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Probing the neurocognitive trajectories of children's reading skills

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ABSTRACT

Emerging evidence of the high variability in the cognitive skills and deficits associated with reading achievement and dysfunction promotes both a more dimensional view of the risk factors involved, and the importance of discriminating between trajectories of impairment. Here we examined reading and component orthographic and phonological skills alongside measures of cognitive ability and auditory and visual sensory processing in a large group of primary school children between the ages of 7 and 12 years. We identified clusters of children with pseudoword or exception word reading scores at the 10th percentile or below relative to their age group, and a group with poor skills on both tasks. Compared to age-matched and reading-level controls, groups of children with more impaired exception word reading were best described by a trajectory of developmental delay, whereas readers with more impaired pseudoword reading or combined deficits corresponded more with a pattern of atypical development. Sensory processing deficits clustered within both of the groups with putative atypical development: auditory discrimination deficits with poor phonological awareness skills; impairments of visual motion processing in readers with broader and more severe patterns of reading and cognitive impairments. Sensory deficits have been variably associated with developmental impairments of literacy and language; these results suggest that such deficits are also likely to cluster in children with particular patterns of reading difficulty.

1. Introduction

1.1. Individual differences in the acquisition of reading skills

From an evolutionary perspective, reading is a recent addition to the human behavioural repertoire. Correspondingly, it is among the most difficult and variable skill sets that must be acquired, and is made possible by the recruitment of a distributed network of brain areas, the components of which are not uniquely endowed for the task of literacy. This study presents a multi-level analysis (see, e.g., Frith, 1997) of some of the cognitive, sensory and behavioural factors which may contribute to variability in children's ability to achieve this complex skill.

In alphabetic languages such as English, reading development requires learning the conventional, yet arbitrarily established, mappings that link visual symbols (i.e., letters) to the sounds of speech within a specific linguistic environment. This learning process is constrained both by the nature of the critical phonological distinctions in oral language that must be acoustically discriminated and the consistency of the relationship between the letter–sound mappings in a given orthography (Mareschal et al., 2007). Reading development is therefore underpinned, at least in the initial stages, by the precision with which visual and auditory discriminations can be made, as well as the ability to accurately link these representations on a timescale of milliseconds to achieve representations of the phoneme, the emergent property associated with the repeated exposure to and learning of letter–sound pairings.

Behavioural measures of phonological awareness and processing are among the strongest predictors of reading aptitude in typically developing children, and in reading impairments (Bradley & Bryant, 1983; Rack, Snowling, & Olson, 1992; Wagner & Torgeson, 1987; Wagner, Torgeson, & Rashotte, 1994). A substantial literature on typical and impaired reading development (i.e., developmental dyslexia) has focussed on estimating the covariance between abilities – cognitive, linguistic and sensory – associated with phonological skills and their statistical contribution to reading outcomes (see Chapter 2 of Hulme & Snowling, 2009 for review). Phonological skills do not account for all the variance in reading ability. Other component skills, such as in orthographic coding, explain unique variance in literacy skill development in typical (Coltheart, 1978; Cunningham & Stanovich, 1990; Stanovich, West, & Cunningham, 1991) and impaired readers (Badian, 2005; Castles & Coltheart, 1993). Moreover, phonological and orthographic skills contribute independently to the heritable and presumed genetic component of risk

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for specific reading difficulties (Castles, Datta, Gayan, & Olson, 1999; Olson, Forsberg, & Wise, 1994), suggesting that their impact is mediated – at least partially – by different underlying mechanisms.

From 40% to 70% of the population variance in reading skill is attributable to heritable factors (Olson, 2002), with the most robust risk genes identified so far implicated in neurodevelopmental mechanisms such as neuronal migration in cortical development (Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006; Paracchini et al., 2006; Williams & O'Donovan, 2006). The strong heritability of reading skills across the range of abilities has potentiated investigations of the underlying mechanisms involved, both those that increase prospective risk for disability, but also those that may act as protective factors to mitigate against these risks. The interactive nature of risk and protective factors is embedded in an emerging view of developmental disorders and their associated symptoms as continuous and overlapping dimensions, rather than as discrete categories (Cramer, Waldorp, van der Maas, & Borsboom, 2010). This framework is consistent with recent evidence for the high overlap between the diagnostic prevalence of these disorders and their associated symptoms and with evidence that common underlying mechanisms likely mediate general population variability on the constructs upon which clinical diagnoses are made (Plomin & Kovas, 2005). Within the domain of reading development and dysfunction, recent studies have focussed on the broad phenotypic manifestations of dyslexia (Menghini et al., 2010; Snowling, 2008), with the appreciation that similar profiles among individuals at the behavioural level may have heterogeneous underlying causes (Frith, 1997; Thomas, 2003).

1.2. Subtypes within atypical and normal reading development

A body of studies have shown that developmental impairments of reading can manifest as clusters, for example, those defined by relative strengths and weaknesses in exception and pseudoword naming (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Stanovich, Siegel, & Gottardo, 1997). These clusters broadly parallel the phonological and surface patterns of reading deficit observed in acquired dyslexia, but with relatively milder dissociations between skills. Within this framework, the phonological subtype is characterized by reading performance that is comparatively weaker ability on naming pseudowords. In contrast, a surface (Castles & Coltheart, 1993) or reading delay (Manis et al., 1996, 1997; Harm & Seidenberg, 1999) subtype is characterized by exception word reading that is below that expected for a given age, but with pseudoword reading skills in the normal range.

Although other subtyping methodologies have been proposed (e.g., Boder, 1973; Mattis, French & Rapin, 1975; Mitterer, 1982; Morris et al., 1998), these alternatives have been most widely developed in the context of capturing variability in developmental reading impairments rather than applied to normal and developing reading.

Orthographic and phonological processes provide independent constraints on children's reading development (e.g., Olson et al., 1994) and may be impaired selectively (although rarely completely dissociated; Van Orden, Pennington, & Stone, 2001). Castles and Coltheart (1993) used a regression methodology to estimate the incidence of subtypes within a sample of children with developmental dyslexia and reported that 85% of the sample of 53 children demonstrated comparatively greater impairments in either exception word or in pseudoword naming accuracy. Castles and Coltheart argued therefore that the majority of children with developmental dyslexia could be classified as having relatively selectively impaired processing in either phonological or orthographic processing. In a subsequent study, however, Manis et al. (1996) argued that the majority of Castles and Coltheart's sample of dyslexic readers were significantly impaired on *both* exception and pseudoword reading when compared to age-matched control children. When the selection criteria for each of the groups was modified to include only the individuals who were *selectively* impaired on either exception word or pseudoword naming, highlighted by accuracy within the normal range on the contrasting naming task, the proportion of dyslexic readers demonstrating a 'pure' deficit was 34% in the original Castles and Coltheart sample and 19.6% in a replication study with 51 dyslexic children (Manis et al., 1996). Therefore, most dyslexic children showed impairments in both routes relative to age-matched controls, although significant numbers also demonstrated a relatively isolated profile of deficit.

In this study, we take a complementary approach by selecting from a wide sample of primary school children, rather than preselecting children based on clinical criteria. This strategy yields a quasi-experimental study of clusters of children with deficits in component reading skills without relying on the presence or absence of clinical diagnoses which depend on exposure to appropriate referral pathways. By contrasting the characteristics of those children in the lower tails of phonological and orthographic skills (or both), we explored a range of cognitive and sensory factors that may impact upon these patterns of reading impairment and their relation to children with typical reading development. This approach has benefits over multivariate approaches because it provides heightened sensitivity to identify individual heterogeneity – a key feature of both typical and disordered reading – yet it also enables generalisations to be made about the population of developing readers which cannot be sufficiently addressed with serial case studies.

1.3. Sensory processing skills as neuropsychological probes of variability in reading skill

Assessing the relative differences in reading skills across orthographic and phonological tasks has also provided evidence of the extent to which linguistic (Manis et al., 1997) and auditory sensory (Cestnick & Jerger (2000), 2000; Talcott et al., 2000) deficits cluster with variability in phonological skills. A number of independent studies have reported moderate to strong statistical relationships between different aspects of auditory processing and phonological skills in dyslexia (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Boets, Wouters, Van Wieringen, De Smedt, & Ghesquiere 2008; Van Ingelghem et al., 2001, Witton et al., 1998), and in typically-developing school children (Talcott et al., 2000; Talcott et al., 2002; cf. Hulslander et al., 2004).

One of the most frequently used tasks in investigations of auditory sensory processing in reading development and dysfunction is in discriminating frequency differences between two or more tonal stimuli. Deficits in such low-level auditory-processing have commonly been reported in samples of individuals with dyslexia (e.g., Banai and Ahissar, 2006; Baldeweg, Richardson, Watkins, Foale, & Gruzilier, 1999; Banai and Ahissar, 2006; deWeirdt, 1988; France et al., 2002; Halliday & Bishop, 2006; Lachmann, Berti, Kujala, & Schröger, 2005; Leppänen et al., 2010). Such studies have predominantly used psychophysical methods, although event-related potential (ERP) measures have also been applied. Application of both methodologies has revealed that beginning readers at risk for familial dyslexia process changes in sound frequency differently to controls (Leppänen et al., 2010; Maurer, Bucher, Brem, & Brandeis, 2003). Deficits in the processing of other non-speech features have also been identified, for example, in detecting their temporal properties (Goswami, 2011; Tallal, 1980), as well as sensitivity to amplitude and frequency modulation (FM) of acoustic stimuli (McAnally and Stein, 1996;