2016) reviews current science on poverty and its impact on the developing brain. Thus it is important to include low SES children in imaging studies. A paper by Washington and Seidenberg (REF) addresses the achievement gap, and is recommended reading. NEED A BOTTOM LINE FROM THIS PAPER.

Studies Specific to Spatial Ability

Researchers could study large groups of dyslexics with multiple spatial tasks, and do latent profiling and see which subgroups empirically cluster. Do they cluster in the high scores on specific spatial tasks or overall on spatial ability (which has not been found in adults but it was noted that larger samples were needed)? This approach could also be used within professions to see if individuals chose those fields based on spatial abilities. With large enough samples, researchers might be able to more accurately profile subpopulation, rather than looking for a priori subtypes. If this were done with both dyslexics and non-dyslexics, it might provide plausible and interesting clusters.

There was speculation on why dyslexics might be better on the impossible figures task, and why the advantage was on speed. It was suggested that perhaps the Nevone task, with letter pairs and attention directed to global shape may be an interesting one to provide some insight, and there was speculation about male-female differences in strategies for visual-spatial tasks. It was suggested that using 3-D tasks and some hands-on tasks might be revealing. Overall, research has shown that the neural substrate for processing spatial information differs between students with and without RD; exploring this in depth is important.

Dyslexia – Reading and Related Abilities

Earlier definitions of dyslexics were based on IQ- reading achievement discrepancies. Children in special schools for dyslexia and learning disabilities were often those with high verbal but weak phonological skills. Research moved to a more inclusive approach to studying all students with reading difficulty, and rather than using a clinical definition, selected those students performing below a designated "cut score"; often those performing at or below the 25%ile on a reading measures. Those remarkable students who were very high IQ usually were not in the pool being studied.

It was suggested that it could be worthwhile to conduct a study of a selected sample of those students, assuming a number of them could be found, to examine some of these hypotheses about areas of unusual ability in students with reading difficulty. Some worry that the term dyslexia is getting used for all reading difficulties, regardless of what type of education they received, while some may actually be "instructional casualties", who could be more easily remediated, but only if they received intervention early enough to enable them to develop solid decoding and comprehension skills as a basis for later learning. All children have areas of relative strength and weakness, but whether such areas can be categorized as "giftedness" relative to the normative population and, then, whether these "gifts" are more prevalent among those with reading disabilities, are questions that bear some attention. Studying students in these specialized schools would give the added benefit of life records and outcomes, enabling a longitudinal view, where it might be possible to track their trajectories of learning.

It was commented that dyslexic students "process things differently, even those who do not exhibit extreme abilities in any particular area – it would be helpful to be able to specify such processing differences more clearly. It was noted that some engineering schools are looking at dyslexic students to follow how they approach problems, so there is interest in this from other quarters. Another comment was that perhaps processing differently is why many students with dyslexia respond well to multisensory approaches. One important factor will be recruitment of students of color. One could assume that, e.g., African American students with dyslexia would process visual-spatially in same way, but that should be documented.

Studies of selected samples (such as one might find in a private school for learning differences) would need to be followed up with larger studies of more inclusive samples from more diverse environments, in order to sort out whether the advantages provided to these students and the attention and opportunities presented enable them to outperform their peers with less advantage who also have reading disabilities. Does giftedness bear any relation to severity of dyslexia? Or might it be that these students are guided to areas of potential success in a more focused way than less fortunate peers? These remain questions to be examined.

While historically schools for dyslexics started with a deficit model, most are now working from strengths model. Some include a heavy infusion of subjects like are and music in the curriculum. It was commented that that might be a pathway to success for particular students, and there is emerging research relating music and rhythm to auditory processing for language and attention (Kraus & Anderson, 2015; Slater & Kraus, 2015; Strait, Slater, O'Connell, Kraus (2015). It was suggested that studying those with exceptional ability in mathematics (reasoning, not calculation), music, and/or art, as an "umbrella" to start with, as these could be seen as prototypical right hemisphere functions.

Future Research

A major conclusion of this meeting was that there some claims being made regarding giftedness and dyslexia are not evidence based; at present no clear link between the two has been established. Those participating in this meeting recommend well-designed, unbiased studies of this issue, as it will have relevance to how we treat dyslexia, how we advise parents with children who are dyslexic, and how we can best serve and identify dyslexic students with potential in academic areas other than reading. We need to be looking for strengths in all students, of course, but that includes all students who struggle with reading, whether already diagnosed as dyslexic or not, regardless of SES, in all sorts of educational environments. If there are specific areas of ability – visual-spatial skills, musical abilities, etc., that we suspect may be more commonly occurring in individuals with dyslexia, then we should be looking at those skills in all children, and figuring out scientifically if there is a greater representation among those with reading difficulties and, if so, how to capitalize on that to their benefit. Therefore, the participants of this meeting made the following initial recommendations for future research.

Generally, research activity could more frequently engage practitioners and behavioral and neuroscience researchers in collaborations, with a standard effort across studies to incorporate some specific tasks, including during neuroimaging, and then pool the data. This could result in a shared methodology yielding a consensus of findings. We could thus make our research more coordinated and intentional.

An important consideration is what research can be done now, what needs to await further foundational information, and what is beyond the scope of potential funding and logistics at this point? Large epidemiological samples would fit the latter category; to conduct new epidemiological research on this issue, the multifactoriality/ heterogeneity of dyslexia means that massive numbers would be needed. It was suggested that research collaborations with those already doing large population-based studies is one way to leverage research time for data collection, participant response burden, and scarce funding.

Beginning by studying selected samples, and oversampling on certain characteristics, was suggested as a feasible way forward initially. Such studies might begin by trying to identify a specific subgroup of students more likely to have certain extreme traits. We could theorize about the implications of knowing such a group exists, and if so, whether there is something we could do about it, and examine these well-articulated theories in focused studies.

We might be to examine what curricula currently in use have multimedia, cross-area requirements. In studying these, it might be possible to inform teachers and leaders of schools for dyslexia and learning differences, of the utility of these for students with specific characteristics, and what might be the benefits of certain strategic interventions.

To engage leadership from these schools, researchers will need to discuss potential benefits to the school, examining the data from the point of view of potential benefits to their students, and any such work would need to be limited, laid out in concrete steps. It might initially target a limited subset of specifically selected students in each school. It was noted that many of these schools are now working on "design thinking" – incremental implementation and evaluation of a process. Researchers would not want to interfere with that, but to approach them with a separate project. It will be important to involve teachers, who are excited by new ways to help their students and can be an invaluable asset in research when successfully engaged.

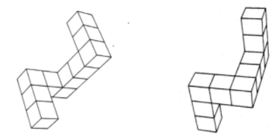
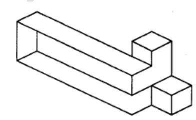
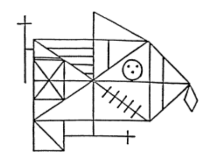
In all studies addressing this topic, it was suggested that certain domains be targeted: mathematics (math reasoning), music, art, and visual-spatial abilities (e.g., in sports). It was also suggested that handedness be considered (left vs. right handers within the groups, but it was noted that it would be important to note first-order vs. familial sinistrality).

The group recommended considering inclusion of the following measures in future studies, where possible: acceptable reading and math batteries; executive Function measures – e.g., the Wisconsin card sort or Tower of London; visual spatial measures (see Table 1); non-Verbal IQ measures, such as the Ravens Progressive Matrices.

Table 1

Spatial Ability Constructs or Tests of Spatial Ability Factors[1]

Common Name or Factor	Description	Example Test[2]	Example Item
Spatial Visualization (SV)	Complicated, multistep manipulations of spatially presented information, may involve rotations, dynamic movement,	Paper From Board[3]	

	part-to-whole analysis		
Spatial Relations or Rotation (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[4]	
Global-Holistic Processing, Closure Speed, Flexibility of Closure (FC)	Ability to identify quickly an incomplete or distorted picture including figures impossible in a normal 3-D environment	Impossible Figures, Gestalt Completion[5]	
Other Miscellaneous Abilities (O)	Navigating virtual environments, building blocks, perceptual organization	Rey-Osterrieth Complex Figure Task[6]	

[1] With the exception of the "Other" category, common names or factors were derived from French, Ekstrom & Price (1963) and Linn & Peterson (1985), although other category names may also appear in the literature.
[2] Many examples were possible. Most tests can be timed or untimed and typically yield accuracy and/or response time data.
[3] Modified example from the Minnesota Paper From Board Test (Likert & Quasha, 1941).
[4] Example from Vandenberg & Kuse (1978).
[5] Example from Schacter et al, 1990.
[6] Test stimulus from Osterrieth (1944) and Rey (1941).

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APPENDIX – MEETING PARTICPANTS

Amelia Baker, The Dyslexia Foundation
William Baker, Jr., The Dyslexia Foundation
Don Compton, Florida State University
Laurie Cutting, Vanderbilt University
Jeff Gilger, University of California – Merced
Peggy McCardle, Haskins Laboratories & PMc Consulting
Michael O'Boyle, Texas Tech University
Ben Powers, Eagle Hill School,
Kenneth Pugh, Haskins Laboratories
Joe Viscomi, Greplytix
Julie Washington, Georgia State University
Ellen Winter, Boston College