



Comorbidities in preschool children at risk of dyslexia

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Comorbidities in preschool children at family risk of dyslexia

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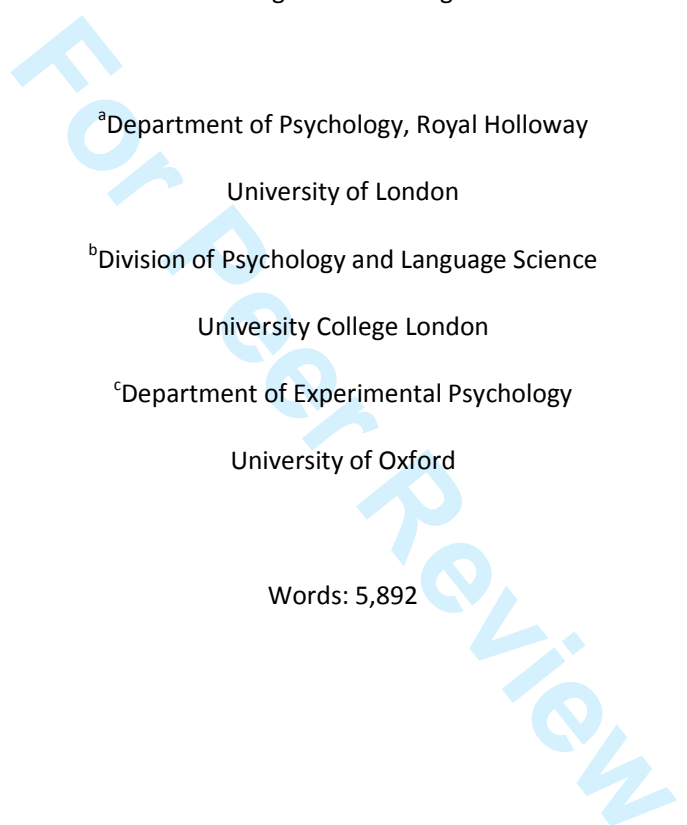
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Abstract

Background. Comorbidity among developmental disorders such as dyslexia, language impairment, attention deficit/hyperactivity disorder and developmental coordination disorder is common. This study explores comorbid weaknesses in preschool children at family risk of dyslexia with and without language impairment and considers the role that comorbidity plays in determining children's outcomes. **Method.** The preschool attention, executive function and motor skills of 112 children at family risk for dyslexia, 29 of whom also met criteria for language impairment, were assessed at ages 3 ½ and 4 ½. The performance of these children was compared to the performance of children with language impairment and typically developing controls. **Results.** Weaknesses in attention, executive function and motor skills were associated with language impairment rather than family risk status. Individual differences in language and executive function are strongly related in the preschool period and preschool motor skills predicted unique variance (4%) in early reading skills over and above children's language ability. **Conclusion.** Comorbidity between developmental disorders can be observed in the preschool years: children with language impairment have significant and persistent weaknesses in motor skills and executive function compared to those without language impairment. Children's early language and motor skills are predictors of children's later reading skills.

Comorbidities in preschool children at family risk of dyslexia

In recent years there has been growing interest in the frequent co-occurrence of developmental disorders; indeed it is now well recognised that pure disorders are rare in development and that 'co-morbidity' is common (Hulme & Snowling, 2009; Williams & Lind, 2013).

Evidence suggests that about 40% of school-aged children with one neurodevelopmental disorder (e.g. dyslexia, language impairment, attention deficit/hyperactivity disorder (ADHD) and developmental coordination disorder (DCD)) will also meet diagnostic criteria for another neurodevelopmental disorder (e.g. Kadesjö & Gillberg, 1999; McArthur, Hogben, Edwards, Heath & Mengler, 2000; Rochelle & Talcott, 2006; Willcutt & Pennington, 2000). These findings suggest that etiological factors that adversely influence brain development can have diverse effects (Pennington, 2006). However, less is known about comorbidity between neurodevelopmental disorders during the preschool years when the foundation for later learning is established.

It is well recognized that children with preschool language impairment are at high risk of developing reading difficulties (Bishop & Snowling, 2004) and that children at family risk of dyslexia who go on to have significant reading difficulties are likely to have a history of oral language difficulties (e.g., Scarborough, 1990; Snowling, Gallagher & Frith, 2003).

Attention deficits might also be expected to increase the risk of learning disorders by compromising the acquisition of key academic skills, including behaviour regulation (Barkley, 1997). Indeed, preschool attention problems have been found to predict later reading achievement (Rabiner, Coie & The Conduct Problems Prevention Group, 2000) which may reflect the operation of shared genetic risk factors influencing the development of both reading and attentional difficulties (e.g. Willcutt et al. 2007; McGrath et al., 2010).

Impairments in motor skills are also frequent in children with dyslexia (Kaplan, Wilson, Dewey & Crawford, 1998) although the evidence for an association between motor difficulties and specific reading difficulties in the school years is not strong (Rochelle et al., 2008). The occurrence of motor deficits in children with language impairment, on the other hand, is well documented (Hill,

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2
3 2001) and Bishop (2002) found shared genetic liability for impairments on speeded motor tasks and
4
5 tasks requiring speech production, suggesting that the genes that put a child at risk of
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7 speech/language difficulties may also affect motor development.
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10 In summary, evidence for comorbidities between neurodevelopmental disorders is strong
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12 but a limitation of current evidence is a lack of longitudinal studies. We would argue that
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14 understanding how symptoms and cognitive markers of different disorders co-occur in the pre-
15
16 school years is critical to the development of causal models of learning disorders as it will enable us
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18 to understand how comorbidities affect children's learning. In this regard, a recent study by Aro,
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20 Eklund, Nurmi and Poikkeus (2012) showed that children at family risk of dyslexia are at increased
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22 risk of poor social outcomes if they have weak language skills *and* poor behavioural regulation in the
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24 pre-school years, ascertained by parental report. In addition, Viholainen, Ahonen, Lyytinen, Cantell,
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26 Tolvanen, and Lyytinen, (2006) found that some children at family risk of dyslexia were slower to
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28 reach developmental motor milestones in the first two years of life. These children also
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30 experienced early language difficulties (they had smaller vocabularies and poorer inflectional skills)
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32 at age 3 and turned out to be slower readers at age 7.
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35
36 Pennington's (2006) multiple deficit model suggests that a child's developmental outcome
37
38 will reflect a complex interplay between multiple risk factors and Hudziak, Achenbach, Althoff and
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40 Pine (2007) posit that the manifestation of any given developmental psychopathology will be
41
42 determined by multiple sources of variance including the degree to which symptoms of comorbid
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44 disorders are present. Studying children at family risk of dyslexia gives us the opportunity to
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46 investigate cognitive precursors of dyslexia and search for these potential risk markers
47
48 (endophenotypes).
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51 In this paper we report data from the first two phases of a longitudinal study comparing
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53 preschool children who are at family risk of dyslexia with and without language impairment to those
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55 who have language impairment-only and TD controls. This design enables us to consider whether
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57 two different risk factors for literacy difficulties (familial genetic risk or early language impairment)
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3 are differentially associated with comorbid weaknesses in motor skills or executive function (and
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5 thus an increased risk of comorbid disorders such as DCD or ADHD). Given that previous studies
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7 have shown that only about 50% of children at family risk for dyslexia will go on to have literacy
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9 difficulties (Scarborough, 1990; Snowling et al., 2003) this study is also novel in considering the
10
11 broader cognitive strengths and weaknesses of children at family risk of dyslexia prior to reading
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13 instruction and thus enables us to explore the developmental progression of comorbidities whilst
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15 avoiding the confound of reading failure.
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18 Our primary research question was: Are children at family risk of dyslexia at increased risk
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20 for motor difficulties and/or impairments in executive function during the pre-school period?
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22 Second, we asked whether these impairments were associated with pre-school language difficulties
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24 that were prevalent in the family risk group. Finally we wanted to explore whether markers of
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26 comorbid disorders (specifically markers of DCD or ADHD as measured by objective measures of
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28 motor skills and executive function) could help predict which children maybe most at risk of later
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30 reading difficulties.
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36 Method

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38 Data are from the first two phases of the Wellcome Language and Reading project; children
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40 were aged 3–4 years old at T1 and 4–5 years old at T2 approximately 11 months later.
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42 Participants

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44 Families with 3-year-old children were recruited to the study via advertisements placed in
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46 local newspapers, nurseries and webpages of support agencies for individuals with
47
48 dyslexia/language difficulties, and via speech and language therapy services in Yorkshire, UK. None
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50 of the 242 children recruited to the study met our exclusionary criteria (MZ twinning, chronic illness,
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52 deafness, English as a 2nd language, care provision by local authority and known neurological
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54 disorder such as cerebral palsy, epilepsy, ASD). Ethical clearance for the study was granted by the
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56 University of York, Department of Psychology's Ethics Committee and the NHS Research Ethics
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3 Committee. Parents provided informed consent for their child to participate. Following recruitment
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5 the children were classified into groups using a two-stage process: first, to determine whether or not
6
7 they were at family risk for dyslexia and second, to determine whether or not they had current
8
9 language impairment. This 2 (family risk yes/no) x 2 (language impairment yes/no) design yielded 4
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11 groups: family risk only (FR), language impaired only (LI), family risk and language impaired (FRLI)
12
13 and typically developing (TD).
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16 **Family risk.** Previous family risk studies have used either self-report or objective measures
17
18 to determine risk status. In the current study we obtained self-report (Adult Reading Questionnaire;
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20 Snowling, Dawes, Nash & Hulme, 2012) and objectively measured the literacy skills of parents who
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22 consented to be assessed. Children were classified as family risk if (1) a parent self-reported as
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24 dyslexic, (2) a parent scored below 90 on a literacy composite of nonword reading and spelling (see
25
26 Snowling et al. 2012 for details), (3) a parent had a discrepancy between nonverbal ability and the
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28 literacy composite of 1.5 standard deviations, with a literacy composite standard score of 96 or
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30 below, or (4) a sibling had a diagnosis of dyslexia from an educational psychologist or a specialist
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32 teacher. According to these criteria, 120/242 children were classified as being at family risk for
33
34 dyslexia.
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38 **Language Impairment.** language impairment status was determined at T1 using three
39
40 subtests, Basic Concepts, Expressive Vocabulary and Sentence Structure, from the *Clinical Evaluation*
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42 *of Language Fundamentals (CELF) – Preschool 2 UK* (Semel, Wiig & Secord, 2006) and the screener
43
44 from the *Test of Early Grammatical Impairment (TEGI; Rice & Wexler, 2001)* comprising the third
45
46 person singular /s/ and past tense probes. These tests assess receptive and expressive skills across
47
48 multiple domains of language (vocabulary, syntax and grammatical inflection) (Tomblin, Records,
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50 Buckwalter, Zhang, Smith, & O'Brien, 1997). Children were classified as language impaired if they
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52 'failed' 2/4 language tests (a fail being a score of 85 or below on the CELF subtests or failure of the
53
54 TEGI screener)¹.
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3 Based on our research criteria, 35/120 children at family risk of dyslexia were classified as
4
5 having language impairment as were 31/46 children referred for speech/language difficulties.
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7 Children who were referred to the study because of speech/language concerns but who did not
8
9 meet our criteria for language impairment were excluded from further analyses (N= 15).
10

11 **Typically Developing group.** Of the 76 children initially referred as typically developing, 5
12
13 met criteria for language impairment. These children were considered to be language impaired for
14
15 the purpose of the study. The remaining 71 children, who were not at family risk of dyslexia, whose
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17 parents did not raise concerns about their speech/language development and who did not meet our
18
19 criteria for language impairment, formed our typically developing group.
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22 There was a small amount of attrition between T1 and T2 therefore data from 2 typically
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24 developing children, 2 children at family risk of dyslexia, 4 children with language impairment and 6
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26 children at family risk of dyslexia who also had language impairment are not included here.
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29 **Sample characteristics.** Appendix 1 includes information about the age, gender, SES status,
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31 Nonverbal IQ (NVIQ) and language ability of the four groups (TD: N= 69, FR: N=83, LI: N=32 and FRLI:
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33 N = 29). The groups did not differ in age but there were group differences in SES status and NVIQ.
34
35 On average the typically developing children were from higher SES backgrounds than children with
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37 language impairment (LI, FRLI) and they performed significantly better on the NVIQ tasks than
38
39 children in the family risk group, who in turn performed better than the children with language
40
41 impairment. There were relatively more boys than girls classified as language impaired but this
42
43 difference was not statistically significant. As expected given the diagnostic criteria the children with
44
45 language impairment (LI, FRLI) performed worse than the typically developing and family risk groups
46
47 on the language measures (CELF Basic Concepts, CELF Expressive Vocabulary, CELF Sentence
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49 Structure and TEGI screener)(see Nash, Hulme, Gooch & Snowling (2013) for further information
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51 regarding the speech and language profiles of the groups).
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55 **Tests and Procedures**

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3 Alongside diagnostic language tests and NVIQ assessment each child completed measures of
4 motor skills and executive function (see Appendix 2 for full details). Parents also completed
5 questionnaires about their child's attention, behaviour and motor coordination skills.
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9 Tests were administered in a single 1.5-hour session at T1 and across two 1-hour sessions at T2. The
10 sessions were conducted in the child's home and breaks were provided as appropriate.
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13 **Motor Skills.** Children completed 3 subtests from the *Movement Assessment Battery for*
14 *Children-2* (Henderson, Sugden, & Barnett, 2007); *Posting Coins*, *Bead Threading* and *Bicycle Trails* to
15 assess fine motor skills (T1, T2).
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20 As part of a structured family interview parents were asked to report the age at which their
21 child started walking and at T2 parents completed the *Developmental Coordination Questionnaire*
22 (DCDQ'07; Wilson et al. 2009), a screening tool to assist in the identification of developmental
23 coordination difficulties.
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29 **Executive Function.** Each child completed a *Visual Search* task (*Apples Task*; Breckenridge,
30 2008) to measure selective attention (T1, T2), a computerised *Auditory Continuous Performance Test*
31 (*ACPT*) (e.g. Kerns & Rondeau, 1998; Mahone, Pillion & Hiemenz, 2001) to assess sustained attention
32 (T2), the *Dog-Bird Go/No-Go task* (a version of the Bear-Dragon Go/No-Go task; Reed, Pien &
33 Rothbart, 1984) (T1) and the *Head Toes Knees and Shoulders (HTKS) task* (Burrage et al., 2008) (T1,
34 T2) to assess behavioural inhibition/self-regulation plus *Block Recall* from the *Working Memory Test*
35 *Battery for Children* (Pickering & Gathercole, 2001) to measure visuo-spatial memory (T2).
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44 At T2 parents completed the *Strengths and Weaknesses of ADHD-symptoms and Normal-*
45 *behaviour Questionnaire (SWAN)* (Swanson et al., 2006), a dimensional scale that captures variations
46 in ADHD symptoms related to strengths as well as weaknesses in attention/behaviour (Polderman et
47 al., 2007).
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52 **Early literacy.** Early literacy skills were also assessed at T2 with the letter sound knowledge and early
53 word reading tasks from the *York Assessment of Reading for Comprehension (YARC)* (Hulme et al.,
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2009) and a letter writing task (children had to write 10 letters). Data from the four groups on the measures of early literacy are presented in Appendix 1.

Data analysis

We had multiple measures of language, early literacy, motor skills and executive function so conducted confirmatory factor analysis on measures administered at T1 (Figure 1) and T2 (Figure 2) (analyses were conducted Stata 12.0 using the MLMV estimator to deal with missing values).

Subsequently, motor and executive function factor scores from these CFAs were analysed in 2x2, family risk (+/-) x language impairment (+/-), ANOVAs. Interactions in these ANOVAs can be taken as evidence for the non-independence of the two factors (family risk and language impairment).

Results

Tables 1 and 2 show means and standard deviations for the four groups on the individual motor skills and executive function measures administered at T1 and T2 together with the motor and executive function factor scores for each group derived from the confirmatory factor analyses presented in Figures 1 and 2. The tables also display results from the ANOVAs along with η_p^2 as a measure of effect size and Games Howell post-hoc comparisons.

Motor Skills

At both T1 and T2 children with language impairment (LI, FRLI) performed more poorly than children without language impairment (TD, FR) on the individual motor tasks and the Motor factor score (note high scores on the raw measures indicate poor performance and hence low factor scores reflect good performance). The significant language impairment x family risk interaction on the T1 and T2 Motor factor scores show that the effect of language impairment was significantly greater for children not at family risk of dyslexia (with post-hoc comparisons revealing TD<FR<LI=FRLI). The correlation between T1 and T2 motor factor scores was strong ($r=.79, p<0.01$) indicating that this factor has good longitudinal stability.

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3 Parental report data supports our findings from objective measures; children with language
4 impairment were reported to have started walking later than children without language impairment.
5 On the DCDQ children with language impairment were rated as having significantly weaker fine-
6 motor and general co-ordination skills compared to children without language impairment. The
7 only exception to the general pattern was that for rated dynamic motor control; children at family
8 risk showed an advantage compared to those not at family risk of dyslexia, although the effect size is
9 small. The relationship between children's T2 Motor factor score and their total DCDQ rating was
10 moderate ($r=-.50, p<0.01$) indicating that our behavioural measures of fine motor skills are sensitive
11 to individual difference in symptoms of DCD.
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22 Together the data suggest that in the preschool years children with language impairment
23 have persistent weaknesses in their motor skills compared to children without language impairment.
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26 **Executive Functions**

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28 At T1 and T2 children with language impairment (LI, FRLI) performed worse than children
29 without language impairment (TD, FR) on the Executive function factor score (a pattern also seen in
30 all the individual measures of executive function²).
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35 The significant language impairment x family risk interaction on the T2 Executive function
36 factor scores show that the effect of language impairment was significantly greater for children not
37 at family risk of dyslexia (with post-hoc comparisons revealing TD>FR>LI=FRLI). The correlation
38 between T1 and T2 Executive function factor scores (which were defined by slightly different
39 measures) was strong ($r=.69, p<0.01$) indicating that this factor has good longitudinal stability.
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46 Together the data suggest that the children with language impairment have persistent
47 weaknesses across several domains of executive function including selective and sustained
48 attention, complex behavioural inhibition and visuo-spatial STM compared to children without
49 language impairment.
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54 T2 parental report data confirm the pattern of performance on objective measures of
55 attention and behaviour control; children with language impairment were rated as having worse
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behaviour and attention skills than children without language impairment on the SWAN inattention and hyperactivity scales. The relationship between children's T2 Executive function factor score and their overall SWAN rating was moderate ($r=.44, p<0.01$) indicating that our behavioural measures of executive function are sensitive to individual difference in symptoms of ADHD.

Individual differences in motor skills and executive function; relationships with language ability.

The data presented so far demonstrate that in the early years the difficulties experienced by children with language impairment are not limited to the verbal domain but are also manifest on measures of motor skills and executive functions.

Figures 3 a and c show a moderate relationship between children's T1 and T2 motor skills and T1 language abilities ($r = -.69, p < .001$ and $r = -.60, p < .001$ respectively; $r = -.66, p < .001$ and $r = -.54, p < .001$ with age controlled). Figures 3 b and d also show that there is very strong relationship between children's executive function skills and their language ability at T1 ($r = .96, p < .001$; $r = .95, p < .001$ with age controlled) but that this relationship weakens by T2 ($r = .63, p < .001$; $r = .61, p < .001$ with age controlled).

There was also a strong relationship between children's motor and executive function skills at T1 ($r = -.70, p < .001$; $r = -.69, p < .001$ with age controlled) and T2 ($r = -.95, p < .001$; $r = -.95, p < .001$ with age controlled).

Predicting outcomes of children at family risk of dyslexia.

Evidence suggests that individual variations in language skills predict which children at family risk of dyslexia will go onto develop reading difficulties (Snowling et al., 2003; Torppa, Lyytinen, Erskine, Eklund, & Lyytinen, 2010) however it also seems possible that variations in executive or motor skills will also predict variations in reading outcomes for these children. Our CFA (see Figure 1) showed that there were three separable factors assessed at time 1 (Language, Motor, Executive function) but that the Language and Executive function factors were highly correlated ($r = .86$). A hierarchical regression model with age, and language skills as predictors showed that they accounted for 31% of the variance in literacy skills, and that motor skills then accounted for a further

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3 4% variance (see Table 3). Due to the colinearity between the T1 Language and Executive function
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5 factors, executive functions were not a separable predictor after language skills were controlled (1%
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7 variance accounted for).
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10 11 **Discussion**

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13 The comorbidity between language learning disorders (e.g. dyslexia and language
14
15 impairment) and disorders that are characterised by symptoms beyond the domain of language (e.g.
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17 DCD and ADHD) is frequently reported. Despite this relatively little is known about the overlap
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19 between these disorders in the preschool years. Understanding the overlap between developmental
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21 disorders is important for theory and practice and here we report novel findings from a study that
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23 investigated comorbidity in children at family risk of dyslexia before they started school.
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27 Our findings clearly show that between the ages of 3 and 5 years, weaknesses in motor skills
28
29 and executive functions are associated with preschool language impairment irrespective of the
30
31 child's family risk status. In this study, children with language impairment demonstrated significant
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33 weaknesses in motor skills and executive functions/attention, as assessed by both objective
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35 measures and parental report, compared to children without language impairment. Furthermore,
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37 these weaknesses were present at both T1 and T2 suggesting that they are persistent through the
38
39 pre-school period. Together these findings question the 'specific' nature of language impairment
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41 and suggest that many children with preschool language difficulties are likely to experience
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43 difficulties in other domains. Furthermore, our findings mirror the frequent comorbidity between
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45 language disorders, ADHD and DCD observed in school aged children (e.g., Kadesjö & Gillberg, 1999;
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47 Willcutt & Pennington, 2000).
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51 Children at family risk of dyslexia who do not have language impairment perform better than
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53 those with language impairment (LI and FRLI) on objective measures of motor skills and executive
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55 function. This group however still has weaknesses on these objective measures compared to TD
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57 children although they are not reflected in parental ratings of motor skills and behaviour/attention.
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3 A key question therefore is whether the comorbidity between dyslexia, ADHD and DCD is only
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5 apparent (or more apparent) in individuals who have a history of language impairment. The
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7 corollary of this would be that individuals with dyslexia who do not have a history of significant
8
9 language difficulties are less likely to have comorbidities. The current study is longitudinal and will
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11 allow a test of this hypothesis once the children reach the age when a reading disorder can be
12
13 diagnosed.
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16 Given the prevalence of motor and executive function weaknesses in children with language
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18 impairment and the correlations between individual difference in language, motor skills and
19
20 executive functions that were observed, the data lend support to the view that the factors which
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22 place an individual at risk for language difficulties also influence the development of attention,
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24 behavioural control and motor skills (e.g. Bishop 2002). Furthermore, although we do not yet know
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26 which of the children at family risk of dyslexia will go on to have reading difficulties the results from
27
28 our regression analysis provide some preliminary support for the idea that multiple risk factors (T1
29
30 language skills and to a lesser but never-the-less significant extent T1 motor skills) play a role in
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32 predicting children's early literacy outcomes and thus are important in determining which children
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34 are most at risk of later literacy difficulties.
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38 Another key finding is the very strong relationship between children's language skills and
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40 executive function in the preschool years. This is particularly important to bear in mind given
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42 research which has shown that executive functions, and behavioural control in particular, are
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44 important for school readiness (Blair, 2002) and later classroom learning (Blair & Razza, 2007; see
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46 Liew, 2012 for a review). Our finding raises the question of whether the proposed role of executive
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48 function in studies of school readiness and classroom learning can be separated from the role that
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50 individual differences in language skills may play. A future aim of our project is to investigate the
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52 role that executive functions play in children's academic outcomes; in particular we are interested in
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54 how these skills impact on children's literacy development (e.g. the development of reading fluency,
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56 reading comprehension and spelling), once formal instruction commences. Indeed our current
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3 findings suggest that language may play a crucial role in mediating the relationship between
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5 executive function and literacy development. The longitudinal design of this study will allow us to
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7 consider whether the pattern of comorbidity between disorders changes over time and/or as a
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9 function of individual children's developmental trajectories and whether children with additional
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11 cognitive deficits beyond the language domain are more at risk of developing reading difficulties and
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13 thus more in need of early intervention.
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19
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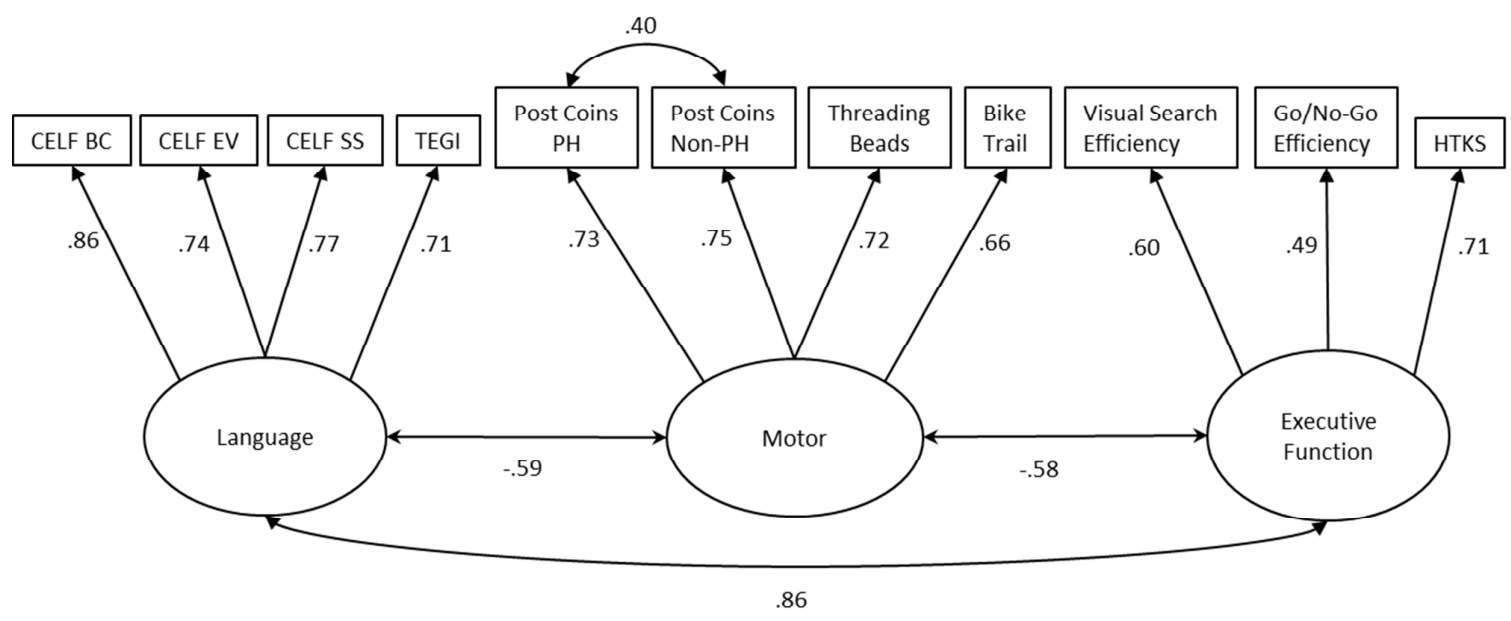
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Key points

- There is considerable comorbidity between developmental disorders such as Dyslexia, language impairment (LI), Attention Deficit/Hyperactivity Disorder (ADHD) and Developmental Coordination Disorder (DCD).
- We investigated comorbid weaknesses in preschool children at family risk of reading difficulties, with and without LI, using measures of executive function and motor skills as markers of ADHD and DCD.
- Children with LI had comorbid weaknesses in executive function and motor skills compared to those without LI; Parents also rated these children as having more symptoms of ADHD (inattention and hyperactivity) and DCD (fine and gross motor coordination).
- Children at family risk of dyslexia without LI performed better on measures of executive function and motor skills than those with LI (LI and FRLI) but worse than TD controls.
- Children's language and executive function skills are strongly related in the preschool years and individual differences in language skills and motor skills both predict unique variance in children's early literacy skills.
- Future work should aim to investigate how comorbidity effects the manifestation of reading difficulties and how they impact on children's broader academic attainment and social/emotional development.

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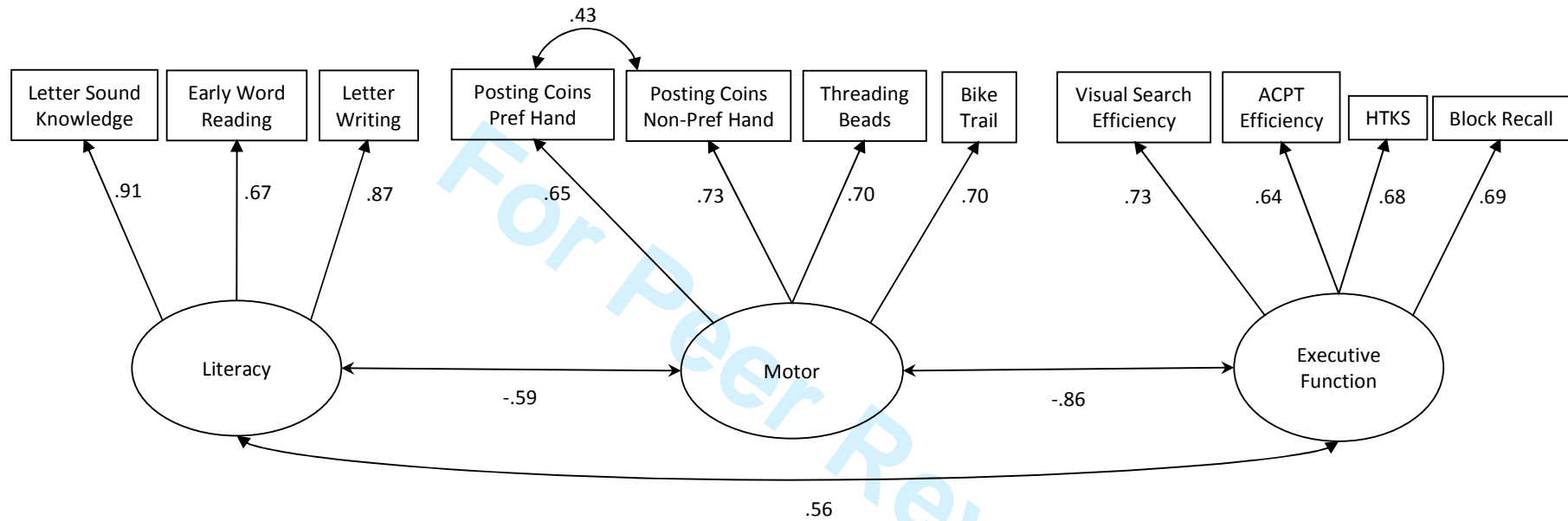
Figure 1 Confirmatory factor analysis of the T1 language, motor and executive function variables.



Chi²(40) = 59.891, p = 0.022; RMSEA = 0.048; CFI = 0.974; TLI = 0.964

view

Figure 2 Confirmatory Factor Analysis of T2 literacy, motor and executive function variables.



$\chi^2(40) = 70.881, p = 0.002; RMSEA = 0.060; CFI = 0.969; TLI = 0.957$

Table 1 Means and standard deviations for the four groups on the T1 and T2 motor skills measures. Main effects and interactions from the 2x2 ANOVA are also displayed.

Measures	TD			FR			LI			FRLI			Main effect				Interaction	
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	FR		LI		FR x LI	
													F	η_p^2	F	η_p^2	F	η_p^2
<i>T1 Tasks</i>																		
Posting Coins pref (sec)	69	27.77 _a	5.24	83	30.86 _b	8.46	31	46.26 _c	29.83	29	34.48 _{bc}	10.56	4.48*	0.02	29.05**	0.12	13.12**	0.06
Posting Coins non-pref (sec)	69	32.23 _a	8.04	81	35.23 _{ab}	9.37	24	47.75 _c	19.65	29	39.45 _{bc}	12.47	2.2	0.01	30.52**	0.13	10.02**	0.05
Threading Beads (sec)	69	55.84 _a	17.98	81	63.41 _{ab}	32.96	28	84.21 _b	44.19	27	68.56 _{ab}	28.32	0.72	0.00	12.43**	0.06	5.97*	0.03
Bicycle Trail errors	66	7.68 _a	3.99	81	8.91 _{ab}	3.94	29	12.17 _c	5.84	27	11.15 _{bc}	5.35	0.02	0.00	22.85**	0.10	2.57	0.01
T1 Motor factor score	69	-0.45 _a	0.43	83	-0.14 _b	0.71	32	0.98 _c	1.32	29	0.38 _c	0.67	1.53	0.01	71.20**	0.25	15.36**	0.07
<i>T2 Tasks</i>																		
Posting Coins pref (sec)	69	23.14 _a	3.60	83	24.51 _a	8.69	31	30.59 _b	10.52	28	26.29 _{ab}	6.19	1.67	0.01	16.41**	0.07	6.19*	0.03
Posting Coins non-pref (sec)	69	26.70 _a	4.97	83	27.72 _{ab}	7.08	31	35.61 _b	16.36	29	29.86 _{ab}	6.85	3.29	0.02	18.00**	0.08	6.77*	0.03
Threading Beads (sec)	68	36.13 _a	10.02	83	41.49 _{ab}	24.31	31	54.35 _b	24.35	29	42.83 _{ab}	16.59	1.04	0.01	10.49**	0.05	7.83**	0.04
Bicycle Trail errors	69	3.72 _a	3.31	83	5.05 _{ab}	4.52	30	7.13 _b	4.88	29	6.28 _b	3.83	0.14	0.00	13.40**	0.06	2.97	0.01
T2 Motor factor score	69	-0.41 _a	0.45	83	-0.09 _b	0.91	32	0.81 _c	1.20	29	0.35 _c	0.70	0.29	0.00	44.51**	0.18	9.71**	0.04
Age of walking (mnths)	69	13.45 _{ab}	2.37	81	12.56 _a	2.33	32	14.58 _b	3.24	29	13.41 _{ab}	3.38	6.43*	0.03	6.00*	0.03	0.12	0.00
<i>T2 DCDQ</i>																		
Dynamic Motor Control (/30)	62	21.87 _a	4.33	76	22.34 _a	4.17	28	19.25 _a	6.02	24	22.29 _a	4.93	5.40*	0.03	3.12	0.02	2.89	0.02
Fine Motor (/20)	60	15.55 _a	3.60	76	14.95 _a	3.67	28	11.18 _b	5.05	25	13.44 _{ab}	4.01	1.69	0.01	21.28**	0.10	5.05*	0.03
General Co-ordination (/25)	62	20.06 _a	3.81	77	19.58 _{ab}	3.91	29	17.14 _b	4.70	25	17.80 _{ab}	4.85	0.02	0.00	12.53**	0.06	0.74	0.00
Total (/75)	60	57.50 _a	9.33	75	57.04 _a	9.05	27	47.59 _b	14.16	24	53.08 _{ab}	11.34	2.19	0.01	16.62**	0.08	3.06	0.02

Note: *p<.05; **p<.01; means with different subscripts are significantly different (Games Howell post-hoc comparison). Family risk only (FR), language impaired only (LI), family risk and language impaired (FRLI) and typically developing (TD). High Motor factor scores reflect poor performance.

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Table 2 Means and standard deviations for the four groups on the T1 and T2 executive function measures and SWAN Questionnaire ratings. Main effects and interactions from the 2x2 ANOVA are also displayed.

Measures	TD			FR			LI			FRLI			Main effect				Interaction	
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	FR		LI		FR x LI	
													F	η_p^2	F	η_p^2	F	η_p^2
<i>T1 Tasks</i>																		
Visual Search efficiency score	68	0.13 _a	0.06	83	0.11 _a	0.06	25	0.05 _b	0.08	27	0.07 _b	0.07	0.02	0.00	33.44**	0.14	2.18	0.01
Go/No-Go efficiency score	63	0.81 _a	0.22	69	0.75 _a	0.23	13	0.75 _a	0.25	17	0.65 _a	0.22	2.54	0.02	3.04	0.02	0.2	0.00
HTKS (/40)	60	13.17 _a	12.22	67	8.63 _{ab}	10.28	17	1.35 _c	3.06	13	4.23 _{bc}	5.07	0.16	0.00	14.80**	0.09	3.10	0.02
T1 Executive Function factor score	69	0.58 _a	0.62	83	0.23 _b	0.60	32	-1.08 _c	0.65	29	-0.85 _c	0.54	0.45	0.00	219.60**	0.51	9.47	0.04
<i>T2 Tasks</i>																		
Visual Search efficiency score	69	0.18 _a	0.05	82	0.16 _{ab}	0.06	29	0.11 _c	0.07	28	0.13 _{bc}	0.07	0.20	0.00	31.17**	0.13	4.95*	0.02
ACPT efficiency score	66	0.17 _a	0.06	80	0.14 _b	0.10	27	0.10 _{abc}	0.15	25	0.05 _c	0.14	7.59**	0.04	25.89**	0.12	0.25	0.00
HTKS (/40)	68	25.76 _a	9.93	79	21.90 _a	11.59	28	9.68 _b	11.67	27	9.70 _b	8.26	1.29	0.01	70.17**	0.26	1.22	0.01
Block Recall (/ 54)	69	16.86 _a	3.36	82	15.51 _{ab}	4.30	26	14.23 _b	4.02	27	14.30 _b	3.75	1.05	0.01	9.51**	0.05	1.28	0.01
T2 Executive Function factor score	69	0.47 _a	0.51	83	0.11 _b	0.90	32	-0.81 _c	1.04	29	-0.52 _c	0.72	0.08	0.00	62.38**	0.23	7.30**	0.03
<i>T2 SWAN Questionnaire</i>																		
Inattention (/63)	63	42.19 _a	6.49	76	40.36 _a	6.81	29	33.76 _b	10.1	25	35.32 _b	4.98	0.01	0.00	34.68**	0.16	2.21	0.01
Hyperactivity (/63)	63	39.71 _a	6.87	77	40.05 _a	7.45	28	35.39 _{ab}	10.2	25	34.68 _b	8.20	0.02	0.00	14.72**	0.07	0.17	0.00
Total (/126)	63	81.90 _a	12.17	76	80.41 _a	13.08	28	69.11 _b	19.5	25	70.00 _b	12.36	0.02	0.00	26.87**	0.13	0.29	0.00

Note: * $p < .05$; ** $p < .01$; means with different subscripts are significantly different (Games Howell post-hoc comparisons). Family risk only (FR), language impaired only (LI), family risk and language impaired (FRLI) and typically developing (TD).

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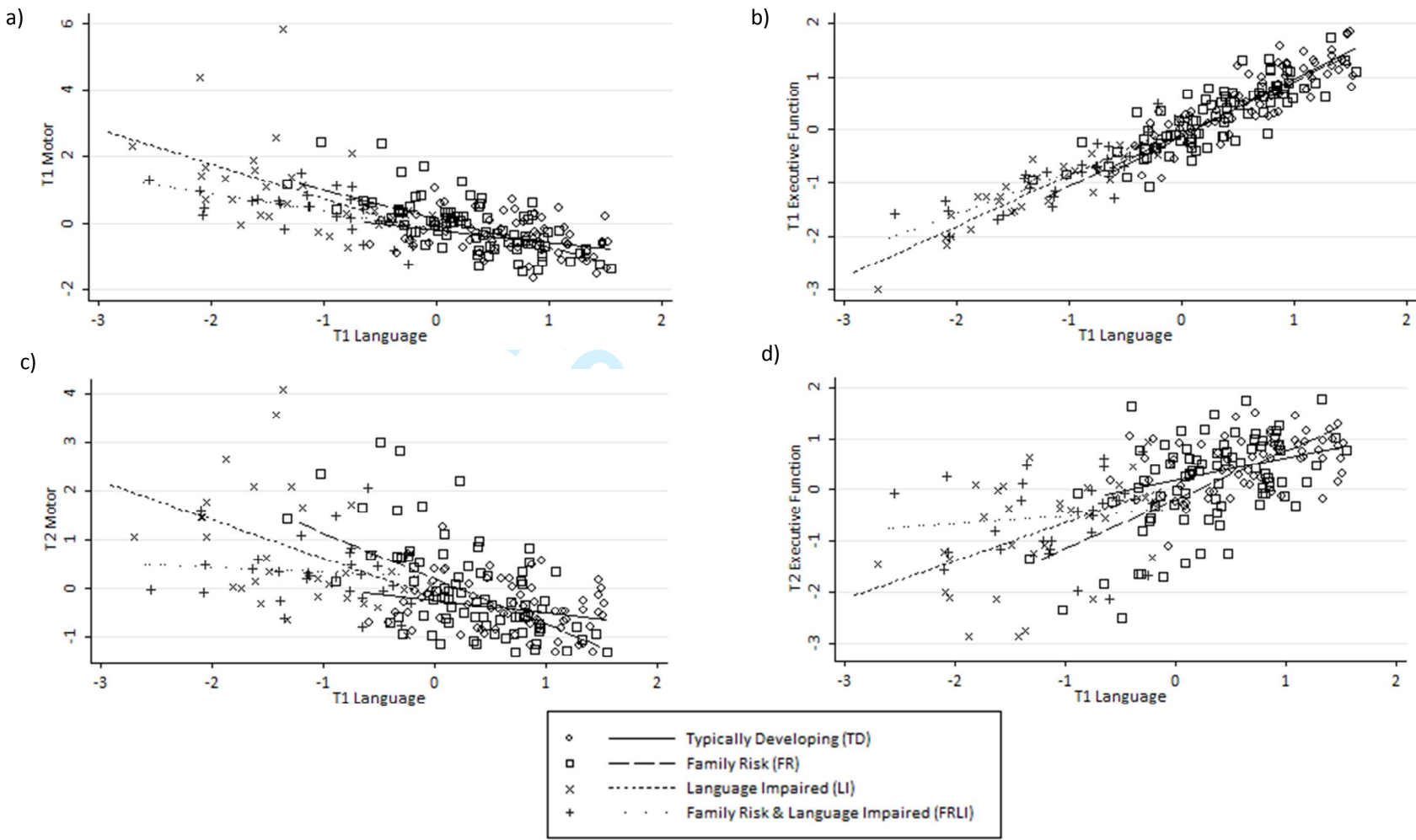


Figure 3 Scatter plots illustrating the relationships between T1 Language and T1 Motor (a), T1 Executive Function (b), T2 Motor (c) and T2 Executive Function (d) factor scores.

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Table 3 Stepwise regression analysis predicting T2 literacy attainment from individual differences in language and motor skills at T1.

Step	Variable	β	t	Unique R^2
1	Age	0.07	4.12**	0.15
2	Language	0.23	2.97**	0.16
3	Motor	-0.31	-3.75**	0.04

Note: ** = $p < .01$

For Peer Review

Footnotes

¹ Given the age and low ability of some of the children there were insufficient data from the diagnostic tests to determine language impairment status for 22 cases. For these cases information from the separate TEGI screener subtests and the Preschool Repetition test (Seeff-Gabriel, Chiat & Roy, 2008) at T1 and CELF sentence structure test at T2 was used to come to a clinical judgement about group membership. Seventeen of the 22 cases were considered language impaired.

² It is important to note that there was a reasonable amount of data missing for the more complex behavioural inhibition tasks (Go/No-Go and HTKS) particularly in the two groups with language impairment at T1 and thus the means reported here are likely to be an overestimation of the actual ability of these groups.

Appendix 1 Descriptive characteristics of the TD, FR, LI and FRLI groups including their performance on the diagnostic language tests (T1) and early literacy measures (T2).

	TD			FR			LI			FRLI			F	p	Group differences
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD			
T1 Age (months)	69	44.59	3.12	83	45.17	3.47	32	43.56	2.09	29	45.07	3.24	2.15	ns	n/a
T2 Age (months)	69	55.46	3.21	83	56.64	3.85	32	55.19	2.58	29	56.76	3.52	2.56	ns	n/a
Gender (% males)	69	49		83	58		32	69		29	72		χ^2 6.74	ns	
SES (% rank - postcode)	69	71.97	27.46	83	62.19	26.67	32	52.62	30.18	29	50.84	30.50	5.57	0.00	TD > LI & FRLI
NVIQ	69	115.61	13.93	82	107.90	14.84	29	96.07	13.10	29	101.03	10.15	16.82	0.00	TD > FR > (LI = FRLI)
<i>Diagnostic language tasks</i>															
CELF Basic Concepts (SS)	69	12.09	2.08	83	10.96	2.38	29	6.90	2.16	29	6.59	2.29	65.55	0.00	TD > FR > (LI = FRLI)
CELF Expressive Vocab (SS)	69	12.03	2.18	83	11.05	2.00	28	7.32	3.31	28	7.11	2.74	46.55	0.00	TD > FR > (LI = FRLI)
CELF Sentence Structure (SS)	69	11.14	2.49	83	10.42	1.94	30	6.27	2.03	27	6.78	2.62	51.16	0.00	(TD = FR) > (LI = FRLI)
TEGI Screen(% failed)	63	14		81	33		18	79		21	77		χ^2 44.18	0.00	
T1 Language factor score	69	0.58	0.62	83	0.23	0.60	32	-1.08	0.65	29	-0.85	0.54	120.50	0.00	TD > FR > (LI = FRLI)
<i>Early literacy tasks</i>															
YARC Letter Sound Knowledge /32	69	19.55	9.44	83	16.82	9.71	30	11.77	9.97	29	11.83	10.41	6.82	0.00	TD > (LI = FRLI)
YARC Early Word Reading /30	69	5.09	7.12	83	3.00	4.88	30	.77	1.61	29	1.72	5.66	5.31	0.00	(TD = FR) > LI
Letter Writing /10	69	4.59	3.03	83	3.96	3.06	30	1.97	2.46	29	2.31	2.82	7.98	0.00	(TD = FR) > (LI = FRLI)
T2 Literacy factor score	69	0.36	0.87	83	0.08	0.93	32	-0.57	0.82	29	-0.44	0.91	10.54	0.00	(TD = FR) > LI; TD > FRLI

Note: SES % rank is based on postcode; all lower super output areas (32482) in UK are ranked according to deprivation value. This % value reflects relative rank (ranked value / 32482 = relative rank); lower = more deprived (Source: Department of Communities and Local Government, Indices of Multiple Deprivation, 2007). Nonverbal IQ (NVIQ) is the average standard score of the Block Design and Object Assembly subtests from the *Wechsler Preschool and Primary Scale of Intelligence – Third Edition (WPPSI-III)*; Wechsler, 2003). SS = Scaled scores (mean 10; SD 3). The T1 Language and T2 Literacy factor scores were derived from the CFA shown in Figures 1 and 2 in the main paper.

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3 Appendix 2 Tests and Procedures
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5 Nonverbal IQ
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7 Each child completed Wechsler Preschool and Primary Scale of Intelligence Block
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9 Design and Object Assembly subtests (WPPSI-III; Wechsler, 2003) according to the test manual.
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11 These standard score were averaged to form the nonverbal IQ (NVIQ) score. The majority of children
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13 obtained average NVIQ standard scores within the normal range (i.e. >80), however, 1 TD, 2 FR, 5 LI
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15 and 1 FRLI children obtained average standard scores below 80 (all children scored > 70 on at least
16
17 one of the two NVIQ tests); in addition 1 FR and 3 LI children were unable to complete the tests.
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19 These data show that the majority of children with LI met criteria for SLI. All children who met LI
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21 criteria, regardless of NVIQ, were included because research suggests that children in the lower
22
23 range of NVIQ show the same overall profile of Language Impairment as children in the range of 85
24
25 and above (Tomblin & Zhang, 1999). Furthermore, proposed revisions to DSM-V do not include
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27 NVIQ as part of the selection criteria for language impairment.
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30
31 Although controlling for NVIQ using techniques such as ANCOVA is common in the SLI
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33 literature recent research suggests that this may be inappropriate and Dennis, Francis, Cirino,
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35 Schachar, Barnes and Fletcher (2009) outline several reasons why NVIQ should not be used as a co-
36
37 variate in studies of neurodevelopmental disorders. Indeed Conti-Ramsden, St Clair, Pickles and
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39 Durkin (2012) found that children with the most severe LI had lower NVIQs than those with less
40
41 severe LI. Thus, 'controlling' for group differences in NVOIQ would at the same time 'control' for the
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43 variable of interest, language impairment.
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47 Motor skills
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49 Children completed 3 subtests from the *Movement Assessment Battery for Children-2*
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51 (Henderson, Sugden, & Barnett, 2007):
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3 *Posting Coins (T1 and T2)*. The child posted 12 coins into a money box as quickly as possible
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5 and the time taken with each hand was recorded. This task had good stability between T1 and T2 (r
6
7 = .69 and .70 for preferred and non-preferred hands respectively).
8

9 *Bead Threading (T1 and T2)*. The child threaded 6 beads onto a piece of string as quickly as
10
11 possible and the time taken was recorded. This task had good stability between T1 and T2 ($r = .67$).
12

13 *Bicycle Trails (T1 and T2)*. The child used their preferred hand to draw a single continuous
14
15 line following a trail without crossing its boundaries and the number of errors was recorded. This
16
17 task had moderate stability between T1 and T2 ($r = .47$)
18

19 *Developmental Coordination Questionnaire 2007 (DCDQ'07; Wilson et al. 2009) (T2)*. This
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21 questionnaire consists of 15 items tapping three distinct factors. The first factor "Control during
22
23 Movement" contains items related to dynamic motor control (max score = 30). The second factor is
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25 "Fine Motor and Handwriting" (max score = 20) and the third factor relates to "General
26
27 Coordination" (max score = 25). For each item parents were asked to compare their child's motor
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29 performance to that of his/her peers using a 5 point Likert scale (Not at all like your child = 1, A bit
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31 like your child = 2, Moderately like your child = 3, Quite a bit like your child = 4, Extremely like your
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33 child = 5). The maximum total DCDQ score is 75; a high score reflects strengths in motor skills.
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40 Executive Function

41 Each child completed tasks to measure attention, behavioural inhibition and memory.
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43 *Visual Search (T1 and T2)*. A visual search task (the *Apples Task*; Breckenridge, 2008), which
44
45 comprised an array of targets (18 red apples) and distracters (81 red strawberries and 81 white
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47 apples), was used to assess selective attention. The child was given 1 minute to search the array and
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49 point to targets whilst ignoring distracters. The number of targets identified and the number of
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51 commission errors made (pointing to a distracter; false alarms) were recorded. A visual search
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53 efficiency score ((Hits: total targets correctly identified – commission errors)/60 seconds) was
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3 calculated; this score was used in T1 and T2 the confirmatory factor analyses: a high score reflects
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5 better selective attention. This measure had moderate stability between T1 and T2 ($r = .53$).
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7 *Auditory Continuous Performance Test (ACPT) (T2)*. An ACPT similar to those developed by
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9 Kerns and Rondeau (1998) and Mahone, Pillion and Hiemenz (2001) was used to assess selective
10
11 attention. The task was designed to not be attention grabbing and thus challenge children's ability
12
13 to sustain their attention. Children saw an image of a farm and heard four different animal sounds
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15 (3 distracters (cow, duck and frog) and 1 target (dog)). The children were asked to press a response
16
17 button when the dog barked. Each auditory stimulus was presented 30 times in a pseudorandom
18
19 order. Each stimulus lasted 2500ms with ITIs of 1750ms. Reaction times as well as omission and
20
21 commission errors were recorded. An ACPT efficiency score ((Hits: total targets correctly identified –
22
23 commission errors)/120 trials) was calculated; this score was used in the T2 confirmatory factor
24
25 analysis and a high score reflects better selective attention.
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28 *Dog-Bird Go/No-Go task (T1)*. This is a version of the Bear-Dragon Go/No-Go task (Reed,
29
30 Pien & Rothbart, 1984) and was used to measure behavioural inhibition. Children had to inhibit their
31
32 natural inclination to follow verbal instructions for motor/hand actions ('thumbs up', 'make a fist',
33
34 'point' or 'wave') given by two puppets (a dog and a bird). The child was instructed to do what the
35
36 dog said but to ignore the bird (i.e. inhibit their action). The number of times that the child correctly
37
38 responded to instructions given by the dog (max 8) or incorrectly followed instructions given by the
39
40 bird (commission errors; max 8) were recorded. A GoNoGo efficiency score (Hits: number of
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42 responses to the dog/total number of responses (responses to dog + bird)) was calculated; this score
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44 was used in the confirmatory factor analysis at T1 and a high score reflects better behavioural
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46 inhibition.
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49 *Head Toes Knees and Shoulders (HTKS) task* (Burrage et al., 2008) (*T1 and T2*). In this
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51 measure of behavioural inhibition the child was first asked to touch their head and then their toes.
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53 Once it had been established that they could perform this action they were instructed to do the
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55 opposite of what the examiner said (e.g. touch their toes if asked to touch their head and vice versa).
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3 The child had four opportunities to practice this, with up to 3 re-explanations of the directions. They
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5 then completed a block of 10 test trials with no feedback. If the child was able to successfully inhibit
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7 on 5/10 trials they went on to complete a further block of harder trials. For these trials, additional
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9 commands to touch their shoulders and knees were added and the child was reminded to do the
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11 opposite of what the examiner said (e.g. touch their shoulders if asked to touch their knees and vice
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13 versa). After four practice trials the child completed 10 further test trials involving all four
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15 commands in a predetermined, pseudorandom order. Each correct response received 2 points, self-
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17 corrected responses (partial inhibitions; where the child moved towards the incorrect, intuitive
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19 response but demonstrated the correct final response) received 1 point and incorrect responses
20
21 received 0 points (max score = 40). This task had moderate stability between T1 and T2 ($r = .51$).
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23

24 *Block Recall (Working Memory Test Battery for Children, Pickering & Gathercole, 2001) (T2).*

25
26 This task was used to measure visuo-spatial memory. The child saw the examiner tap a sequence of
27
28 blocks on a board and then recalled the sequence by tapping the blocks in the same order. The
29
30 number of correct trials was recorded (max 52).
31
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33 *Strengths and Weaknesses of ADHD-symptoms and Normal-behaviour Questionnaire (SWAN;*
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35 *Swanson et al., 2006) (T2).* The items on the SWAN constitute the 18 DSM-IV symptoms of ADHD
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37 and include 9 items tapping Inattention and 9 items tapping Hyperactivity/Impulsivity. For each item
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39 parents were asked to compare their child's attention/behavioural skills to those of his/her peers
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41 using a 7 point Likert scale (Far Below Average = 1, Below Average = 2, Somewhat Below Average =
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43 3, Average = 4, Somewhat Above Average = 5, Above Average = 6, and Far Above Average = 7). The
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45 maximum score on the SWAN is 126 (63 for each of the subscale: Inattention and
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47 Hyperactivity/Impulsivity). A low score reflects weaknesses in attention/behavioural skills.
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