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SLD Specifier	Subskill	Etiology	Associated impairments / Cognitive correlates
With impairment in reading	**Word reading accuracy**	Several cortical and subcortical structures are frequently implicated, including the planum temporale, temporal lobes, corpus callosum, and cerebellum (e.g., Eckert et al., 2003). More recent work appears to identify dysfunction in a left hemispheric network that includes the occipitotemporal region, inferior frontal gyrus, and inferior parietal region of the brain (Silani et al., 2005; Shaywitz et al., 2000; Fletcher, Simos, Papanicolaou, & Denton, 2004; Richlan et al., 2009; Richlan, 2012). Numerous imaging studies have also found that dysfunctional responses in the left inferior frontal and temporo-parietal cortices play a significant role with regard to phonological deficits (Skeide et al., 2015). Family and genetic factors have long been identified as crucial in dyslexia, with some researchers suggesting that a child with a parent with a reading disability is eight times more likely to be dyslexic compared to the general population (Pennington & Olson, 2005). Certainly, there is converging evidence from family and twin studies	**Phonological awareness** – primary cognitive correlate; the metacognitive understanding that words have internal structures based on phonemes (Fletcher et al., 2007; Kudo, Lussier, & Swanson, 2015; Melby-Lervåg, Lyster, & Hulme, 2012; Willcutt et al., 2013). When this awareness is impaired, word recognition is delayed and fluency and comprehension skills are consequently affected. **Rapid naming** – some researchers have found that phonological awareness and rapid letter naming both uniquely predict word recognition skills (Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Wagner, Torgesen, & Rashotte, 1994; Wagner, Torgesen, Rashotte, & Hecht, 1997). However, a meta-analysis of studies examining the relationship between rapid naming and dyslexia found little evidence to support a central and persistent deficit in naming speed in individuals with the disorder (Vukovic & Siegel, 2006). On the other hand, there are findings to suggest that phonological awareness and rapid

		demonstrating the heritability and familiality of dyslexia (Grigorenko, 2001). Recently, genetic linkage studies have also identified several susceptibility genes for reading disabilities. These include sites on chromosomes 1, 2, 3, 4, 6, 11, 15, and 18, with one of the most commonly identified genetic locus being on chromosome 6 (Grigorenko, 2005; Paracchini et al., 2007; Scerri & Schulte-Korne, 2010; Scerri et al., 2011; Skeide et al., 2015). Shared environmental factors include: language and literacy environment during childhood (Wadsworth et al., 2000), quality of reading instruction.	naming, although correlated, are distinct variables and contribute uniquely to word recognition (Petrill, Deater-Deckard, Thompson, DeThorne, & Schatschneider, 2006). **Phonological memory** – working memory for verbal and sound-based information has also been found to be significantly related to word recognition, although it may not uniquely contribute when phonological processing is accounted for (Melby-Lervag, Lyster, & Hulme, 2012; Schatschneider et al., 2004; Wagner et al., 1997; Willcutt et al., 2013).
	Reading comprehension	Several brain regions are often implicated in reading comprehension. These include the anterior temporal lobe, inferior temporal gyrus, inferior frontal gyrus, inferior frontal sulcus, and middle and superior frontal and temporal regions (Ferstl et al., 2008; Gernsbacher & Kaschak, 2003). More recent research has revealed a relationship between listening and reading comprehension and activation along the left superior temporal sulcus,	**Oral language** – difficulties in reading comprehension are frequently associated with deficits oral language in general, including areas such as vocabulary, morphology, and syntax (Catts et al., 1999; Cutting & Scarborough, 2006; Share & Leikin, 2004; Torgesen, 2000; Willcutt et al., 2013). **Listening comprehension** – several studies have demonstrated that a unique portion of the variance in

		which has referred to by some as the "comprehension cortex" (Berl et al., 2010). However, broader pathways are also activated in reading comprehension, reflecting increased cognitive demand compared to listening comprehension. Genetic factors are said to account for 41 to 76 percent of the variance in comprehension (e.g., Betjemann et al., 2008; Harlaar, Dale, & Plomin, 2007; Olsen et al., 2011; Petrill et al., 2007). While genetic factors that influence decoding and listening comprehension account for nearly 40 percent of the variance in reading comprehension, there is little evidence for an independent source of genetic influence on comprehension alone (Harlaar et al., 2010; Keenan et al., 2006). However, estimating the genetic influences on reading comprehension may be particularly sensitive to the type of assessment test used (Betjemann, Keenan, Olson, & DeFries, 2011).	reading comprehension can be explained by listening comprehension (Cutting & Scarborough, 2006; Kendeou, van den Broek, White, & Lynch, 2009). **Working memory** – comprehension involves holding words and sentences in awareness, while integrating prior knowledge with incoming information (Carretti et al., 2009). Poor comprehenders may have particular difficulty updating / revising information already in working memory (Pelegrina et al., 2014; Peng et al., 2018; Peng & Fuchs, 2016). **Executive functioning –** several executive functions are involved in reading comprehension, including planning, organization, and self-monitoring (Cutting et al., 2009; Locascio, et al., 2010; Sesma et al., 2008). Weaknesses in these executive functions result in difficulties with higher-order comprehension skills such as inferencing, integrating prior knowledge, monitoring comprehension, and adapting to text structure or genre (Fletcher et al., 2007; Kendeou, van den Broek, Helder & Karlsson, 2014).
	Reading rate or fluency	Brain regions activated are similar to the network	**Rapid automatized naming (RAN)** – while the

		implicated in word reading, but additional activation is observed in areas involved in eye movement and attention (Jones, Ashby, & Branigan, 2013). Further, there is also evidence for increased activation in the left occipitotemporal region, in particular the occipitotemporal sulcus, which is important for rapid processing of letter patterns (Shaywitz et al., 2004; Dehaene & Cohen, 2011). Some studies have found increased activation in this region when normal reading automaticity is disrupted (Benjamin & Gaab, 2012). While limited, there is evidence of genetic influences specific to rapid naming and reading, suggesting that RAN may be etiologically distinct from phonological awareness (Byrne et al., 2005; Compton et al., 2001; Petrill et al., 2006). Genetic linkage studies have identified susceptibility genes for fluency, namely chromosome 2 (Raskind et al., 2005).	exact relationship between RAN and reading remains unclear, RAN is believed to be one of the best predictors of reading fluency (Georgiou et al., 2008, Tan et al., 2005). The automaticity required to complete RAN tasks is related to the ability to synthesize and automatize letter sequences / words when reading (Norton & Wolf, 2012). There are also a variety of cognitive processes implicated in rapid naming. These include attention, executive functions (i.e., response inhibition, set shifting), lexical retrieval, and processing speed (Moll, Gobel, & Snowling, 2015). **Orthographic processing** – processing of orthographic information (i.e., the ability to process units of words based on visual long-term memory representations) is considered critical in automatic word recognition and consequently plays a crucial role in fluency (O'Brien et al., 2011). This ability is often impaired or underdeveloped in some reading disabled individuals.
With impairment in mathematics	**Number sense**	Researchers differentiate between the basic processing of numerical information and processes	**Number representation** – math disorders are associated with weaknesses in fundamental number

		involved in math calculation and problem solving, suggesting that these are both structurally and functionally distinct (Ansari, 2010). The intraparietal sulcus in both hemispheres is widely viewed as crucial in processing and representing numerical quantity, although there may be differences in activation as a function of age (Ansari & Dhital, 2006; Ansari, Garcia, Lucas, Hamon, & Dhital, 2005; Dehaene et al., 2004; Kaufmann et al., 2006; Kucian, von Aster, Loenneker, Dietrich, & Martin, 2008; Price & Ansari, 2013; Mussolin et al., 2010).	representation and processing, which manifest in difficulties with quantifying sets without counting, using non-verbal processes to complete simple numerical operations, and estimating the relative magnitude of sets (Feigenson, Dehaene, & Spelke, 2004; Geary, 2013; Geary et al., 2012; Geary et al., 2008; Geary et al., 2009; Halberda et al., 2008; Mazzocco, Feigenson, & Halberda, 2011; Julio-Costa, 2015; Rouder & Geary, 2014). **Number comparison** – several studies have indicated that math difficulties are associated with deficient basic number-processing abilities, such as number comparison (Price & Ansari, 2013). These weaknesses are characterized by increased reaction times and error rates on tasks that involve comparing numbers, with particular difficulty when numbers are closer together (Mussolin, Mejias, & Noel, 2010).
	Memorization of arithmetic facts	A left hemisphere network that includes the precentral gyrus, inferior parietal cortex, and intraparietal sulcus, is often implicated in math fact retrieval (Dehaene & Cohen, 1992; 1992, 1997; Dehaene et al., 1999).	**Long-term retrieval** – weak or impaired long-term retrieval of facts and increased error rates in recall (Geary, 1993; Mazzocco, Devlin, & McKenney, 2008). Because fact-retrieval mechanisms

		Further, some researchers believe that rote math facts are retrieved from verbal memory, thereby requiring activation of the angular gyrus and other regions associated with linguistic processes (Dehaene, 1992; Dehaene & Cohen, 1995; Dehaene et al., 1999).	fail to develop adequately, fluency is impaired and those with dyscalculia continue to utilize procedural strategies rather than memory-based strategies (Geary, Bow-Thomas, & Yao, 1992; Geary, Hamson, & Hoard, 2000; Jordan & Hanich 2003; Hanich et al., 2001; Landerl, Bevan, & Butterworth, 2004).
	Accurate or fluent calculation	Regions of the left fronto-parietal cortex, including the intraparietal sulcus, angular gyrus, and supramarginal gyrus have been consistently associated with math calculation (Ansari, 2008; De Smedt, Holloway, & Ansari, 2011; Dehaene, Molko, Cohen, & Wilson, 2004; Chong & Siegel, 2008; Dehaene et al., 2004). However, there is evidence to suggest that math fluency, while related to other skills, may be genetically distinct and may reflect variance above and beyond untimed calculation abilities (Hart, Petrill, & Thompson, 2010; Petrill et al., 2012). The dorsolateral prefrontal cortex has also been found to show increased activation during calculation, implying that executive functioning and working memory may be playing a role in the process (Davis et al., 2009).	**Long-term retrieval** (see above) **Rapid naming** – the rate of access to information in long-term storage is believed to affect calculation fluency (D'Amico & Passolunghi, 2009). Some studies have found that math disorders are associated with deficits in rate of access of numerical information alone (e.g., D'Amico & Guarnera, 2005), while others have demonstrated that rate of access to both numerical and non-numerical information is impaired (e.g., Temple & Sherwood, 2002). **Processing speed** – there is a body of evidence to support the contribution of processing speed in math calculation fluency; however, the relationship remains unclear, as

			processing speed is often highly related to working memory and general intelligence (Berg, 2008; Bull & Johnston, 1997; Geary, 2011; Mazzocco & Rasanen, 2013; Willcutt et al., 2013).
	Accurate math reasoning	As mentioned above, the intraparietal sulcus is often identified as a neural correlate of math disorders. However, it is likely that an entire network of brain regions is implicated, as the intraparietal sulcus plays a role in a variety of cognitive processes involved in math achievement (Szucs & Goswami, 2013). It has been suggested that the parietal network is involved in manipulating numerical quantities (Lemer et al., 2003). Further, some studies have found that individuals with dyscalculia have structural abnormalities in the parietal cortex (Rotzer et al., 2008; Rykhlevskaia et al., 2009). Prevalence of math disabilities is about 10 times higher in those with family members who had math disabilities (Shalev et al., 2001). Twin studies suggest a moderate genetic influence, with some studies finding additive genetic influences shared between math calculation and	**Working memory** – because mathematical reasoning relies on concurrently retaining multiple pieces of information while performing one or more procedures or mental operations, working memory is often implicated. Those with math difficulties tend to struggle with holding information in working memory, updating or revising the information, and tracking or monitoring the process, resulting in difficulties in sequencing, increased errors in counting, and other procedural errors (David, 2013; Geary, 2003; Lukowski et al., 2014; Pelegrina et al., 2014; Peng & Fuchs, 2016; Raghubar, Barnes, & Hecht, 2010; Swanson & Jerman, 2006; Willcutt et al., 2013). **Visual-spatial ability** – visual-spatial skills, such visual perception, spatial reasoning, and mental rotation, have been found

		problem solving and several working memory components (Kovas et al., 2007; Lukowski et al., 2014). Environmental factors, including motivation, emotional functioning (e.g., math anxiety), and suboptimal or inadequate teaching may also contribute to math difficulties (Szucs & Goswami, 2013; Vukovic et al., 2013). Further, math achievement in particular may be associated with cultural or gender-based attitudes that may be transmitted in the family environment (e.g., Chiu & Klassen, 2010; Gunderson et al., 2011).	to influence math performance (Gunderson et al., 2012; Swanson, Olide, & Kong, 2017; Yang, Chung, & McBride, 2018). Weaknesses in these may present as difficulties with representing numbers and aligning numerals, and problems in areas such as geometry or fractions (Geary, 2004; Swanson & Jerman, 2006). **Attention and executive functioning** – math difficulties often reflect weaknesses in executive functioning skills, such as set shifting and cognitive inhibition (D'Amico & Passolunghi, 2009; van der Sluis, de Jong, & van der Leij, 2004; Willcutt et al., 2013). Further, poor attentional control (i.e., difficulty ignoring irrelevant information and focusing on goal-relevant information) is often observed (Geary, 2013; Yang, Chung, & McBride, 2019).
With impairment in written expression	**Spelling accuracy**	Functional neuroimaging studies have provided substantial evidence for the role of the ventral-temporal inferior frontal gyrus and the posterior inferior frontal gyrus in spelling (Rapp et al., 2015; van Hoorn et al., 2013). Other areas that have been identified include the left ventral cortex, bilateral lingual gyrus, bilateral	**Phonological processing** – phonological awareness is a significant predictor of spelling achievement (Caravolas, Hulme, & Snowling, 2001; Cornwall, 1992; Holm, Farrier, & Dodd, 2008; Skeide et al., 2015; Yeong, Fletcher, & Bayliss, 2014). Weaknesses in this area may manifest as poor

		fusiform gyrus (Planton et al., 2013; Purcell et al., 2014; Richards et al., 2005; Richards et al., 2006). However, many of these regions have also been associated with reading and are not distinct to spelling / writing disorders. There is evidence that links spelling to a region of chromosome 15 (Schulte-Korne, 2001), although this locus has also been reported in dyslexia (Grigorenko, 2005).	segmentation of words into phonemes, poor sequencing of sounds, and omission or addition of sounds (Berninger, 1999). **Orthographic processing / orthographic coding** – effective spelling involves storing and retrieving commonly occurring letter patterns in visual and motor memory; these skills are often impaired in poor spellers (Caravolas, Hulme, & Snowling, 2001; Ehri, 2014; Yeong, Fletcher, & Bayliss, 2014). **Motor skills** – poor spelling is often accompanied by underlying skill deficits in areas such as fine-motor control, motor planning, orthographic motor coordination, and visual-motor integration (Christensen, 2004; Daly, Kelley, & Krauss, 2003; Feder & Majnemer, 2007).
	Grammar and punctuation	With regard to English grammar, some researchers distinguish between the mental lexicon (i.e., memorized associations) and mental grammar (i.e., language rules and structure) and posit that each has distinct neural correlates (Pinker, 1994). There is some evidence to support this view, with data indicating that the mental lexicon involves left	**Long-term memory** – it has been suggested that some components of long-term storage, in particular procedural and declarative memory, may be involved in grammar; however, much of this research has focused on children with language impairments (Conti-Ramsden, Ullman, & Lum, 2015; Hedenius, et al., 2011).

		temporal and temporo-parietal regions, whiles the mental grammar recruits a system that includes left frontal regions (Ullman et al., 2005).	
	Clarity of written expression	Neural correlates of writing are less understood, but some studies have suggested that the cerebellum and parietal cortex, particularly the left superior parietal lobe, may be involved (Katanoda et al., 2001; Magrassi et al., 2010). In addition, the frontal lobes have also been implicated and are considered crucial in planning, brainstorming, organizing, and goal setting (Shah et al., 2013). While there is a significant genetic component involved in the development of writing skills, this etiology is often shared with a broad variety of reading and language skills (Olson et al., 2013).	**Working memory** – a substantial body of research has highlighted the role of working memory in written expression, as text generation requires the coordination of multiple processes, such as synthesizing multiple ideas, retrieving grammar rules from long-term storage, and ongoing self-monitoring (Berninger, 1999; Bourke et al., 2013; Hooper et al., 2002; McCutchen, 1996). **Attention and executive functioning** – a variety of executive functions, including attention, planning, self-monitoring have been implicated in written expression (Altemeier, Jones, Abbott, & Berninger, 2006; Graham, Gillespie, & McKeown, 2013; Graham & Harris, 2005; Hooper et al., 2002; Mason, Harris, & Graham, 2011; Reiter, Tucha, & Lange, 2005; Rosenblum et al., 2009; Troia & Graham, 2002). **Language** – level of knowledge of syntax, morphology, semantics,

			vocabulary has a significant impact on text generation ability (Dockrell, Lindsay, & Connelly, 2009; Fey, Catts, Proctor-Williams, Tomblin, & Zhang, 2004; Olinghouse & Wilson, 2013). Language impairments are associated with higher rates of grammatical errors, less lexical diversity, and poorer overall content (Fey et al., 2004; Mackie & Dockrell, 2004).

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