LITERATURE REVIEW: Relationship between mathematics performance, working memory, short-term memory and attention in typically developing children – a systematic review

EMPIRICAL PAPER: Working memory, short-term memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention

Submitted by Emma Matthews, to the University of Exeter as a thesis for the degree of Doctor of Clinical Psychology, May 2015

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: …………………………………………………………………………………
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SCHOOL OF PSYCHOLOGY
DOCTORATE IN CLINICAL PSYCHOLOGY

LITERATURE REVIEW

Relationship between mathematics performance, working memory, short-term memory and attention in typically developing children – a systematic review

Trainee Name: Emma Matthews

Primary Research Supervisor: Dr Anna Adlam
Senior Lecturer/Clinical Psychologist, Psychology, University of Exeter

Secondary Research Supervisor: Dr Phil Yates
Academic/Research Tutor, DClinPsy Programme, University of Exeter and Consultant Clinical Psychologist, Devon Partnership Trust

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Submitted in partial fulfilment of requirements for the Doctorate Degree in Clinical Psychology, University of Exeter
Abstract

Background: Domain-general processes, such as working memory (WM), short-term memory (STM), and attention, have been found to be related to mathematical performance in children. The relationship between these abilities, however, is not well understood.

Objective: This systematic review aimed to evaluate the literature investigating the relationship between mathematical performance and WM, STM, and attention in typically developing primary school aged children.

Methods: Three databases were searched for studies published between January 1974 and February 2015 reporting associations between mathematics performance and at least one measure of WM, STM, and attention. Study selection was undertaken by applying inclusion and exclusion criteria and 43 studies were selected for inclusion. The methodological quality of the included studies was assessed using a validated checklist.

Results: WM, STM, and attention were all significantly related to mathematics performance. Visuospatial STM and WM were strongly related to mathematics performance in younger children, while verbal STM and WM were more strongly related in older children; although some studies found the opposite pattern. The relationship between attention and mathematics performance increased in strength with age.

Conclusions: There are many factors relevant to the relationship between mathematical performance and WM, STM, and attention which can affect the strength of the association, including the types of tasks used to measure the constructs, the confounding variables considered, and the age of the participants.
Future research needs to focus on the construction of an integrated model of mathematical development.
Introduction

Mathematical skills at school entry are more important predictors of later academic achievement than early language or reading skills (Claessens & Engel, 2013; Duncan et al., 2007). Despite this, approximately 6% of children leave primary school in the UK with mathematics skills equivalent to those of a 7- to 8-year-old (Duckworth, 2007). Gaining an understanding of the cognitive underpinnings of mathematical ability is important for identifying children at risk of developing difficulties with mathematics and for informing intervention (Raghubar, Barnes, & Hecht, 2010). Primary school is an appropriate time for mathematical intervention as this is when the foundational concepts are being taught (Claessens & Engel, 2013).

Mathematical performance in children is comprised of a variety of interacting factors (Dowker, 2005). These can be divided into domain-specific abilities, i.e. precursors of mathematics, such as representations of numerical magnitude, learning arithmetical facts, and quantity comparison (Butterworth, 2005; Cantlon, 2012; Geary, 2011b), and domain-general abilities, which constrain all learning, such as intellectual functioning (IQ), working memory (WM), processing speed, and attention (Cowan, 2008; Dowker, 2005; Gathercole, Pickering, Knight, & Stegmann, 2004; Geary, 2011b; Steele, Karmiloff-Smith, Cornish, & Scerif, 2012). Demographic variables, such as socioeconomic status (SES), are also important (Cowan, 2008). With regard to mathematics performance, WM has been the most extensively investigated domain-general ability.

The dominant model of WM is Baddeley and Hitch’s (1994) multi-component model. This proposes that WM is composed of three modular systems: a phonological loop (PL) which stores verbal information, a visuospatial sketchpad (VSSP) which stores visual information, and a central executive (CE; Baddeley,
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2000) which combines information from the PL and VSSP with external stimuli to enable task completion (Baddeley, 2002). For the purpose of this review, WM refers to the CE, and short-term memory (STM) refers to the PL and VSSP.

Findings have been mixed from studies investigating the relationship between WM and/or STM and mathematics in children (Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Pina, Fuentes, Castillo, & Diamatopoulou, 2014). This may be due to the multi-faceted nature of these abilities and the types of tasks used to measure them (Pina et al., 2014; Stipek & Valentino, 2014). WM is usually measured by complex span tasks that require the individual to manipulate information before remembering it, for example, repeating a series of numbers in reverse order (Friso-van den Bos et al., 2013). The STM systems are commonly measured using simple span tasks where strings of information of increasing length must be remembered (Friso-van den Bos et al., 2013). The association between WM, STM, and mathematics can also vary depending on other variables included in the analysis, such as IQ and SES (Cowan, 2008).

The role of attention on mathematical performance has been studied less widely than WM and STM. Significant associations between attentional processes and mathematical achievement have been found in typically developing children (Duncan et al., 2007) and children with specific attentional difficulties (Alloway, Elliott, & Place, 2010; Zentall, 2007). Attention is a multi-faceted construct (Steele et al., 2012). Components which have been found to be relevant in children include sustained attention, selective attention, attention shifting, attentional control, and divided attention (Scerif, 2010; Steele et al., 2012). There is some debate about the interrelation between attention and WM processes. The multi-component model has traditionally included attentional control in the CE component of WM (e.g., Baddeley,
2002; St Clair-Thompson, & Gathercole, 2006), while other models suggest that WM guides attention to memory and is thus an attention rather than a memory system (e.g., Engle & Kane, 2004, Oberauer, Süß, Wilhelm, & Sander, 2007).

This review aims to answer the question: are WM (defined as the CE from the multi-component model; Baddeley, 2002), STM, and attention associated with mathematics performance in typically developing primary school aged children?

**Method**

Relevant research papers were identified by searching electronic databases and examining the reference lists of selected articles. Three databases, PsychInfo, PsychArticles, and MEDLINE were searched from January 1974 to February 2015. 1974 was selected as the earliest date to correspond with the publication of Baddeley and Hitch’s (1974) WM model. The search terms were: working memory, short-term memory, phonological loop, visuospatial sketchpad, central executive, attention, mathematics, arithmetic, numeracy, child, and school-age (see Appendix 1 for search strategy of one database).
Figure 1. Flow-diagram of study selection process based on the guidelines for preferred reporting items for systematic reviews and meta-analyses (PRISMA: Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009).
Figure 1 outlines the study selection process. Citations and abstracts were screened using the inclusion and exclusion criteria in Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
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<tbody>
<tr>
<td>Typically developing children</td>
<td>Children with neurological and learning difficulties</td>
</tr>
<tr>
<td>Children aged between 4 and 11 years</td>
<td>Mean age of any of the children in the sample younger than 4 years or older than 11 years, 11 months</td>
</tr>
<tr>
<td>Reported on at least one variable measuring mathematics ability and one or more component of working memory, short-term memory or attention</td>
<td>Children with mathematical difficulties or disabilities</td>
</tr>
<tr>
<td>Reported a statistical test of association between working memory, short-term memory, attention and mathematics performance</td>
<td>Not original research</td>
</tr>
<tr>
<td>Written in English</td>
<td>Intervention studies</td>
</tr>
</tbody>
</table>

After eligible studies were selected relevant information was extracted using a data extraction form (see Appendix 2). This form was designed specifically for this review based on the approach of McGowan, Alderdice, Holmes and Johnston (2011). Data extracted included: author and publication date, study design, number and age of participants, explanatory and confounding variables, measures used, statistical analysis, and author conclusions.

The methodological quality of the studies was assessed using the National Institute for Health and Care Excellence (NICE; 2012) quality appraisal checklist for studies reporting correlations and associations (see Appendix 3). This checklist had four sections covering population, selection of variables, outcomes, and analysis. Three questions concerning the selection of a comparison group and the benefits and harms of an intervention were removed as these study design elements were not relevant for any of the studies reviewed. Each checklist item was rated according to how well it had been designed or conducted to reduce bias. These item ratings
were then used to inform the selection of one of three possible overall quality ratings for each study (see Table 2).

<table>
<thead>
<tr>
<th>Rating</th>
<th>Criteria</th>
</tr>
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<tbody>
<tr>
<td>++</td>
<td>All or most of the checklist items have been fulfilled. Where they have not been fulfilled the conclusions are unlikely to alter</td>
</tr>
<tr>
<td>+</td>
<td>Some of the checklist items have been fulfilled, where they have not been fulfilled or not adequately described, the conclusions are unlikely to alter</td>
</tr>
<tr>
<td>-</td>
<td>Few or no checklist items have been fulfilled and the conclusions are likely to alter</td>
</tr>
</tbody>
</table>

Results

The 43 selected studies were separated into four categories: WM and mathematics, STM and mathematics, attention and mathematics, and studies investigating a combination of WM, STM and/or attention and mathematics.

**WM and mathematics**

The five studies investigating the association between WM and mathematics performance are summarised in Table 3. One study received the highest quality rating (++), and four received the “+” quality rating.

Studies which used longitudinal designs followed-up their participants over a period of between 1 and 3 years. Two studies measured verbal WM only (studies 3 and 4), and three studies measured both verbal and visuospatial WM (studies 1, 2 and 5). Three studies did not consider any confounding variables in the statistical analysis (studies 1-3).

Overall, both verbal and visuospatial WM were found to significantly predict mathematical performance. The relationship, however, varied with the age of the participants and type of WM task. In 4- to 5-year-olds both verbal and visuospatial
WM were related to mathematical performance (study 1). For older children (7- to 8-year-olds), however, only verbal WM continued to predict mathematical performance (study 2). Numerical verbal WM tasks were found to be significant predictors of mathematical performance, while tasks using words were not (study 4). The relationship between verbal WM and mathematics was also mediated by previous number knowledge (study 3). It should be noted, however, that only study 2 received the highest quality rating. Caution, therefore, may be needed when interpreting the findings of these studies. In particular, consideration of possible confounds was poor in these studies and the power of each study was not explicitly discussed.
Table 3
Summary of Studies Investigating the Relationship Between Working Memory and Mathematics Performance

<table>
<thead>
<tr>
<th>Authors and study n°</th>
<th>Study design (follow-up period if longitudinal)</th>
<th>Age of participants (mean and range)</th>
<th>Sample size</th>
<th>Inclusion/exclusion criteria</th>
<th>Mathematics outcome measures</th>
<th>WM measures</th>
<th>Confounding variables</th>
<th>Results</th>
<th>Quality score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Toll &amp; van Luit (2014)</td>
<td>Longitudinal (1 year)</td>
<td>Mean age at start of study = 4.59 years</td>
<td>806</td>
<td>Inclusion: achieved above the 15th percentile on the Early Numeracy Test – Revised</td>
<td>Early Numeracy Test – Revised</td>
<td>Visuospatial WM: odd-one-out task from AWMA. Verbal WM: word recall backward task from AWMA.</td>
<td>None considered</td>
<td>Both WM measures significantly predicted early mathematics performance. Visuospatial WM was significantly related to rate of development in mathematics ability.</td>
<td>+</td>
</tr>
<tr>
<td>2. Weijer-Bergsma, Kroesbergen &amp; Van Luit (2014)</td>
<td>Cross-sectional and longitudinal (1 year)</td>
<td>Grades 2 to 6</td>
<td>4285 included in analysis</td>
<td>Arithmetic Tempo Test – 4 domains: addition, subtraction, multiplication and division</td>
<td>None considered</td>
<td>Visuospatial WM: visuospatial complex span task (measured proportion correct). Verbal WM: verbal span backwards (measured proportion correct)</td>
<td>+ +</td>
<td>Visuospatial and verbal WM predicted individual differences in all domains of mathematics performance. Until Grade 4 (7-8-years-old) visuospatial and verbal WM were equally strong predictors of mathematics performance. After Grade 4 verbal WM was a stronger predictor</td>
<td></td>
</tr>
<tr>
<td>Authors and study no</td>
<td>Study design (follow-up period if longitudinal)</td>
<td>Age of participants (mean and range)</td>
<td>Sample size</td>
<td>Inclusion/exclusion criteria</td>
<td>Mathematics outcome measures</td>
<td>WM measures</td>
<td>Confounding variables</td>
<td>Results</td>
<td>Quality score</td>
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<tr>
<td>3. Östergren &amp; Träff (2013)</td>
<td>Cross-sectional and longitudinal (1 year)</td>
<td>Preschool mean age = 6.62 years (range = 5.71 – 7.33 years); 1st grade mean age = 7.66 years (range = 6.83 – 8.37 years)</td>
<td>315</td>
<td>Inclusion: Fluent Swedish speaker, normal/corrected to normal vision, no hearing loss</td>
<td>Addition and subtraction word problems</td>
<td>Verbal WM: complex word repetition, word fluency, segment subtraction task</td>
<td>None considered</td>
<td>Verbal WM predicted mathematics ability in preschool and Grade 1. Preschool verbal WM had a direct effect on Grade 1 mathematics ability and an indirect effect through number knowledge</td>
<td>+</td>
</tr>
<tr>
<td>4. Seethaler, Fuchs, Star &amp; Bryant (2011)</td>
<td>Longitudinal (3 years)</td>
<td>All children in Grade 3 and Grade 5</td>
<td>688</td>
<td>Excluded children who scored less than 80 on the WASI</td>
<td>Arithmetic subtest from WRAT-3 – separated into whole number items and rational number items</td>
<td>Listening recall task from WMTB-C and Numbers Reversed subtest from the Woodcock-Johnson-III</td>
<td>Previous calculation skill, language, non-verbal reasoning, concept formation, and processing speed were entered into each regression analysis as predictors prior to the WM variables</td>
<td>Numbers Reversed task significantly predicted both mathematical variables after all other variables were entered but listening recall did not</td>
<td>+</td>
</tr>
</tbody>
</table>
Table 3 (continued)

<table>
<thead>
<tr>
<th>Authors and study no.</th>
<th>Study design (follow-up period if longitudinal)</th>
<th>Age of participants (mean and range)</th>
<th>Sample size</th>
<th>Inclusion/exclusion criteria</th>
<th>Mathematics outcome measures</th>
<th>WM measures</th>
<th>Confounding variables</th>
<th>Results</th>
<th>Quality score</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Swanson (2004)</td>
<td>Cross-sectional</td>
<td>Grades 2 and 3 mean age = 8.46 years. Grades 5 and 6 mean age = 11.61 years</td>
<td>69 (25 from Grades 2 and 3) and 44 from Grades 5 and 6</td>
<td>None given</td>
<td>Calculation subtest from Woodcock-Johnson Psycho-Educational Battery</td>
<td>Verbal WM: sentence span task and auditory digit sequencing task from SCPT. Visuospatial WM: visual matrix and mapping and directions tasks from SCPT</td>
<td>Fluid IQ, phonological processing, reading comprehension, calculation skill and chronological age</td>
<td>A domain-general WM variable was a significant predictor of mathematical accuracy when confounding variables were included as predictors in the regression model. Results suggested that decreased reliance on visuospatial WM was related to an increase in mathematical accuracy</td>
<td>+</td>
</tr>
</tbody>
</table>

*Note. AWMA = Automated Working Memory Assessment; SCPT = Swanson Cognitive Processing Test; SD = standard deviation; WASI = Wechsler Abbreviated Scale of Intelligence; WM = working memory; WMTB-C = Working Memory Test Battery for Children; WRAT = Wide Range Achievement Test.*
The six studies investigating the relationship between STM and mathematics performance are summarised in Table 4. Two studies received the highest quality rating (++), three studies received the “+” quality rating, and one study received the lowest quality rating (-).

Studies which used longitudinal designs followed-up their participants over a period of between 1 and 6 years. One study measured only verbal STM (study 9), four studies measured only visuospatial STM (studies 6-8 and 10), and one study measured both verbal and visuospatial STM (study 11). Three studies did not include any confounding variables in the statistical analysis (studies 6, 7 and 11). One study accounted for chronological age (study 9), and two studies accounted for IQ (studies 8 and 10).

Overall, both verbal and visuospatial STM were significant predictors of mathematical performance. Although, one study found that visuospatial STM was not a significant predictor of mathematical performance (study 11). This finding should be treated with caution, however, due to the low overall quality of the study, particularly regarding the selection of measures of visuospatial STM. Contrary to the findings from the WM studies (see above) visuospatial STM was found to predict more aspects of mathematics in older children (9-years-old) than younger children (7-years-old; study 7).
<table>
<thead>
<tr>
<th>Authors and study n°</th>
<th>Study design (follow-up period if longitudinal)</th>
<th>Age of participants (mean and range)</th>
<th>Sample size</th>
<th>Inclusion/ exclusion criteria</th>
<th>Mathematics outcome measures</th>
<th>STM measures</th>
<th>Confounding variables</th>
<th>Results</th>
<th>Quality score</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. LeFevre et al. (2010)</td>
<td>Longitudinal (2 years)</td>
<td>Preschool median age = 5:00 years (range 4:05 – 5:08 years). Kindergarten median age = 5:11 years (range 4:07 – 6:06 years)</td>
<td>182 included in the analysis from 196</td>
<td>None given.</td>
<td>Numeration, Geometry and Measurement subtests from the KeyMath Test-Revised, Calculation subtest from WJ-R, experimental number line and symbolic magnitude comparison tasks</td>
<td>Spatial span task</td>
<td>Language ability included as a predictor</td>
<td>Spatial span significantly predicted all mathematical outcomes but was never the dominant predictor</td>
<td>++</td>
</tr>
<tr>
<td>7. Holmes, Adams &amp; Hamilton (2008)</td>
<td>Cross-sectional</td>
<td>Year 3 mean age = 7:07 years (range = 7:01 – 8:03 years). Year 5 mean age = 9:07 years (range = 9:03 – 10:03 years)</td>
<td>107 (51 Year 3 and 56 Year 5)</td>
<td>No children excluded.</td>
<td>Age appropriate curriculum based assessment from the Qualifications and Curriculum Authority assessing 4 domains: 1) number and algebra, 2) shape, space and measures, 3) handling data, 4) mental arithmetic</td>
<td>Visual Patterns Test and block recall task from WMTB-C</td>
<td>None considered</td>
<td>In younger children the VSSP composite significantly predicted total mathematics scores and block recall significantly predicted number and algebra scores. In older children the Visual Patterns Test significantly predicted number and algebra, handling data and total mathematics scores</td>
<td>+</td>
</tr>
</tbody>
</table>
Table 4 (continued)

<table>
<thead>
<tr>
<th>Authors and study n°</th>
<th>Study design (follow-up period if longitudinal)</th>
<th>Age of participants (mean and range)</th>
<th>Sample size</th>
<th>Inclusion/exclusion criteria</th>
<th>Mathematics outcome measures</th>
<th>STM measures</th>
<th>Confounding variables</th>
<th>Results</th>
<th>Quality score</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Simmons, Singleton &amp; Horne (2008)</td>
<td>Longitudinal (1 year)</td>
<td>Mean age at Time 1 = 5:03 years ($SD = 4$ months). Mean age at Time 2 = 6:02 years ($SD = 3$ months)</td>
<td>42</td>
<td>None given.</td>
<td>British Ability Scales</td>
<td>“Rabbits” task from Cognitive Profiling System (corsi span task)</td>
<td>IQ, reading attainment, vocabulary, and non-verbal reasoning included as predictors in regression</td>
<td>VSSP was a significant predictor of arithmetic performance independent of reading attainment, vocabulary and non-verbal reasoning</td>
<td>+</td>
</tr>
<tr>
<td>9. Durand, Hulme, Larkin &amp; Snowling (2005)</td>
<td>Cross-sectional</td>
<td>Mean age = 8:11 years ($SD = 10.69$ months; range = 7:05 – 10:04 years)</td>
<td>102 included in analysis from 162</td>
<td>In target class at target school.</td>
<td>Numerical operations subtest from WOND and speeded addition and subtraction tasks</td>
<td>Word list recall and Non-Word Repetition Test. Scores combined to form a phonological memory composite</td>
<td>Chronological age</td>
<td>Verbal STM tasks significantly correlated with the numerical operations task when age was controlled. Phonological memory was indirectly correlated with arithmetic ability through verbal ability</td>
<td>++</td>
</tr>
<tr>
<td>10. Kyttälä, Aunio, Lehto, Van Luit &amp; Hautamäki (2003)</td>
<td>Cross-sectional</td>
<td>Mean age = 6:02 years ($SD = 4$ months, range = 5:03 – 6:10 years)</td>
<td>46</td>
<td>None given</td>
<td>Early Numeracy Test for Toddlers (ENT) – 2 subgroups of tasks relational and counting</td>
<td>Matrix pattern task and corsi block span task</td>
<td>IQ</td>
<td>Visuospatial STM did not correlate significantly with the total ENT score but significantly correlated with counting tasks when IQ was controlled for</td>
<td>+</td>
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</tbody>
</table>
Table 4 (continued)

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<thead>
<tr>
<th>Authors and study no</th>
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<th>Age of participants (mean and range)</th>
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<th>Inclusion/exclusion criteria</th>
<th>Mathematics outcome measures</th>
<th>STM measures</th>
<th>Confounding variables</th>
<th>Results</th>
<th>Quality score</th>
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</thead>
<tbody>
<tr>
<td>11. Bruininks &amp; Mayer (1979)</td>
<td>Longitudinal (6 years)</td>
<td>Kindergarten participants: mean age = 5:07 years (range 5:00 – 6:02 years) Grade 6 participants: no age given</td>
<td>58</td>
<td>None given.</td>
<td>Subtests from the Iowa Test of Basic Skills – map reading and reading tables and graphs composite, math concepts and math problem solving.</td>
<td>Visual sequential memory from Illinois Test of Psycholinguistic Ability Auditory attention span for related syllables from Detroit Tests of Learning Aptitude</td>
<td>None considered</td>
<td>Auditory STM was significantly related to the map reading, and reading graphs and tables composites. Visual STM was not significantly related to any mathematics performance measures</td>
<td>-</td>
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</tbody>
</table>
Attention and mathematics

The two studies investigating the association between attention and mathematics are summarised in Table 5. Both studies were given the “+” quality rating meaning distinctions cannot be made about the study findings based on quality of the studies reviewed. As for the WM studies consideration of possible confounding variables was again poor. Both studies measured attention using cognitive measures. Study 12 included gender and school grade as confounding variables, while study 13 did not consider any confounding variables.

Study 12 found that different aspects of attention were related to different elements of mathematical ability, for example, selective attention was related to all aspects of mathematics performance, while divided attention did not predict any mathematical skills. Study 13 found that executive attention, defined as attentional control processes, was a significant predictor of both concurrent mathematical ability and development in arithmetical fluency over one school year.
<table>
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<tr>
<th>Authors and study number</th>
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<th>Attention measures</th>
<th>Confounding variables</th>
<th>Results</th>
<th>Quality score</th>
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<tbody>
<tr>
<td>12. Commodari &amp; Di Blasi (2014)</td>
<td>Cross-sectional</td>
<td>Grade 1 mean age = 6.2 years, Grade 3 mean age = 8.4 years, Grade 5 mean age = 10.2 years</td>
<td>314 total (101 from Grade 1, 107 from Grade 3 and 116 from Grade 5)</td>
<td>Inclusion: children with “average” linguistic, social, cognitive and behavioural skills. Exclusion: children with diagnosed physical and/or mental disabilities, children with social difficulties</td>
<td>The Calculation Ability MT Group 6-11 – written calculation, size discrimination, word-number transcoding, number ordering, basic single-digit arithmetic</td>
<td>Attention and Concentration Battery: simple reaction time, reaction time related with a choice, selective auditory and visual attention, digit span, divided attention, modified Stroop, attention shifting</td>
<td>Gender and school grade entered into the regression analysis first to control for their contribution</td>
<td>Selective attention was related to all aspects of mathematics. Reaction time in response selection, maintenance, span, and shifting tasks were related to calculation competency. Reaction times on phonological decoding and attention shifting tasks predicted numerical knowledge. Executive attention was related to measures of mathematics knowledge and fluency and predicted development in arithmetic fluency</td>
<td>+</td>
</tr>
</tbody>
</table>
Combination of WM, STM, attention and mathematics

Thirty studies (summarised in Table 6) investigated the association between one or more of the explanatory variables and mathematics. Ten studies were given the highest (++) quality rating, 18 were given the “+” quality rating, and two received the lowest quality rating (-).

Twenty studies measured WM and STM, six measured WM and attention, and four measured all three explanatory variables. Studies which used a longitudinal design followed-up their participants over a period of between 4 months and 6 years. WM was most commonly measured using complex span tasks, while STM was most commonly measured using simple span tasks. In studies which measured attention, six measured attention using cognitive measures, and four measured attention behaviour using teacher- or parent-rated questionnaires. Nine studies did not consider any confounding variables. IQ was the most commonly considered confounding variable. Additional confounding variables considered were: reading or language ability, previous mathematics ability, SES, chronological age, ethnicity, and processing speed.

Overall, these studies found that visuospatial STM was a robust predictor of mathematical performance in all age groups, while verbal STM did not consistently significantly predict mathematical performance. The highest quality studies found variable results. Some studies found that, while verbal STM was correlated with mathematics performance it was not a significant predictor (e.g., study 37). Others found that verbal STM predicted unique variance in mathematics performance but was not the strongest predictor (e.g., study 33). Verbal and visuospatial WM were also significant predictors of mathematics performance. Different components of
STM and WM were significantly related to different aspects of mathematics, for example, visuospatial STM predicted number writing and symbolic magnitude judgements, verbal STM predicted multiplication accuracy, and verbal and visuospatial WM predicted addition accuracy (study 20). Some studies found that as well as being directly related to mathematics performance, the relationship between mathematical performance and STM and WM was mediated by other variables, such as non-verbal IQ, literacy ability (study 37), and mathematical precursors (study 27).

The inclusion of additional variables also affected the relationship between STM, WM, and mathematics performance. When IQ was included in the analysis it was generally found that WM and STM continued to significantly predict mathematics performance (e.g., studies 22 and 30), but when multiple STM or WM measures were included, significant predictive relationships could become non-significant (e.g., study 42).

Both cognitive and behavioural measures of attention were found to be significantly related to mathematics performance, but different components of attention had different relationships with mathematics. Executive attention was a significant predictor of mathematics performance (study 35), while sustained attention (study 15), and attentional inhibition (study 19) were not.
Table 6
Summary of Studies Investigating the Relationship Between Mathematics Performance and a Combination of Working Memory, Short-Term Memory and Attention

<table>
<thead>
<tr>
<th>Authors and study n°</th>
<th>Study design (follow-up period if longitudinal)</th>
<th>Age of participants (mean and range)</th>
<th>Sample size</th>
<th>Inclusion/exclusion criteria</th>
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<th>Measures of WM, STM and attention</th>
<th>Confounding variables</th>
<th>Results</th>
<th>Quality score</th>
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</thead>
<tbody>
<tr>
<td>14. Vanbinst, Ghesquière &amp; De Smedt (2015)</td>
<td>Longitudinal (1 year)</td>
<td>Mean age = 6.02 years</td>
<td>67</td>
<td>None given</td>
<td>Digit naming, numerical magnitude comparison, single digit addition and subtraction</td>
<td>Visuospatial STM: corsi block recall task from WMTB-C. Verbal WM: listening span task from WMTB-C</td>
<td>Intellectual ability and preschool mathematics ability included in correlational analyses but not partialled out</td>
<td>Visuospatial STM and verbal WM were significantly correlated with mathematical precursors but did not predict single-digit arithmetic</td>
<td>++</td>
</tr>
<tr>
<td>15. Szűcs, Devine, Soltesz, Nobes &amp; Gabriel (2014)</td>
<td>Cross-sectional</td>
<td>Mean age girls = 8.9 years (range 7.8 – 10.5 years), mean age boys = 9 years (range 8.3 – 10.5 years)</td>
<td>95 – 98</td>
<td>Inclusion: at least average reading skill on assessment</td>
<td>Composite derived from Mathematics Assessment for Learning and Teaching Test and numerical operations subtest from WIAT</td>
<td>Verbal STM: digit span and word recall. Verbal WM: listening span. Visuospatial STM: dot matrix. Visuospatial WM: odd one out. All tasks from AWMA Attention: sustained attention and stop signal experimental tasks</td>
<td>Intellectual ability controlled in all analyses</td>
<td>Visuospatial STM and WM were robust predictors of mathematical performance. Attention measures, verbal WM, and verbal STM did not significantly predict mathematics performance</td>
<td>++</td>
</tr>
<tr>
<td>Authors and study n°</td>
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<td>16. Vukovic et al. (2014)</td>
<td>Longitudinal (4 years)</td>
<td>Grade 1 mean age = 6:06 years, Grade 2 mean age = 7:11 years, Grade 4 mean age = 10:00 years</td>
<td>163</td>
<td>None given</td>
<td>Number sets task (manipulating whole numbers &lt;10), number line estimation task, Arithmetic subtest from WRAT-3, fraction questions from National Assessment of Educational Progress</td>
<td>Visuospatial STM: mazes memory and block recall subtests from WMTB-C (mean score used as a composite of “visuospatial memory”). Verbal WM: listening recall task from WMTB-C (measuring “executive control”). Attention: Teacher-rated questionnaire of attentive behaviour</td>
<td>Ethnic identity, SES, general academic achievement in 1st grade controlled for in all analyses. Non-verbal reasoning was included as a predictor</td>
<td>Visuospatial STM and attentive behaviour in Grade 1 were significantly related to number line estimation and whole number computations in Grade 2 respectively. These mathematical domains were significantly related to fraction concepts in Grade 4</td>
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<td>Study design (follow-up period if longitudinal)</td>
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<tr>
<td>Longitudinal (6 months to 1 year)</td>
<td>Mean age at start of study = 8.8 years</td>
<td>357</td>
<td>None given</td>
<td>Fraction questions from recent National Assessments of Educational Progress, experimental fraction procedures task, mathematics subtest from the WRAT – 4th edition</td>
<td>WM: counting recall subtest from WMTB-C. Attention: inattention subscale from teacher-rated questionnaire</td>
<td>Language ability and mathematics fluency included as predictors in regression analysis</td>
<td>WM was a significant predictor for fraction procedures and number line estimation. Attention was a significant predictor for fraction concepts, fraction procedures, general mathematics ability, and number line estimation.</td>
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<tr>
<td>Cross-sectional</td>
<td>7 to 9 years</td>
<td>74</td>
<td>Inclusion: full scale IQ &gt; 80 on WASI-II. Exclusion: history of psychiatric illness or medication use</td>
<td>Numerical operations and mathematical reasoning subtests from WIAT-II</td>
<td>PL: digit recall. VSSP: corsi block tapping. CE: counting recall. All subtests from WMTB-C</td>
<td>None considered</td>
<td>All WM measures were significantly correlated with mathematics subtests, except PL with numerical operations. VSSP was the strongest predictor of mathematics performance.</td>
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<tr>
<td>Authors and study no.</td>
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<tr>
<td>19. Lee et al. (2012)</td>
<td>Cross-sectional</td>
<td>Mean age = 6.9 years</td>
<td>163</td>
<td>None given</td>
<td>Numerical operations task from WIAT-II. Experimental geometric and numerical pattern identification tasks</td>
<td>WM: listening recall and Mister X tasks from AWMA, and pictorial updating task. Attention: flanker task, modified Simon task and picture-symbol task</td>
<td>Fluid intelligence considered in post-hoc analysis</td>
<td>WM strongly predicted all mathematical abilities. This relationship remained significant when fluid intelligence was controlled for. Attention measures did not predict any mathematics abilities</td>
<td>+</td>
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<tr>
<td>20. Simmons, Willis &amp; Adams (2012)</td>
<td>Cross-sectional</td>
<td>Year 1 mean age = 5:10 years, Year 3 mean age = 7:11 years</td>
<td>90 (41 in Year 1 and 49 in Year 3)</td>
<td>None given</td>
<td>Experimental computer tasks to measure single digit arithmetic, symbolic magnitude judgement and number writing</td>
<td>PL: word and non-word recall tasks from AWMA, VSSP: mazes memory and block recall tasks from AWMA. CE: odd-one-out, spatial recall and listening recall tasks from AWMA, backward digit span from WMTB-C</td>
<td>None considered</td>
<td>WM significantly predicted variance in mathematical skills. VSSP contributed unique variance in number writing and symbolic magnitude judgements. PL contributed unique variance in multiplication accuracy. WM contributed unique variance in addition accuracy</td>
<td>+</td>
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Table 6 (continued)

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</thead>
<tbody>
<tr>
<td>21. Alloway &amp; Passolunghi (2011)</td>
<td>Cross-sectional</td>
<td>7 year olds mean age = 7.3 years, 8 year olds mean age = 8.6 years</td>
<td>206 (100 7 year olds and 106 8 year olds)</td>
<td>Exclusion: Receiving special education, documented brain injury or behavioural problems</td>
<td>Italian AC-MT Test – 4 domains: 1) number operations, 2) quantity discrimination, 3) number production, 4) number ranking and numerical operations subtest from the WOND</td>
<td>All 12 tests from AWMA covering verbal WM, verbal STM, visuospatial WM and visuospatial STM</td>
<td>Vocabulary entered as a predictor in regression analyses</td>
<td>At 7-years-old visuospatial STM predicted quantity discrimination and number production and verbal STM predicted variance on the numerical operations task. Verbal WM uniquely predicted number ranking. At 8-years-old only visuospatial STM predicted variance on the number ranking, number production and numerical operations tasks</td>
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<tbody>
<tr>
<td>22. Geary (2011a)</td>
<td>Longitudinal (5 years)</td>
<td>Preschool mean age = 6.2 years, Grade 5 mean age = 10.7 years</td>
<td>177</td>
<td>None given</td>
<td>Numerical operations subtest from WIAT-II</td>
<td>All 9 subtests from WMTB-C, CE, PL and VSSP component scores entered separately in the analysis</td>
<td>IQ controlled for and processing speed included as a variable in the model</td>
<td>WM contributed to mathematics performance above IQ. CE measures were significant predictors for mathematics performance, particularly in later school grades. VSSP measures contributed more variance to mathematics performance than PL measures. WM and STM tasks significantly correlated with mathematics. Attention only correlated with mathematics performance in 7-year-olds. Attention and WM were significant predictors of mathematics</td>
<td>++</td>
</tr>
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<tr>
<td>Alloway &amp; Alloway (2010)</td>
<td>Longitudinal (6 years)</td>
<td>Time 1 mean age = 5:00 years (range = 4.3 – 5.7 years), time 2 mean age = 10:11 years (range = 10.3 – 11.3 years)</td>
<td>98</td>
<td>None given</td>
<td>Wechsler Objective Numerical Dimensions</td>
<td>Verbal STM: digit and word recall tasks (composite score used in analysis), Verbal WM: backward digit recall and listening recall tasks (composite score used in analysis) All tests from AWMA</td>
<td>IQ included as a predictor in the analysis</td>
<td>Verbal WM at 5-years-old was a significant predictor of mathematics ability at 11-years-old and contributed more variance in mathematics than non-verbal IQ</td>
<td>++</td>
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<tr>
<td>Meyer, Salimpoor, Wu, Geary &amp; Menon (2010)</td>
<td>Cross-sectional</td>
<td>Grade 2 mean age = 7.59 years (range = 7–8.4 years), Grade 3 mean age = 8.52 years (range = 7.8 – 9.3 years)</td>
<td>98 (48 in Grade 2 and 50 in Grade 3)</td>
<td>Inclusion: Full scale IQ between 80 and 120. Exclusion: children who had behavioural and/or emotional problems on the CBCL</td>
<td>Numerical operations and mathematical reasoning subtests from WIAT-II</td>
<td>PL: digit recall, VSSP: block recall, CE: counting recall and backward digit recall. All tasks from WMTB-C</td>
<td>None considered</td>
<td>CE and PL measures significantly predicted performance on both mathematics measures in Grade 2. In Grade 3 VSSP significantly predicted both mathematics measures</td>
<td>++</td>
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<tr>
<td>Authors and study n°</td>
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<tr>
<td>26. De Smedt et al. (2009)</td>
<td>Cross-sectional and longitudinal (1 year)</td>
<td>Grade 1 mean age = 6:04 years, Grade 2 mean age = 7:04 years</td>
<td>106</td>
<td>None given</td>
<td>Maths assessment from the Flemish Student Monitoring System</td>
<td>PL: Dutch adaptation of Children's Test of Nonword Repetition and digit span forward task from WISC-III. VSSP: block recall task from WMTB-C and Visual Patterns Test. CE: listening span, counting span and backward digit span</td>
<td>IQ included as a predictor. Grade 1 mathematics achievement controlled in prediction of Grade 2 mathematics achievement. Correlation between VSSP and mathematics was stronger in Grade 1 than Grade 2 with the opposite pattern for PL. PL and CE were significant predictors of Grade 2 mathematics. When all WM measures and IQ were entered only PL was a significant predictor of Grade 2 mathematics. Only PL and CE significantly predicted Grade 2 mathematics when Grade 1 mathematics achievement was controlled.</td>
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<tr>
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<td>27. Krajewski &amp; Schneider (2009)</td>
<td>Longitudinal (4 years)</td>
<td>Pre-schoolers mean age = 5:07 years (range = 4:11 – 6:06 years); Grade 3 mean age = 8:08 years (range = 8:00 – 9:07 years)</td>
<td>91</td>
<td>None given</td>
<td>German Mathematics Test</td>
<td>PL: digit span forwards. VSSP: corsi block span and matrix tasks. CE: digit span backwards</td>
<td>None considered</td>
<td>All WM measures significantly correlated with mathematics achievement in Grade 3. VSSP only entered into model, had no significant direct influence on Grade 3 mathematics achievement, indirect influence through phonological awareness and mathematical precursors</td>
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<tr>
<td>Authors and study no</td>
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<tr>
<td>28. Andersson (2008)</td>
<td>Cross-sectional</td>
<td>Mean age = 10.3 years</td>
<td>141</td>
<td>Inclusion: Fluent Swedish speaker, normal/ corrected to normal vision and no hearing loss</td>
<td>Paper and pencil test of written arithmetic skills with 3 subtests: 1) standard arithmetical calculation, 2) arithmetical equations, 3) arithmetical combination and arithmetic fact retrieval task</td>
<td>PL: digit span VSSP: corsi block span. CE: semantic verbal fluency, trail-making task, colour Stroop task, counting span and visual-matrix task</td>
<td>Chronological age, IQ and reading ability controlled in the regression analysis</td>
<td>All WM measures significantly correlated with the mathematics tasks when age was controlled. Counting span, verbal fluency, trail-making, and digit span significantly predicted written arithmetic skill. Verbal fluency and trail-making predicted arithmetical fact retrieval. Counting span predicted all mathematical subtests</td>
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### Table 6 (continued)

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<tr>
<th>Authors and study no</th>
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<tbody>
<tr>
<td>29. Bull, Espy &amp; Wiebe (2008)</td>
<td>Longitudinal (3 years)</td>
<td>Preschool mean age = 4:06 years</td>
<td>104</td>
<td>Inclusion: Native English speakers</td>
<td>Performance Indicators in Primary School</td>
<td>STM: corsi blocks forwards and digit span forwards, WM: inhibition and switching conditions of the Shape School task and Tower of London task. Corsi blocks backwards and digit span backwards (not included in some analyses due to high levels of missing data)</td>
<td>Reading achievement.</td>
<td>In preschool all variables, except corsi span backwards and switching, significantly correlated with mathematics achievement and significantly predicted mathematics. Mathematics achievement 3 years later significantly predicted by corsi span backwards when reading ability controlled</td>
<td>+</td>
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<tr>
<td>Study design (follow-up period if longitudinal)</td>
<td>Mean age (mean and range)</td>
<td>Sample size</td>
<td>Inclusion/exclusion criteria</td>
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<tr>
<td>Longitudinal (6 months)</td>
<td>Mean age = 6:04 years</td>
<td>170</td>
<td>None given</td>
<td>Standardised mathematics test for first year primary school students</td>
<td>STM: word and digit span forwards tasks, WM: listening span task, word and digit span backwards (WISC-R) tasks</td>
<td>IQ</td>
<td>WM measures were more strongly correlated with mathematics achievement than STM measures. WM significantly influenced mathematics achievement directly and through counting ability. Influence of IQ on mathematics achievement was mediated by WM.</td>
<td>+</td>
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<tr>
<td>Cross-sectional</td>
<td>All children in Grade 3 at time of assessment</td>
<td>312</td>
<td>None given</td>
<td>Assessment of Math Fact Fluency and Double-Digit Addition and Subtraction Tests from the Grade 3 Math Battery, 14 words problems</td>
<td>WM: Listening recall task from WMTB-C and numbers reversed task from Woodcock-Johnson-III. Attention: teacher-rated questionnaire.</td>
<td>None considered</td>
<td>Most robust predictor of mathematics was attentive behaviour. WM only became a significant predictor when language abilities were controlled for</td>
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<th>Confounding variables</th>
<th>Results</th>
<th>Quality score</th>
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<tr>
<td>33. Holmes &amp; Adams (2006)</td>
<td>Cross-sectional</td>
<td>Year 3 mean age = 8:01 years (range = 7:01 – 8:09 years), Year 5 mean age = 9:10 years (range = 9:01 – 10:09 years)</td>
<td>148 (78 in Year 3 and 70 in Year 5)</td>
<td>None given</td>
<td>Key Stage 2 mathematics assessment developed by the Qualifications and Curriculum Authority covering number and algebra, shape, space and measure, handling data and mental arithmetic</td>
<td>PL: Non-word list recall task from WMTB-C. VSSP: Mazes memory from WMTB-C. CE: Listening recall task from WMTB-C</td>
<td>Chronological age controlled for in all regression analyses</td>
<td>VSSP and CE components of WM contributed unique variance in all aspects of mathematics, with CE being the strongest predictor. In year 3 children VSSP and CE components contributed unique variance in mathematics, while in year 5 children PL predicted unique variance on one aspect of mathematics but CE remained the strongest predictor</td>
<td>++</td>
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<tr>
<td>34. Lundberg &amp; Sterner (2006)</td>
<td>Longitudinal (1 year)</td>
<td>Mean age at start of study = 8.9 years, mean age at end of study = 9.8 years</td>
<td>60</td>
<td>None given</td>
<td>Time 1 – Butterworth’s Dyscalculia Screener Time 2 – mathematics tasks from the Sweden National Assessment Program</td>
<td>WM: Backward digit span from WISC. Attention: teacher rated task orientation composite comprising motivation, attention and concentration</td>
<td>None considered</td>
<td>WM and attention significantly correlated with mathematics one year later.</td>
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<tr>
<td>35. Swanson (2006)</td>
<td>Longitudinal (1 year)</td>
<td>Range of mean ages = 6.21 – 9.27 years</td>
<td>320</td>
<td>None given</td>
<td>Arithmetic subtest from WISC-III, Word problem-solving processes task, arithmetic subtest from WRAT-3, adapted Test of Computational Fluency</td>
<td>PL: digit span forwards from WISC-III, VSSP: visual matrix and mapping and directions tasks, CE: listening sentence span, semantic association task, digit/sentence span, backward digit span task from WISC-III. Attention: verbal fluency task (fluency latent variable) and random number generation task (inhibition latent variable)</td>
<td>All target variables accounted for in analysis</td>
<td>Changes in mathematical problem solving were related to changes in CE. CE contributed significant variance to calculation and word problem-solving. STM, inhibition, and VSSP also contributed significant variance to elements of mathematics performance</td>
<td>+</td>
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<td>Rasmussen &amp; Bisanz (2005)</td>
<td>Cross-sectional</td>
<td>Preschool mean age = 5:03 years (range 4:05 – 6:00 years). Grade 1 mean age = 6:11 years (range 6:02 – 7:07 years)</td>
<td>63 (34 in preschool and 29 in Grade 1)</td>
<td>In target classes at schools</td>
<td>Non-verbal and verbal addition problems and standard verbal and non-verbal arithmetic problems</td>
<td>PL: digit span. VSSP: corsi block span. CE: Counting span and backward digit span tasks</td>
<td>None considered</td>
<td>WM measures related to mathematics performance in both age groups. In preschool children visuospatial WM was strongly correlated with mathematical performance, while in Grade 1 children WM measures only predicted performance on verbal mathematical tasks</td>
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<tr>
<td>37. Lee, Ng, Ng &amp; Lim (2004)</td>
<td>Cross-sectional</td>
<td>Mean age = 10.7 years</td>
<td>151</td>
<td>None given</td>
<td>10 word based mathematics problems, 9 focussing on algebra</td>
<td>All 9 subtests from WMTB-C. CE, PL and VSSP scores entered separately in the analysis</td>
<td>Performance IQ included as a predictor</td>
<td>All WM components significantly correlated with mathematics performance. CE was the only significant predictor. Path analysis found CE to have a direct influence on algebra performance and an indirect influence through performance IQ and literacy. PL had an indirect influence on algebra performance through literacy and VSSP had an indirect effect through performance IQ</td>
<td>++</td>
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<tr>
<td>38. Noël, Seron &amp; Trovarelli (2004)</td>
<td>Longitudinal (4 months)</td>
<td>Mean age = 6:07 years</td>
<td>25</td>
<td>Inclusion: No sign of precocity (starting Grade 1 before 6 years) and no sign of disability (repeating Grade 1)</td>
<td>40 written addition questions.</td>
<td>PL: forward digit span, word span using short and long words, non-word repetition with CV and CCV structure. CE: listening span task.</td>
<td>None considered</td>
<td>Mathematics performance significantly correlated with all WM measures. CCV non-word repetition had the highest correlation with mathematics performance</td>
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<tr>
<td>40. Maybery &amp; Do (2003)</td>
<td>Cross-sectional</td>
<td>Mean age = 10:02 years</td>
<td>49</td>
<td>None given</td>
<td>Wood and Lowther Easymark Diagnostic Mathematics Test – 3 sections (number, measurement and space) entered separately in analysis</td>
<td>Verbal STM: fixed verbal span task. Verbal WM: running verbal span task. Visuospatial STM: fixed spatial span task. Visuospatial WM: running spatial span task</td>
<td>Word reading</td>
<td>Fixed span tasks were significant predictors of mathematics performance (except fixed verbal span on measurement) when all other tasks were accounted for. Visuospatial STM was more highly correlated with mathematics than verbal STM. WM tasks did not significantly predict mathematics. These relationships remained when word reading was controlled for</td>
<td>+</td>
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<tr>
<td>41. Hecht, Torgesen, Wagner &amp; Rashotte (2001)</td>
<td>Longitudinal (3 years)</td>
<td>Grade 2 mean age = 7.7 years, Grade 3 mean age = 8.7 years, Grade 4 mean age = 10.2 years, Grade 5 mean age = 11.2 years</td>
<td>201</td>
<td>Fluent English speaker. Passed gross articulation measure in kindergarten</td>
<td>Calculation subtest from Woodcock-Johnson Psycho-Educational Battery and speeded simple arithmetic task</td>
<td>STM: Digit span, memory for sentences WM: listening complex span task. Combined into a “phonological memory” composite</td>
<td>Prior mathematics ability controlled in all analyses. Phonological awareness, general verbal ability and reading skills also controlled in some analyses</td>
<td>++</td>
<td></td>
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</table>

| 42. Gathercole & Pickering (2000) | Longitudinal (1 year) | Time 1 mean age = 7:04 years (range = 6:09 – 8:05 years); Time 2 mean age = 8:05 years (range = 7:10 – 9:06 years) | 87 | None given | Time 1: Group Mathematics Test Time 2: Basic Number Skills subtest of the Differential Ability Scales | PL: digit span, serial recall and recognition of words and non-words, non-word repetition. VSSP: static and dynamic matrices and mazes. CE: listening, counting, and backward digit recall | Chronological age | PL was significantly correlated with mathematics at 7-but not 8-years-old but not when CE was controlled. CE tasks were significantly correlated with mathematics at 7- and 8-years-old and this remained when PL was controlled for | ++ |
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<tbody>
<tr>
<td>43. De Jong (1993)</td>
<td>Cross-sectional</td>
<td>All children were 9 years old and in Grade 6</td>
<td>376</td>
<td>Excluded children who had at least one parent born outside of the Netherlands</td>
<td>National Institute of Educational Measurement arithmetic assessment and Multiple choice test of arithmetic</td>
<td>WM: Star Counting Test, syllable counting and digit span task from the WISC-R. Attentional behaviour: teacher-rated questionnaire of classroom behaviour and parent-rated questionnaire of behaviour at home</td>
<td>SES included as a predictor</td>
<td>WM and attentive behaviour at home and in the classroom significantly influenced academic achievement</td>
<td>+</td>
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*Note. AWMA = Automated Working Memory Assessment; CBCL = Child Behaviour Checklist; CE = central executive; CV = consonant-vowel; CCV = consonant-consonant-vowel; IQ = intelligence quotient; PL = phonological loop; SD = standard deviation; STM = short-term memory; VSSP = visuospatial sketchpad; VSSTM = visuospatial short-term memory; VWM = verbal working memory; WIAT-II = Wechsler Individual Attainment Test (2nd edition); WISC = Wechsler Intelligence Scale for Children; WM = working memory; WMTB-C = Working Memory Test Battery for Children; WOND = Wechsler Objective Numerical Dimensions; WRAT = Wide Range Achievement Test.*
Critical analysis

A strength of the literature was the selection of explanatory variables using a good theoretical rationale drawn from diverse research areas, such as cognitive neuroscience, cognitive neuropsychology, and previous experimental research. Many studies also used statistical techniques, such as structural equation modelling, to build and test models of mathematical development (e.g., LeFevre et al., 2010; Östergren & Träff, 2013). This represents a useful attempt to contribute to the theoretical literature, however, there was a lack of integration across these models and more recent studies have not attempted to replicate or extend these proposed models.

Another strength was the widespread use of longitudinal studies to investigate the relationship between mathematics performance and WM, STM, and attention. Longitudinal designs are often preferred to cross-sectional designs in developmental research because they allow age-related developmental changes to be mapped more reliably (Schmidt & Teti, 2005). Cautious interpretations can also be made about the causal relationships between these variables, although it should be recognised that, even though the changes measured are unidirectional, developmental processes may not be (Schmidt & Teti, 2005). The length of follow-up varied across studies from 4 months to 6 years. The appropriateness of the length of follow-up is related to the aim of the study, statistical analyses used, and the developmental stage of the children in the sample. Noël, Seron and Trovarelli (2004) used the shortest follow-up time of 4 months. It could be argued that this was appropriate because the children in their study were at the beginning of their mathematical education and so interference from education-related variables would be minimal. It is also possible, however, that such a short follow-up period does not
allow sufficient time for development of formal mathematical ability. This is supported by the participants' high error rate on the mathematics outcome measure. For studies aiming to evaluate the relationship between explanatory variables and rate of development in mathematical abilities, Weijer-Bergsma et al. (2014) suggested that a period of at least 2 years should be used to capture enough variation in ability. Other studies, however, have been able to draw reliable conclusions about the development of mathematical ability using a follow-up period of 1 year (e.g., LeFevre et al., 2013; Toll & van Luit, 2014).

An area of weakness for the majority of studies was the consideration of confounding variables. Of the selected studies 37% did not consider any confounding variables in their analysis, even when additional variables were highly correlated with WM, STM, or attention (e.g., Simmons et al., 2012). When confounds were considered, however, they were either accounted for using appropriate statistical techniques, or included as predictor variables in the primary analysis. This was often the case for IQ. This is important as, although WM and IQ are dissociable in children (Alloway, Gathercole, Willis, & Adams, 2004), they are still highly related constructs (see Chooi, 2012, for a review). Although some studies found that when IQ was included in the analysis domain-general abilities were no longer significant predictors of mathematical performance (study 26), the majority of studies found that the relationships between domain-general abilities and mathematical performance were independent of IQ. In these studies domain-general predictors either contributed more variance to mathematical performance than IQ, or continued to be significantly related to mathematical performance when the contribution of IQ was accounted for. These findings suggest that, although IQ may explain some of the contribution of domain-general predictors to mathematical performance, domain-
general abilities contribute additional variance in mathematical attainment to that accounted for by IQ. SES is another variable which has been found to be related to cognitive and academic development and mathematical performance (Conger & Donellan, 2007; Cowan, 2008), however, this was only accounted for in two studies, one of which received the lowest quality rating.

The description of the study sample was generally poor across studies. A high proportion of studies did not report any inclusion or exclusion criteria. This is problematic when comparing studies as the age and composition of the sample was not always clear. This may, however, reflect the cohort sampling technique often employed, for example, including all children within a particular school class. This approach potentially provides findings which can generalise to identifying the cognitive underpinnings of mathematics in a 'real-world' setting; however, this can be problematic for data analysis and interpretation. For example, if data are clustered either within schools or classrooms, the standard error of regression parameters are underestimated (Clarke, 2008) leading to the calculation of misleading significance levels for individual predictors. In some studies the clustered nature of the data was appropriately accounted for (e.g., Toll & van Luit, 2014; Weijer-Bergsma et al., 2014), while in others it was unclear if this had been considered (e.g., Andersson, 2008; Fuchs et al., 2006; Seethaler et al., 2011).

As found by Friso-van den Bos et al. (2013) the terms WM and STM were not always clearly defined or consistently applied across the studies reviewed resulting in variation in measurement of these constructs. This was further complicated in this review by the addition of attention as an explanatory variable, as some researchers consider attention to be part of the functions of the CE component of Baddeley and Hitch’s (1994) multi-component model. Clearer definitions of the constructs being
investigated would ensure that the tasks used to measure WM, STM, and attention are more clearly differentiated.

The multi-component model was the most commonly used model of WM and STM in the studies reviewed. Some studies used well-validated assessments of WM and STM which provide multiple measures of each component, for example, the Automated Working Memory Assessment (Alloway, 2007). Many studies, however, used one measure of each component, limiting the generalisability of the inferences made about the role of CE, PL, and VSSP in mathematics performance. This is particularly problematic when measuring the CE as this consists of a number of different functions (Baddeley, 2002).

Measurement of attention also varied between studies. In studies which investigated the relationship between only attention and mathematics performance a range of cognitive tasks were used to measure attention, appropriately reflecting the multi-faceted nature of this construct (Scerif, 2010; Steele et al., 2012). In studies which investigated a combination of variables, however, attention was most commonly measured using teacher- or parent-rated questionnaires of attention behaviour. The lack of correlation between cognitive and questionnaire measures of attention means they cannot be assumed to be measuring the same aspects of attention (Steele et al., 2012). This is important when interpreting the findings of studies which include attention as a predictor of mathematical performance. Some cognitive measures of attention were also used as measures of WM, for example, Bull, Espy and Wiebe (2008) included inhibition and switching tasks in their WM measures. This reflects the conceptual overlap between the CE component of WM (Baddeley, 2000; 2002) and attention more broadly (Scerif, 2010). In studies investigating the relationship between mathematics and both WM and attention,
therefore, it is important for researchers to be clear about the tasks they are using to measure each of these constructs and how they are differentiating them.

**Discussion**

Overall, this review found that WM, STM, and attention were significantly related to mathematics performance in typically developing primary school children, although not all aspects of each ability were significantly related to mathematical performance. Due to the small number of studies which included a measure of WM, STM, and attention, and the variety of tasks and statistical analyses used, clear conclusions cannot be drawn about the relative contributions of each domain-general ability to mathematical performance from these studies. The inclusion of confounding variables in the analysis, such as IQ, further affected the relationships between different aspects of the domain-general abilities and mathematics performance.

Of the four studies, which measured all three domain-general abilities, only one, which received the highest quality rating, accounted for IQ in the analysis (study 15). This study found that visuospatial STM and visuospatial WM were significant predictors of mathematics performance when IQ had already been entered into the analysis. This suggests that these domain-general abilities predict additional variance in mathematics performance beyond that predicted by IQ.

The findings related to verbal WM and IQ are more complex. Study 15 found that when IQ was accounted for in the analysis verbal WM did not significantly predict mathematics performance. This pattern was also found in study 16, which accounted for academic achievement, rather than IQ, in the analysis. These findings suggest that WM does not predict mathematical performance independently of IQ. Study 16, however, included a measure of IQ (nonverbal reasoning) as a predictor of
mathematical performance. When the contributions of other domain-general abilities, including verbal WM, were accounted for in the analysis, IQ was not a significant predictor of mathematical performance. This suggests that IQ did not predict mathematical performance independently of other domain-general abilities, including verbal WM. This suggests that while IQ and verbal WM may explain some of the same variance in mathematical performance the causal relationship between IQ, verbal WM, and mathematical performance is less clear as the order these abilities are entered into the analysis affects the interpretation of the findings.

Attention behaviour, but not executive attention, also significantly predicted mathematics performance in study 16, suggesting that attention behaviour may predict additional variance beyond general intellectual ability. As discussed above, however, this study controlled for academic achievement rather than IQ so further studies are required to elucidate the effect of IQ on the relationship between attention behaviour and mathematics performance.

Consistent with previous findings, the nature of the relationship between mathematical performance and WM, STM, and attention varied according to a number of different factors, including the age of the sample, the tasks used to measure the constructs, and the other predictor variables included in the study (Cowan, 2008; Friso-van den Bos et al., 2013). Visuospatial STM and WM were generally more strongly related to mathematics performance in younger than older children, although studies which investigated only STM found the opposite pattern. Verbal STM and WM appeared to become more strongly related to mathematics performance with age, although, this relationship varied between studies. The relationship between attention and mathematics also appeared to become stronger with age. Different components of STM, WM, and attention were related to different
aspects of mathematics and relationships between mathematical performance and
domain-general abilities were sometimes mediated by domain-specific abilities.

Strengths of the literature were: the interplay between the empirical and
conceptual literature, with empirical studies drawing on the theoretical WM, STM,
and attention literature to develop and test models of mathematical development
using statistical techniques, and the widespread use of longitudinal designs.
Statistical procedures were generally appropriately applied but it would be helpful for
more studies to explicitly consider the impact of possible clustering on the data to
ensure that misleading results are not reported. The ecologically valid cohort
sampling method often employed, although it has limitations, also encouraged useful
discussions about the relationship between the findings and appropriate
interventions for improving mathematical performance in primary school children. For
example, gaining an understanding of which cognitive abilities seem particularly
relevant for predicting mathematical performance in a heterogeneous group of
children provides a framework for identification of children who may struggle with
mathematics. It also highlights both domain-general and domain-specific
interventions which could be beneficial, such as WM training (Alloway & Alloway,
2010), or an increased emphasis on teaching number knowledge and fluency
(Vukovic et al., 2014).

Comparison of results between studies was challenging in this review as the
level of detail given about the study sample was often insufficient. In particular, the
age of the sample, and inclusion and exclusion criteria need to be reported. It would
also be helpful for definitions of WM, STM, and attention to be made explicit so that
the reader can place findings into the relevant theoretical context. This is particularly
important for WM and attention as different models propose different definitions of
these constructs and how they interrelate (see Baddeley, 2012, for a review). Further exploration of the interaction between attentional processes and the CE component of the multi-component model would be helpful to inform the interpretation of the relationship between different measures of these constructs and mathematical performance. The lack of detail provided in the studies also meant that only 30% of studies reviewed received the highest quality rating. Future studies need to provide sufficient details for the quality of the study to be determined.

Study authors need to be clear about which confounding variables they have considered in their analysis and provide a clear rationale for their inclusion or exclusion. In this review it was difficult to summarise the mediating or moderating effects of confounding variables due to the broad range considered. This issue may be improved by including a greater variety of measures for each construct as discussed above.

The multi-faceted nature of WM, STM, and attention needs to be more carefully considered. The use of a variety of tasks to measure each domain would be helpful. This needs to be balanced, however, with the length of the protocol, and the reliability and validity of the measures being used. As different types of tasks appear to be differentially related to mathematical performance, it is important that broad inferences are not made based on single measures of a construct as the inclusion of different measures could substantially alter the findings (Cowan, 2008).

**Strengths and weaknesses of this review**

Strengths of this review were that it focused on a specific population of children within a specific age range, used an objective quality assessment tool specific to studies conducting tests of association, and extended previous reviews
conducted in the area (Friso-van den Bos et al., 2013; Raghubar et al., 2010) by considering the impact of attention on mathematical performance.

A limitation of the review was that it only included correlational studies. An individual differences approach exploring differences between children with higher or lower performance in different areas of cognition is also a useful method for investigating the relationship between cognitive abilities and mathematics performance (e.g., López, 2014) which was not considered in this review. Another limitation was that the search terms may not have comprehensively captured the variety of definitions of WM, STM, and attention. In particular the term executive function can be used to refer to both WM and attention processes and this was not included in the search strategy for this review.

It should also be acknowledged that there are many other domain-general and domain-specific factors which are thought to be related to mathematical development which were not considered. This review, therefore, does not provide a full account of the factors related to mathematical performance in primary school children.

**Conclusion and future directions**

This review found that WM, STM, and attention are all associated with mathematical performance in typically developing primary school aged children. There are many factors relevant to these relationships, however, which may change the strength of the association. This is relevant for intervention research, for example, WM training. Studies in this area have produced varied results with some finding that children who complete adaptive WM training show an increase in their mathematical performance compared to baseline (Holmes, Gathercole, & Dunning,
and others finding that these children do not demonstrate any such differences (Dunning, Holmes, & Gathercole, 2013). This may be related to the types of WM task which the child was trained on and the age of the child as different WM tasks are related to different aspects of mathematics and the strength of those relationships varies with chronological age.

Future research could focus on integrating the models of mathematical development that have been developed in the current literature (e.g., LeFevre et al., 2010) into a coherent theoretical framework of mathematical development. This would help to provide a cohesive context and rationale in which to design future studies.
References


Appendices

Appendix A – Search strategy for one electronic database

Appendix B – Data extraction form

Appendix C – National Institute for Health and Care Excellence (NICE; 2012) quality appraisal checklist items for studies reporting correlations and associations

Appendix D – Instructions for authors of Pediatrics journal
Appendix A

Search strategy for electronic database

1. working memory
2. short term memory
3. phonological loop
4. visuospatial sketchpad
5. central executive
6. or/1-5
7. attention
8. math*
9. and/7-8
10. arithmetic
11. numeracy
12. or/8, 10 and 11
13. child*
14. and/13
15. school?age
16. or/13 and 15
Appendix B

Data extraction form

Systematic review of association between WM, STM and attention and mathematics performance in primary school aged children

Title

Author(s)

Source

Date: Vol.: Part: Pages:

Objective

Setting

Population

Study population – country, setting, location (urban, rural), population demographics

Sampling method

Power Calculation?

Entry and exclusion criteria

Representativeness of sample
Explanatory variables

What are the explanatory variables? How defined?

Selection of explanatory variables based on theoretical basis?

Confounding variables – what? How controlled?

Timing of measures

Instruments used

WM

STM

Attention

Were instruments validated?

Length of follow up

Outcome measures

Mathematics measures
Measures reliable?

Outcome measures complete?

Analysis

Statistical analysis

Were confidence intervals, p values or effect estimates given?

Conclusions

Author’s conclusions

Reviewer’s comments
Appendix C

National Institute for Health and Care Excellence (2012) quality appraisal checklist items for studies reporting correlations and associations

Section 1: Population

1.1 Is the source population or source area well described?

- Was the country (e.g., developed or non-developed, type of health care system), setting (primary schools, community centres etc), location (urban, rural), population demographics etc adequately described?

1.2 Is the eligible population or area representative of the course population or area?

- Was the recruitment of individuals, clusters or areas well defined (e.g., advertisement, birth register)?
- Was the eligible population representative of the source? Were important groups underrepresented?

1.3 Do the selected participants or areas represent the eligible population or area?

- Was the method of selection of participants from the eligible population well described?
- What % of selected individuals or clusters agreed to participate? Were there any sources of bias?
- Were the inclusion or exclusion criteria explicit or appropriate?

Section 2: Method of selection of exposure group

2.1 Was the selection of explanatory variables based on a sound theoretical basis?

- How sound was the theoretical basis for selecting the explanatory variables?

2.2 How well were likely confounding factors identified and controlled?

- Were there likely to be other confounding factors not considered or appropriately adjusted for?
- Was this sufficient to cause important bias?

2.3 Is the setting applicable to the UK?

- Did the setting differ significantly from the UK?

Section 3: Outcomes

3.1 Were the outcome measures and procedures reliable?

- Were outcome measures subjective or objective (e.g., biochemically validated nicotine levels ++ vs self-reported smoking -)?
- How reliable were outcome measures (e.g., inter- or intra-rater reliability scores)?
- Was there are any indication that measures had been validated (e.g.,
validated against a gold standard measure or assessed for content validity?)?

3.2 Were the outcome measures complete?

- Were all or most of the study participants who met the defined study outcome definitions likely to have been identified?

3.3 Were all the important outcomes assessed?

- Were all the important benefits and harms assessed?
- Was it possible to determine the overall balance of benefits and harms of the intervention versus comparison? Non-applicable

3.4 Was there a similar follow-up time in exposure and comparison groups?

- If groups are followed up for different lengths of time, then more events are likely to occur in the group followed-up for longer distorting the comparison.
- Analyses can be adjusted to allow for differences in length of follow-up (e.g., using person-years).

3.5 Was follow-up time meaningful?

- Was follow-up long enough to assess long-term benefits and harms?
- Was it too long, e.g., participants lost to follow-up?

Section 4: Analyses

4.1 Was the study sufficiently powered to detect an intervention effect (if one exists)?

- A power of 0.8 (i.e. it is likely to see an effect of a given size if one exists, 80% of the time) is the conventionally accepted standard.
- Is a power calculation presented? If not, what is the expected effect size? Is the sample size adequate?

4.2 Were multiple explanatory variables considered in the analysis?

- Were there sufficient explanatory variables considered in the analysis?

4.3 Were the analytical methods appropriate?

- Were important differences in follow-up time and likely confounders adjusted for?

4.4 Was the precision of association given or calculable? Is association meaningful?

- Were confidence intervals or p values for effect estimates given or possible to calculate?
- Were CIs wide or were they sufficiently precise to aid decision-making? If precision is lacking, is this because the study is under-powered?
Appendix D
Instructions for authors of Pediatrics journal

Review Article, Systematic Reviews and Meta-Analyses – Pediatrics author guidelines

Abstract length: 250 words or less (structured or unstructured, depending on review type)

Article length: 4,000 words or less

Review Articles combine and/or summarize data from the knowledge base of a topic. Preference is given to systematic reviews and meta-analyses of clearly stated questions over traditional narrative reviews of a topic. Both types of review require an abstract; the abstract of a narrative review may be unstructured (no headings, run in a single paragraph). See below for abstracts of systematic reviews and meta-analyses.

The general instructions regarding submission (including cover letter, title page requirements, contributors' statement page, journal style guidance, and conflict of interest statements) also apply to Review Articles.

Systematic Reviews and Meta-Analyses

Reports of systematic reviews and meta-analyses should use the PRISMA statement (http://www.prisma-statement.org/) as a guide, and include a completed PRISMA checklist and flow diagram to accompany the main text. Blank templates of the checklist and flow diagram can be downloaded from the PRISMA Web site (http://www.prisma-statement.org/statement.htm).
Structured abstracts for systematic reviews are recommended. Headings should include: Context, Objective, Data Sources, Study Selection, Data Extraction, Results, Limitations, and Conclusions.
Working memory, short-term memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention

Trainee Name: Emma Matthews

Primary Research Supervisor: Dr Anna Adlam
Senior Lecturer/Clinical Psychologist,
Psychology, University of Exeter

Secondary Research Supervisor: Dr Phil Yates
Academic/Research Tutor, DolinPsy Programme, University of Exeter and
Consultant Clinical Psychologist, Devon Partnership Trust

Field Collaborators: Dr Vaughan Lewis and Dr Richard Tomlinson
Consultant Paediatricians, Royal Devon and Exeter Hospital

Target Journal: Pediatrics

Word Count: 9242 words (excluding acknowledgements, abstract, references and appendices)

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Abstract

Background: Moderate to late preterm children (MLPT; born between 32 weeks and 36 weeks and 6 days) are at increased risk of developing cognitive difficulties compared to term children (born between 37 weeks and 41 weeks and 6 days). Mathematical attainment is an important area of academic development. Domain-general cognitive abilities, which constrain all learning, and domain-specific mathematical precursors are both important for mathematical development.

Objectives: The current study had two aims: 1) to investigate the relationship between gestational age (GA), mathematical attainment, working memory (WM), short-term memory (STM), and attentional control; and 2) to investigate WM, STM, and attentional control as domain-general predictors of mathematical attainment. It was hypothesised that WM would predict additional variance in mathematical attainment after attentional control, STM, and demographic variables (intellectual ability (IQ) and socioeconomic status) were accounted for.

Methods: A cross-sectional and correlational design was used to investigate the study aims. Participants were 34 MLPT children and 25 term children who were between 72 and 107 months at the time of the study. Children who weighed less than 1500 grams at birth, had cerebral palsy, epilepsy, severe hearing or vision loss, or had a diagnosed learning disability were excluded. Each participant completed a cognitive assessment which measured their mathematical attainment and components of WM, STM, and attentional control.

Results: GA was only significantly correlated with IQ. In the model of mathematical attainment, GA also significantly moderated the relationship between attentional switching and mathematical attainment. The hypothesis regarding the role of WM in
predicting mathematical attainment was partially supported as only verbal WM predicted significant additional variance in mathematical attainment. Attention behaviour and IQ also predicted significant additional variance in mathematical attainment.

**Conclusion:** These findings suggest that birth weight greater than 1500g, higher socioeconomic status, and lower levels of co-morbid medical conditions may serve as protective factors against the potential negative consequences of MLPT birth. Findings regarding the domain-general predictors of mathematical attainment supported some previous findings and highlighted the need for a variety of tasks to be used to measure each domain-general ability. Longitudinal studies in MLPT children would be helpful for further understanding the role of GA and domain-general abilities in the development of mathematical attainment.
Introduction

Six percent of all UK births are preterm, i.e. before 37 weeks gestation (Health and Social Care Information Centre, 2015). Of those preterm births 72% are between 32 and 36 weeks gestation (Health and Social Care Information Centre, 2015). Children born at this gestational age (GA) are classified as moderate (32 to 35 weeks gestation) and late (35 to 36 weeks gestation) preterm (World Health Organisation [WHO], 2012).

The risk of developmental difficulties in moderate to late preterm (MLPT) children is lower than for very preterm children (born before 32 weeks gestation; de Jong, Verhoeven & van Baar, 2012). They, however, remain at increased risk of developing difficulties related to prematurity, such as feeding difficulties, infections, and respiratory diseases, compared to term children (Bérard, Le Tiec, & De Vera, 2012; de Jong et al., 2012). The exact mechanisms of MLPT birth are unknown but it is likely to be caused by a combination of factors including: maternal infection, poor nutrition, and chronic maternal illness, such as diabetes (Goldenberg, Culhane, Iams, & Romero, 2008; Shapiro-Mendoza & Lackritz, 2012; Talay-Ongan, 1998). MLPT birth is also more likely in women with lower socioeconomic and educational status and if the pregnancy is a multiple (Goldenberg et al., 2008). It has been suggested that these sociological risk factors for MLPT birth may influence the child’s cognitive development (Brito & Noble, 2014). Evidence for this is mixed in MLPT children (Cserjesi et al., 2012; Kerstjens et al., 2011; Odd, Emond, & Whitelaw, 2012). MLPT birth, however, disrupts a critical period of neurological development (Adams-Chapman, 2006).
Approximately 65% of the total brain volume is present at 34 weeks gestation (Kinney, 2006). Studies of preterm children, including those born MLPT, have shown reductions in grey and white matter volumes, compared to term children, in temporal and parietal lobes, and the parietal association cortex (Ball et al., 2013; Soria-Pastor et al., 2009). These regions are associated with goal-setting and monitoring, working memory (WM), attention, language, social and emotional processing, number processing, and mathematics (Ball et al., 2013; Davis et al., 2009; Dehaene, Piazza, Pinel, & Cohen, 2003). Disruptions in brain development caused by MLPT birth could lead to difficulties in these domains (Kinney, 2006; Kugelman & Colin, 2013).

Consistent with this MLPT children can show a variety of cognitive difficulties compared to term children, including language, attention, verbal and visuospatial WM, and social functioning (Caravale, Mirante, Vagnoni, & Vicari, 2012; Caravale, Tozzi, Albino, & Vicari, 2005; Cserjesi et al., 2012; Kerstjens et al., 2011; Mulder, Pitchford, Hagger, & Marlow, 2009; Talge et al., 2010; van Baar, Vermaas, Knots, de Kleine, & Soons, 2009). Academically, compared to term children, MLPT children are more likely to perform worse on tests of reading, spelling, and mathematics (Chan & Quigley, 2014; Chyi, Lee, Hintz, Gould, & Sutcliffe, 2008). Although, some studies have not found these differences (e.g., Gurka, LoCasale-Crouch, & Blackman, 2010; Kirkegaard, Obel, Hedegaard, & Henriksen, 2006). Findings related to general intellectual functioning (IQ) have also been mixed, with some studies finding that MLPT children score lower than term children (e.g., Caravale et al., 2005; van Baar et al., 2009), while others found no difference (e.g., Gurka et al., 2010; Odd et al., 2012). This variation in findings may depend on the extent of co-morbid medical complications (de Jong et al., 2012).
Mathematics is an important area of academic development. Mathematical skills at school entry have been found to be better predictors of later academic achievement than early language or reading skills (Claessens & Engel, 2013; Duncan et al., 2007). Moreover, mathematical skills are strongly positively correlated with employment status and level of earnings in adulthood (Bynner et al., 2001; Geary, 2011; Grinyer, 2005). In both very preterm and term children, domain-specific and domain-general abilities have been found to be related to mathematical development (Dowker, 2005; Simms, Cragg, Gilmore, Marlow, & Johnson, 2013a). Domain-specific abilities are precursors of mathematics, such as representations of numerical magnitude, learning arithmetical procedures, and quantity comparison (Butterworth, 2005; Cantlon, 2012; Geary, 2011). Domain-general abilities are skills which influence and constrain all learning, such as IQ, WM, processing speed, and attention (Cowan, 2008; Dowker, 2005; Geary, 2011; Steele, Karmiloff-Smith, Cornish, & Scerif, 2012). Demographic variables such as socioeconomic status (SES) and the education level of parents are also important (Cowan, 2008). Building on prior research, the current study focused on three domain-general processes: WM, short-term memory (STM), and attentional control. The relationship with SES and IQ was also considered.

The dominant model of WM is the multi-component model (Baddeley, 2000; Baddeley & Hitch, 1994) which proposes that WM is composed of three systems: a phonological loop which stores verbal information (verbal STM), a visuospatial sketchpad which stores visual information (visuospatial STM), and a central executive which combines information from the verbal and visuospatial STM systems with external stimuli to enable task completion (Baddeley, 2002). In the current study WM will be used to describe tasks that require both the temporary storage (STM)
and processing (central executive) of information, and STM will be used to describe tasks that require only the storage of information.

In children, WM tasks have generally been found to be more strongly correlated with mathematics ability than STM tasks (Bull & Scerif, 2001; Cowan, 2008). Studies with term children, which have included both WM and STM variables as predictors, have generally found that WM variables are stronger predictors of mathematical attainment than STM variables (e.g., Holmes & Adams, 2006; Lee, Ng, Ng, & Lim, 2004). It has been suggested that WM variables predict general mathematical ability, while STM variables predict specific aspects of mathematics (Swanson, 2006). Based on these empirical findings, and the theoretical literature, it is possible that WM will predict general mathematical attainment beyond the contribution made by STM processes. Different relationships have also been found between mathematics performance and verbal and visuospatial STM and WM (Raghubar, Barnes, & Hecht, 2010; Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2014). It is helpful, therefore, to examine the relationship between mathematical performance and verbal and visuospatial STM and WM separately.

Attentional control is defined as the top-down control and co-ordination of attention resources that enables goal-driven tasks to be completed while ignoring potential distractions (Milham et al., 2002; Unsworth & Spillers, 2010). The ability to ignore distractors while completing a task has been termed executive attention (Rueda et al., 2004). Other important aspects of attentional control include attention switching, where the individual shifts their attention from one task to another, and divided attention, where the individual allocates their attention to two concurrent tasks (Scerif, 2010; Steele et al., 2012).
The relationship between attentional control and mathematics performance has not been investigated in MLPT children. Studies with term children have found that executive attention (LeFevre et al., 2013) and attention shifting (Commodari & Di Blasi, 2014) predict mathematical performance. Attentive behaviour at home and in the classroom has also been found to be important for mathematical attainment in term children (de Jong, 1993). Research with MLPT children has suggested that differences in attention may be related to their academic and cognitive difficulties (de Jong et al., 2012). Studies with term children, which have included measures of WM, STM, and attention, have found that the predictive significance of attentional processes on mathematical attainment varies depending on the type of attention measured. For example, when WM and STM were included in the analysis, Vukovic et al. (2014), found that attention behaviour remained a significant predictor of mathematical attainment, while Szücs et al. (2014) found that sustained attention and inhibition were not significant predictors. It is possible, therefore, that WM variables will make a contribution to mathematical attainment above that made by attentional control.

Traditionally the central executive component of the multi-component WM model (Baddeley, 2000; Baddeley & Hitch, 1994) has been ill-defined and hypothesised to include multiple cognitive processes, including aspects of attention (Baddeley, 2002). This has led some to suggest that WM and attentional control, particularly executive attention, are the same construct (e.g., Engle, 2002). Engle and colleagues’ (Engle & Kane, 2004; Kane & Engle, 2000) model of WM emphasises the role of executive attention in ensuring that information is maintained in a quickly retrievable state and not disrupted by possible distractors. This model, however, does not account for how information is integrated within the WM system to
complete problem-solving tasks. If WM variables contribute to the prediction of mathematical attainment beyond attentional control variables, this would suggest that WM and attentional control, while perhaps sharing some functions (Baddeley, 2012), are separable constructs.

The strength of the relationship between domain-general abilities and mathematics has been found to vary based on other variables included in the analysis, particularly IQ (Pina, Fuentes, Castillo, & Diamantopoulou, 2014). WM and IQ are highly related constructs (see Chooi, 2012, for a review). This could be interpreted as suggesting that any difficulties in WM are due to reductions in IQ. Research with children, however, has found that WM, STM, and IQ are dissociable (Alloway, Gathercole, Willis, & Adams, 2004; Hornung, Brunner, Reuter, & Martin, 2011) and do not measure the same underlying processes (Hornung et al., 2011). Mathematical attainment in very preterm children was significantly predicted by both IQ and WM (Simms et al., 2013b), suggesting that both abilities contribute unique variance to mathematical attainment in these children. If STM, WM, and attention contribute additional variance to mathematical attainment beyond that contributed by IQ it would suggest that these constructs are measuring additional processes beyond, or different to, those measured by IQ.

GA is also significantly correlated with mathematical development in term children, with children born at a younger GA obtaining lower scores in mathematics (Noble, Fifer, Rauh, Nomura, & Andrews, 2012). The differences between MLPT and term children on a range of cognitive abilities suggests that GA may also be related to domain-general abilities, such as WM (Caravale et al., 2005). As brain development continues throughout the 32 to 36 week gestational period (Kinney, 2006), it is possible that birth at different GAs results in differing patterns of brain
development. These differing biological constraints may lead to children born at different GAs developing domain-general cognitive abilities along different developmental trajectories (Karmiloff-Smith, 1998). If this is the case it may be that the relationship between domain-general abilities and mathematical attainment is moderated by GA.

**Current study aims and hypotheses**

The study had two aims: 1) to investigate the relationship between gestational age (GA), mathematics performance, WM, STM, and attentional control, and 2) to investigate WM, STM, and attentional control as domain-general predictors of mathematical attainment in MLPT and term children.

For Aim 1, the relationship between GA, mathematical performance and the domain-general abilities was investigated, as well as the moderating effect of GA on the relationships between the domain-general predictors and mathematical performance. No hypotheses were made about these effects as previous findings have been mixed.

For Aim 2, a hypothesis based on the literature was that WM would predict additional variance in mathematics attainment after attentional control, STM, and demographic variables (SES and IQ) were accounted for. No hypotheses were made about the differential contributions of visuospatial and verbal STM and WM to the prediction of mathematics performance as previous findings in this area have been mixed.
No hypotheses were made about the contribution of attentional control processes to mathematical performance as this was the first study to investigate this relationship in a combined group of MLPT and term children.

Method

Design

This study used a cross-sectional correlational design to investigate the relationships between GA, mathematical attainment, IQ, WM, STM, and attentional control.

Participants

Two groups of children were recruited: MLPT children (born between 32 weeks and 36 weeks and 6 days gestation) and term children (born between 37 weeks and 41 weeks and 6 days gestation). Thirty-four MLPT children (mean age = 85.9 months; range = 75-95 months) and 25 term children (mean age = 86.9 months; range = 72-103 months) participated. The mean age of the total sample (N = 59) was 86.3 months (range 72-103 months). Nineteen MLPT children were singleton births, six children were triplets, and nine children were twins. All of the term children were singleton births, and two children were siblings. One child’s first language was not English. All of the children had normal or corrected to normal hearing and vision. Three MLPT children were reported to have mild difficulties with fine motor skills.

To be included in the study children needed to be aged between 72 and 107 months at the time of the assessment, able to understand enough English to follow the standardised assessment instructions, and be able to use a computer keyboard. Children with cerebral palsy, epilepsy, diagnosed learning disability, severe loss of
hearing or vision, or a birth weight of less than 1500 grams were excluded. Additional exclusion criteria were applied for each recruitment pathway.

Participants were recruited via three pathways. The primary recruitment pathway involved searching the Royal Devon and Exeter (RD&E) hospital neonatal unit admissions database for all children who met the study inclusion criteria. To reduce the risk of biasing the sample towards children who had experienced a greater degree of post-natal complications, MLPT children who had attended the RD&E hospital for multiple neurophysiological or genetic appointments and children who were not born in the RD&E hospital were excluded. For the term children, those who were born after 42 weeks gestation, were over two days old at admission to the neonatal unit, or received any intensive or specialist care were also excluded.

Parents of eligible children were sent an information pack containing an initial contact letter (Appendix A), parent and child information sheets (Appendices B and C), and a consent to be contacted form (Appendix D). Information packs were sent to parents of 232 eligible MLPT children and 32 responses were received. Of these, 31 children were included in the study. One child’s parents agreed to participate but could not be contacted to arrange an assessment. One child was identified through their twin. This child was not initially contacted as they had not required admission to the neonatal unit following birth. Information packs were sent to parents of 126 eligible term children. 11 responses were received, all of whom were included in the study. In the second pathway, children were identified via advertisements on the University of Exeter website and in a staff newsletter (see Appendix E). Nine term children and no MLPT children were identified via this pathway. In the third pathway participants were identified through a local school. Study information packs (see
Appendix F) were sent to parents of 155 children in the target age range at the school. Two MLPT children and five term children were identified via this pathway.

An a priori sample size calculation was conducted based on Bull and Scerif's (2001) data on the prediction of mathematics ability by inhibitory control, attention shifting, and STM capacity in children aged between 7- and 8-years-old ($R^2 = .37$, $F^2 = .59$). At a power of .8 and an alpha level of .05 a total sample size of 52 participants was estimated. The analyses conducted on the present sample ($N = 59$), therefore, had sufficient power to detect an effect.

Measures

**Outcome measure.**

**Mathematical attainment.** This was measured using the Numerical Attainment Index of the Wechsler Individual Achievement Test – Second UK Edition (WIAT-II UK; Wechsler, 2005) which consists of two subtests: Numerical Operations and Mathematical Reasoning. The WIAT-II UK is a standardised assessment for measuring children’s academic achievement (Johnson, Marlow, & Wolke, 2011) and has good internal consistency with reliability coefficients ranging from .80 to .98 (Pearson Education Limited, 2015). The Numerical Attainment Index standard score (mean = 100, $SD = 15$) was used in all analyses.

**Predictor measures.**

**Intellectual ability.** IQ was measured using the two-subtest form of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II; Wechsler, 2011), which consists of the Vocabulary and Matrix Reasoning subtests. This form has good internal consistency ($\alpha = .93$) when used with children (Wechsler, 2011). The test-retest reliability of the subtests ranges from .86 to .94 for Vocabulary and
from .85 to .89 for Matrix Reasoning (Wechsler, 2011). The two-subtest form of the full scale IQ standard score (mean = 100, SD = 15) was used in all analyses.

**WM and STM.** These abilities were measured using the Automated Working Memory Assessment (AWMA; Alloway, 2007). This is a computerised standardised assessment consisting of 12 subtests measuring verbal STM, verbal WM, visuospatial STM, and visuospatial WM (Alloway, 2007). All 12 subtests were administered. Test-retest reliability for the individual subtests ranges from .69 to .90 (Alloway & Passolunghi, 2011). The three subtests within each domain were combined to produce an index standard score (mean = 100, SD = 15), which were used in the analysis as composite measures of verbal WM, verbal STM, visuospatial STM, and visuospatial WM.

**Attentional control.** Four components of attentional control were measured: attentional switching, divided attention, executive attention, and attention behaviour.

Attentional switching and divided attention were measured using the Creature Counting and Score DT! subtests respectively, from the Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson & Nimmo-Smith, 1999). The Creature Counting accuracy and Score DT! scaled scores (mean = 10, SD = 3) were used in the analysis. The test-retest reliability for these measures was .69 and .74 respectively (Manly et al., 2001).

Executive attention was measured using the Child Attentional Network Task (Child ANT; Rueda et al., 2004). The Child ANT is a computerised experimental task in which one or five fish are presented to the child and they are asked to feed the central fish by pressing a button on the keyboard which matches the direction it is facing. The task is a modified flanker task and measures the efficiency of three
attentional networks: orienting, alerting, and executive attention (Rueda et al., 2004). The conflict score is a measure of executive attention and represents the child’s ability to perform the task accurately in the presence of incongruent flankers. The score is computed by subtracting the child’s median reaction time (RT) on congruent trials from their median RT on incongruent trials and is measured in milliseconds (ms; Rueda et al., 2004). This raw score was entered into the analysis.

Attention behaviour was measured using the hyperactivity and concentration scale from the Strengths and Difficulties Questionnaire (SDQ; see below).

**Characterisation measures.**

*Demographic information.* Parents completed a short questionnaire (see Appendix G) providing information about the child’s gender, date of birth, GA at birth, birth weight, sensory ability, and any disabilities.

*Socioeconomic status (SES).* This was measured at an individual level via self-report of maternal education level, and at a neighbourhood level using the Index of Multiple Deprivation 2010 (IMD 2010). The IMD 2010 was published by the Department for Communities and Local Government (2012) and provides a measure of deprivation for each UK postcode representing the level of deprivation across seven domains: income, employment, health and disability, education and training, barriers to housing and services, living environment, and crime. The rank of a postcode compared to the rest of the UK was used as an indication of the SES of that area (Oxford Consultants for Social Inclusion, 2011).

*Child behaviour.* This was measured using the 25-item SDQ (Goodman, 1997), a parental-report questionnaire covering five areas: emotional regulation, conduct, hyperactivity and concentration, peer relationships, and prosocial
behaviour. Scores from each of these areas, apart from prosocial behaviour, are summed to give an overall stress score (Goodman, 1997). The SDQ has good concurrent and predictive validity and test-retest reliability for the overall stress score ranges from .72 to .86 (Stone, Otten, Engels, Vermulst, & Janssens, 2010). The Cronbach’s alpha score for each subscale in the current sample ranged from .38 to .80. The alpha for the overall stress scale was .74. The conduct and peer relationships subscales achieved an alpha of less than .70 suggesting they may not be reliable measures of these constructs (Kline, 1999). These two scales, therefore, were not used to characterise the sample.

The raw score from the hyperactivity and concentration scale was entered into the analysis as a measure of attention behaviour. On this scale a higher score indicates more difficulties with attention.

**Procedure and ethical considerations**

Participating parents and children were given the study information sheets prior to the assessment session and given opportunities to ask questions. Informed consent was obtained from the parent of each participating child (see Appendix H). Each child assented to participate (Appendix I). Parents and children were informed that they could withdraw from the study at any time during or after the assessment using the details on the parental information sheet.

The children completed the cognitive assessments in one session of two hours or two sessions of approximately one hour. Seven children completed the assessment over two sessions (mean = 19 days between sessions; range = 6-38 days). All sessions took place at the University of Exeter or in the child’s home. All of
the measures were administered in the same order to each child, to minimise fatigue, by the same experimenter using standardised instructions.

Parents were offered the opportunity to receive a clinical research report, supervised by a qualified clinical psychologist, with details of their child’s performance on the standardised assessment tasks. Parents were advised to speak with their child’s general practitioner or teacher if they had concerns about their child’s performance. All children were given opportunities for breaks and no children became distressed during the assessment. The study protocol was approved by the NHS Research Ethics Service (East of Scotland Research Ethics Service (EoSRES) Rec 1; reference 14/ES/1033; see Appendix J), RD&E hospital Research and Development department (see Appendix K), and the University of Exeter School of Psychology ethics committee (see Appendix L). For details of amendments to the protocol and relevant ethical approvals see Appendix M.

**Analysis plan**

**Data structure and analysis method selection.** The data had a multilevel structure. The first level (individual children) contained all of the study variables. No variables were measured at the second level (families). Forty-nine families contributed 59 participants. Each family contained between one and three children. Due to genetic and environmental influences it was possible that children from the same family would produce scores which were more similar to each other than to those of children to whom they were unrelated, violating the assumption of independence of observations. Multilevel models can be used to manage this lack of independence by taking into account the family cluster to which each child belongs.
The fit of a single-level linear regression model compared to a multilevel model was compared using a log likelihood ratio test.

The log likelihood ratio test was non-significant ($D(1) = 2.05; p = .15$) suggesting that the clustered nature of the data could be ignored. In addition, in sample sizes of 50 participants, a single-level linear regression provides the least biased estimation of the model parameters (McNeish, 2014). A single-level linear regression model with robust standard errors was selected, therefore, to analyse the data.

**Data cleaning and identifying outliers.** Data were screened using procedures recommended by Tabachnik and Fidel (1996). Missing data were all from the same variable (highest level of maternal education) suggesting that the data were not missing at random so this variable was removed from the analysis. Univariate and multivariate outliers were identified using procedures suggested by Langford and Lewis (1998). Multivariate outliers were identified by calculating Mahalanobis distances for each participant. The assumptions for parametric tests were checked.

**Aim 1: Relationship between GA, mathematical attainment and domain-general abilities.** The relationship between GA and the study variables was investigated by comparing MLPT and term children on all study variables using chi-square, Mann-Whitney U, and independent samples t-tests as appropriate given the distribution of the variables. The degree of relationship between GA and the other study variables was then explored using zero-order Pearson’s product-moment correlations (Tabachnik & Fidel, 1996). Partial correlation coefficients (controlling for IQ and SES) were also conducted.
The moderating effect of GA on the relationships between the domain-general predictors and mathematical attainment was investigated by including two-way interaction terms in the multiple linear regression analysis (see below). Significant interactions were explored using simple slopes analysis (Hayes & Matthes, 2009). The relationship between the predictor and mathematical attainment was investigated for high, low and mean levels of GA. The mean level of GA was defined as the grand mean. High and low levels of GA were defined as one standard deviation above and below the grand mean respectively (Hayes & Matthes, 2009).

**Aim 2: Domain-general predictors of mathematical attainment.** The degree of relationship between the domain-general predictors and mathematical attainment was investigated using Pearson’s product-moment correlations. A multiple linear regression analysis was then used to explore which domain-general predictors contributed significant variance to mathematical attainment. All predictor variables were centred around the grand mean to reduce multicollinearity with the interaction terms. Individual predictors were entered into the model in a sequential manner based on previous literature described above. IQ was entered on step one, GA on step two, attentional control variables on step three, WM and STM variables on step four, and all interaction terms on step five. Non-significant interactions and predictors were then removed from the model, beginning with the least significant, to find the model which best predicted mathematical attainment in this sample. The fit of the model to the data was compared after each variable removal using the AICC statistic. The AICC is a goodness-of-fit measure which takes into account model complexity and sample size (Field, 2013).

An alpha level of \( p < .05 \) was used to determine statistical significance in all analyses.
Results

Outliers

One participant was a multivariate outlier and a univariate outlier on the Child ANT accuracy measure, suggesting a lack of effort on this task. They were excluded from the analysis as they had not appeared to give their best effort during the assessment process compromising the reliability of their scores. Another child was a univariate outlier on the Child ANT accuracy measure but were not excluded as they had appeared to give good effort during assessment. Two further children were identified as multivariate outliers using the Mahalanobis distance statistic. The Cook’s distance statistic was less than one for both of these participants, however, suggesting that they did not exert undue influence on the regression model so they were retained. 58 participants were included in the analyses.

Assumptions

Tolerance statistics were all above .2 and VIF values were less than 10 for all variables suggesting there was no multicollinearity in the data (Field, 2013). Examination of the scatterplot of standardised predicted values against standardised residuals suggested that there was homoscedasticity of variance and the relationship between the variables was linear. The Shapiro Wilk test for the standardised residuals was non-significant ($W(58) = .97; p = .216$) indicating that they were normally distributed. These analyses suggested that the assumptions for multiple linear regression were met.
Aim 1: Relationship between GA, mathematical attainment and domain-general abilities

Comparisons of MLPT and term children. Table 1 shows the mean scores of the MLPT and term groups on all study variables. As expected the two groups differed significantly on GA ($U = 393.50, z = -.30, p = .76$), number of males ($\chi^2(1) = .01, p = .910$), everyday behaviour (SDQ overall stress: $U = 490.50, z = 1.23, p = .219$; SDQ emotional distress: $U = 44.50, z = .43, p = .666$; SDQ prosocial difficulties: $U = 459.50, z = .77, p = .442$), or mathematical attainment ($t(56) = 1.80, p = .077$). There was also no significant difference between the groups on SES ($t(56) = .23, p = .818$). The MLPT children’s ranking was in the 53rd percentile for the UK, while the term children’s ranking was in the 54th percentile.

There was a significant difference between the groups on IQ ($t(56) = 3.20, p = .002$), with the MLPT children obtaining lower mean scores, although both groups’ scores were in the average range (see Table 1). There were no significant differences between the groups on verbal STM ($t(56) = -.01, p = .989$), verbal WM ($t(56) = 1.49, p = .143$), visuospatial STM ($t(56) = .48, p = .633$), visuospatial WM ($U = 314.50, z = -1.54, p = .124$), attention behaviour ($U = 478, z = 1.04, p = .3$), executive attention ($t(56) = -.43, p = .670$), attentional switching ($t(56) = 1.67, p = .10$), or divided attention ($t(50.6) = .71, p = .479$).
Table 1

Mean and Standard Deviations for the MLPT and Term Groups on all Study Variables

<table>
<thead>
<tr>
<th>Measure</th>
<th>Moderate to late preterm (n = 33)</th>
<th>Term (n = 25)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clinical characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gestational age (weeks; M, SD)*</td>
<td>34.75 (1.24)</td>
<td>39.38 (1.32)</td>
</tr>
<tr>
<td>Age at assessment (months; M, SD)</td>
<td>86.18 (6.09)</td>
<td>86.92 (8.37)</td>
</tr>
<tr>
<td>Birth weight (g; M, SD)*</td>
<td>2183.97 (403.79)</td>
<td>3720.52 (821.31)</td>
</tr>
<tr>
<td>Male gender (%)</td>
<td>55</td>
<td>56</td>
</tr>
<tr>
<td>Twin birth (%)*</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>Triplet birth (%)*</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td><strong>Socioeconomic status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index of Multiple</td>
<td>17200.06 (5995.10)</td>
<td>17572.56 (6167.20)</td>
</tr>
<tr>
<td>Deprivation 2010 rank (M, SD, percentile)</td>
<td>53^rd percentile</td>
<td>54^th percentile</td>
</tr>
<tr>
<td><strong>Behaviour measures (raw scores)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDQ overall stress^a</td>
<td>9.58 (4.94)</td>
<td>8.08 (4.39)</td>
</tr>
<tr>
<td>SDQ emotional distress^a</td>
<td>2.45 (2.32)</td>
<td>2.16 (2.14)</td>
</tr>
<tr>
<td>SDQ prosocial behaviour^a</td>
<td>8.52 (1.89)</td>
<td>8.12 (2.10)</td>
</tr>
<tr>
<td><strong>Outcome measure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematical attainment^b</td>
<td>103.39 (12.32)</td>
<td>110.56 (17.93)</td>
</tr>
<tr>
<td><strong>Domain-general predictors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQ^c</td>
<td>100.97 (9.50)</td>
<td>109.08 (9.65)</td>
</tr>
<tr>
<td>Verbal STM^b</td>
<td>110 (11.26)</td>
<td>109.96 (10.10)</td>
</tr>
<tr>
<td>Verbal WM^b</td>
<td>109.76 (11.62)</td>
<td>114.6 (13.13)</td>
</tr>
<tr>
<td>Visuospatial STM^b</td>
<td>108.82 (15.17)</td>
<td>110.56 (11.35)</td>
</tr>
<tr>
<td>Visuospatial WM^b</td>
<td>111.7 (13.53)</td>
<td>116.68 (12.70)</td>
</tr>
<tr>
<td>Attention behaviour^a</td>
<td>3.85 (2.80)</td>
<td>3.04 (2.09)</td>
</tr>
<tr>
<td>Executive attention (RT, ms)</td>
<td>108.73 (74.35)</td>
<td>100.2 (75.75)</td>
</tr>
<tr>
<td>Attentional switching^c</td>
<td>8.79 (3.60)</td>
<td>10.32 (3.25)</td>
</tr>
<tr>
<td>Divided attention^c</td>
<td>11.09 (4.10)</td>
<td>11.68 (2.13)</td>
</tr>
</tbody>
</table>

*Significant at the p<.05 level, g = grams, M = mean, SD = standard deviation, SDQ = Strengths and Difficulties Questionnaire.

**Degree of relationship between GA and study variables.** The significant difference between the MLPT and term groups on IQ was investigated using a zero-order correlation to investigate the strength of this relationship (aim 1). GA and IQ were significantly positively correlated (r(56) = .31, p = .017).
Mathematical attainment and IQ were also significantly positively correlated ($r(56) = .66, p < .001$). It was possible, therefore, that the relationship between GA and mathematical attainment was confounded by their shared relationship with IQ. Another possible confound of the relationship between GA and the other study variables was SES. In this sample, however, SES was not significantly correlated with mathematical attainment ($r(56) = -.09, p = .525$). Partial correlation coefficients were calculated with and without SES held constant and the level of significance remained the same for all relationships, therefore, the analysis with only IQ controlled for is presented. The correlation coefficients are shown in Table 2.

The correlations between GA, domain-general predictors, and mathematical attainment remained non-significant when the effect of IQ was controlled.

**Aim 2: WM, STM, and attentional control as domain-general predictors of mathematical attainment**

**Degree of relationship between domain-general predictors and mathematical attainment.** Mathematical attainment was significantly positively correlated with IQ, verbal STM, verbal WM, visuospatial STM, visuospatial WM, and attentional switching (see Table 2). When IQ was controlled, however, only the correlations with verbal WM and attentional switching remained significant. Attention behaviour was significantly negatively correlated with mathematical attainment, meaning that higher mathematics scores were associated with fewer difficulties with attention behaviour.

**Domain-general abilities as predictors of mathematical attainment.** Multiple linear regression analyses using a generalised linear model with robust standard errors were conducted to investigate which predictors contributed
significant variance in mathematical attainment. SES was not significantly correlated with mathematical attainment (see Table 2), although evidence from previous research suggests that SES can be related to mathematical attainment in MLPT and term children (Brito & Noble, 2014; Cserjesi et al., 2012). The analyses were run with and without SES as a predictor and the findings did not change. The analysis without SES is, therefore, presented. Predictors were entered hierarchically into the regression. The model accounted for a significant amount of variance at the end of each step.
### Table 2
Zero-Order Correlation Coefficients Between Gestational Age and Measures of Mathematical Attainment, Socioeconomic Status, IQ, Working Memory, Short-Term Memory, and Attentional Control (Below Principle Diagonal) and Partial Correlation Coefficients Controlling for IQ (Above Principle Diagonal)

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>9</th>
<th>10</th>
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<tr>
<td>Gestational age</td>
<td>1.0</td>
<td>-.07</td>
<td>-.12</td>
<td>-</td>
<td>-.4</td>
<td>.09</td>
<td>.15</td>
<td>.11</td>
<td>-.12</td>
<td>-.03</td>
<td>.04</td>
<td>-.13</td>
</tr>
<tr>
<td>Mathematical attainment</td>
<td>.16</td>
<td>1.0</td>
<td>.06</td>
<td>-</td>
<td>.22</td>
<td>.41</td>
<td>.21</td>
<td>.19</td>
<td>-.36</td>
<td>-.01</td>
<td>.33</td>
<td>.17</td>
</tr>
<tr>
<td>Socioeconomic status</td>
<td>-.09</td>
<td>.10</td>
<td>1.0</td>
<td>-</td>
<td>.10</td>
<td>.11</td>
<td>-.08</td>
<td>.14</td>
<td>.08</td>
<td>-.08</td>
<td>-.06</td>
<td>.22</td>
</tr>
<tr>
<td>IQ</td>
<td>.31</td>
<td>.66</td>
<td>.09</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Verbal STM</td>
<td>.04</td>
<td>.33</td>
<td>.12</td>
<td>.25</td>
<td>1.0</td>
<td>.49</td>
<td>.12</td>
<td>.07</td>
<td>-.12</td>
<td>-.13</td>
<td>.25</td>
<td>.04</td>
</tr>
<tr>
<td>Verbal WM</td>
<td>.24</td>
<td>.61</td>
<td>.14</td>
<td>.54</td>
<td>.54</td>
<td>1.0</td>
<td>.48</td>
<td>.37</td>
<td>-.13</td>
<td>.13</td>
<td>.32</td>
<td>.23</td>
</tr>
<tr>
<td>Visuospatial STM</td>
<td>.21</td>
<td>.31</td>
<td>-.06</td>
<td>.24</td>
<td>.17</td>
<td>.52</td>
<td>1.0</td>
<td>.48</td>
<td>.03</td>
<td>.06</td>
<td>.16</td>
<td>.18</td>
</tr>
<tr>
<td>Visuospatial WM</td>
<td>.21</td>
<td>.36</td>
<td>.16</td>
<td>.35</td>
<td>.16</td>
<td>.48</td>
<td>.52</td>
<td>1.0</td>
<td>.35</td>
<td>-.01</td>
<td>-</td>
<td>.01</td>
</tr>
<tr>
<td>Attention behaviour</td>
<td>-.07</td>
<td>-.17</td>
<td>-.06</td>
<td>.15</td>
<td>-.08</td>
<td>-.03</td>
<td>.06</td>
<td>-.03</td>
<td>1.0</td>
<td>.18</td>
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<td>-.30</td>
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<tr>
<td>Executive attention</td>
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<td>-.13</td>
<td>-.10</td>
<td>-.19</td>
<td>-.17</td>
<td>.002</td>
<td>.01</td>
<td>.26</td>
<td>.15</td>
<td>1.0</td>
<td>.04</td>
<td>-.15</td>
</tr>
<tr>
<td>Attentional switching</td>
<td>.11</td>
<td>.40</td>
<td>-.04</td>
<td>.25</td>
<td>.29</td>
<td>.39</td>
<td>.21</td>
<td>.08</td>
<td>-.18</td>
<td>-.01</td>
<td>1.0</td>
<td>.31</td>
</tr>
<tr>
<td>Divided attention</td>
<td>-.06</td>
<td>.24</td>
<td>.23</td>
<td>.17</td>
<td>.08</td>
<td>.28</td>
<td>.21</td>
<td>.06</td>
<td>.26</td>
<td>-.18</td>
<td>.33</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Note. For zero-order correlations df = 56 and for partial correlations df = 54. *p<.05, **p<.01, ***p<.001.
IQ was entered on step one and significantly predicted mathematical attainment ($b = .98, \chi^2(1) = 29.73, p \leq .001$). GA was added in step two and did not significantly predict any additional variance in mathematical attainment above IQ ($b = -.05, \chi^2(1) = .35, p = .555$). The attentional control variables (attention behaviour, executive attention, attentional switching and divided attention) were added in step three. Evaluation of the coefficients showed that attention behaviour significantly predicted additional variance in mathematical attainment when IQ and GA were already present in the model ($b = -1.5, \chi^2(1) = 10.87, p = .001$). The WM and STM variables were entered on step four. Evaluation of the coefficients showed that only verbal WM predicted significant additional variance in mathematical attainment ($b = .34, \chi^2(1) = 5.66, p = .017$) when all other predictors were in the model. The interaction terms were entered on step five. The full model accounted for a significant amount of variance in mathematics attainment ($\chi^2(19) = 63.80, p \leq .001, R^2 = .67, \text{adjusted } R^2 = .5$). Evaluation of the coefficients showed that only the interaction between GA and attentional switching was significant ($b = .06, \chi^2(1) = 10.06, p = .002$). The unstandardised coefficients for variables in the full model are shown in Table 3.
**Table 3**

*Regression Coefficients for IQ, Gestational Age, Attentional Control, WM and STM Dependent Variables*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$b$</th>
<th>$SE$</th>
<th>Wald $\chi^2$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>105.67</td>
<td>1.56</td>
<td>4580.92</td>
<td>$\leq .001$</td>
</tr>
<tr>
<td>IQ</td>
<td>.70</td>
<td>.18</td>
<td>14.56</td>
<td>$\leq .001$</td>
</tr>
<tr>
<td>Gestational age</td>
<td>-.13</td>
<td>.08</td>
<td>2.67</td>
<td>.101</td>
</tr>
<tr>
<td>Executive attention</td>
<td>-.002</td>
<td>.02</td>
<td>.02</td>
<td>.900</td>
</tr>
<tr>
<td>Attentional switching</td>
<td>.91</td>
<td>.47</td>
<td>3.74</td>
<td>.053</td>
</tr>
<tr>
<td>Divided attention</td>
<td>-.65</td>
<td>.71</td>
<td>.82</td>
<td>.364</td>
</tr>
<tr>
<td>Attention behaviour</td>
<td>-1.40</td>
<td>.54</td>
<td>6.80</td>
<td>.009</td>
</tr>
<tr>
<td>Verbal STM</td>
<td>-.17</td>
<td>.20</td>
<td>.71</td>
<td>.398</td>
</tr>
<tr>
<td>Verbal WM</td>
<td>.38</td>
<td>.16</td>
<td>5.67</td>
<td>.017</td>
</tr>
<tr>
<td>Visuospatial STM</td>
<td>.12</td>
<td>.13</td>
<td>.97</td>
<td>.324</td>
</tr>
<tr>
<td>Visuospatial WM</td>
<td>.10</td>
<td>.10</td>
<td>.93</td>
<td>.334</td>
</tr>
<tr>
<td>Gestational age x IQ</td>
<td>-.004</td>
<td>.01</td>
<td>.15</td>
<td>.695</td>
</tr>
<tr>
<td>Gestational age x executive attention</td>
<td>-.001</td>
<td>.001</td>
<td>1.61</td>
<td>.205</td>
</tr>
<tr>
<td>Gestational age x attentional switching</td>
<td>.06</td>
<td>.02</td>
<td>10.06</td>
<td>.002</td>
</tr>
<tr>
<td>Gestational age x divided attention</td>
<td>-.03</td>
<td>.04</td>
<td>.87</td>
<td>.352</td>
</tr>
<tr>
<td>Gestational age x attentional behaviour</td>
<td>-.04</td>
<td>.03</td>
<td>2.25</td>
<td>.134</td>
</tr>
<tr>
<td>Gestational age x verbal STM</td>
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<td>.35</td>
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<tr>
<td>Gestational age x verbal WM</td>
<td>-.004</td>
<td>.01</td>
<td>.54</td>
<td>.464</td>
</tr>
<tr>
<td>Gestational age x visuospatial STM</td>
<td>.005</td>
<td>.005</td>
<td>1.03</td>
<td>.309</td>
</tr>
<tr>
<td>Gestational age x visuospatial WM</td>
<td>.01</td>
<td>.01</td>
<td>1.22</td>
<td>.269</td>
</tr>
</tbody>
</table>

**Model of mathematical attainment.** Non-significant interactions were removed from the model, with the least significant interaction being removed at each step, until only significant interactions remained (see Appendix N for full order). The interaction between GA and attentional switching remained significant ($b = .04$, $\chi^2(1) = 6.63$, $p = .01$). The fit of the full model was compared to the model with the non-significant interactions removed. The reduced model had a lower AICc value (454.94) compared to the full model.
MATHEMATICAL ATTAINMENT IN MLPT AND TERM CHILDREN

(483.71), suggesting it fit the data better. This change was significant ($\chi^2(8) = 28.76, p \leq .001$). Non-significant predictors and remaining interactions were then removed, with the least significant predictor or interaction being removed at each step, until only significant predictors and interactions remained (see Appendix N for order). The final model contained six predictors (IQ, GA, attentional switching, attention behaviour, verbal WM), and an interaction between GA and attentional switching. It significantly accounted for 63% of the variance in mathematical attainment ($\chi^2(6) = 57.36, p \leq .001, R^2 = .63, \text{adjusted } R^2 = .58$). IQ, attention behaviour, and verbal WM significantly contributed directly to the prediction of mathematical attainment. The significant interaction between GA and attentional switching suggested that the effect of attentional switching on mathematical attainment depended on the child’s GA. This final model had a lower AICC statistic (441.41) compared to the reduced model and the change was significant ($\chi^2(4) = 13.53, p = .009$), suggesting the final model fit the data better than the reduced model. The coefficients for each predictor in the final model are shown in Table 4.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$b$</th>
<th>SE</th>
<th>Wald $\chi^2$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
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<td>7789.85</td>
<td>$\leq .001$</td>
</tr>
<tr>
<td>IQ</td>
<td>.77</td>
<td>.18</td>
<td>19.22</td>
<td>$\leq .001$</td>
</tr>
<tr>
<td>Gestational age</td>
<td>-.12</td>
<td>.18</td>
<td>19.22</td>
<td>.054</td>
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<tr>
<td>Attentional switching</td>
<td>.65</td>
<td>.39</td>
<td>2.73</td>
<td>.099</td>
</tr>
<tr>
<td>Attention behaviour</td>
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<td>.45</td>
<td>7.35</td>
<td>.007</td>
</tr>
<tr>
<td>Verbal WM</td>
<td>.34</td>
<td>.12</td>
<td>8.33</td>
<td>.004</td>
</tr>
<tr>
<td>Gestational age x attentional switching</td>
<td>.04</td>
<td>.02</td>
<td>4.40</td>
<td>.036</td>
</tr>
</tbody>
</table>
The significant interaction between GA and attentional switching was investigated by testing the simple slopes for the association between attentional switching and mathematical attainment at low, mean, and high levels of GA (see analysis plan). Table 5 shows the regression coefficients and significance levels for the moderation analysis. Figure 1 plots the simple slopes for the interaction.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$b$</th>
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<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
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<td>Constant</td>
<td>105.99</td>
<td>1.84</td>
<td>57.76</td>
<td>≤ .001</td>
</tr>
<tr>
<td>Attentional switching (centred)</td>
<td>1.77</td>
<td>.60</td>
<td>2.95</td>
<td>.005</td>
</tr>
<tr>
<td>Gestational age (centred)</td>
<td>.02</td>
<td>.09</td>
<td>.24</td>
<td>.810</td>
</tr>
<tr>
<td>Attentional switching x gestational age</td>
<td>.07</td>
<td>.03</td>
<td>2.48</td>
<td>.016</td>
</tr>
<tr>
<td>Low GA</td>
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<td>.70</td>
<td>.71</td>
<td>.481</td>
</tr>
<tr>
<td>Mean GA</td>
<td>1.78</td>
<td>.60</td>
<td>2.95</td>
<td>.005</td>
</tr>
<tr>
<td>High GA</td>
<td>3.05</td>
<td>.88</td>
<td>3.49</td>
<td>.001</td>
</tr>
</tbody>
</table>

For MLPT children (low GA) there was a non-significant relationship between attentional switching and mathematical attainment, meaning that, for children with a GA one standard deviation below the mean, attentional switching did not significantly contribute to mathematical attainment. For children born on the boundary between MLPT and term birth (mean GA) there was a significant positive relationship between attentional switching and mathematical attainment which strengthened with increasing GA (high GA). This suggests that, for children born at the mean GA or one standard deviation above the mean, as a child’s attentional switching score increases their mathematical attainment...
score also increases and attentional switching makes a significant contribution
to mathematical attainment in these children.

Figure 1. Simple slopes of attentional switching predicting mathematical
attainment for low, mean, and high levels of gestational age.

Discussion

The first aim of this study was to investigate the relationship between
GA, mathematics performance, WM, STM, and attentional control. This study
found that MLPT and term children differed significantly on IQ, and GA
significantly moderated the relationship between attentional switching and
mathematical performance.

The second aim was to investigate WM, STM, and attentional control as
domain-general predictors of mathematics attainment in MLPT and term
children. The hypothesis that WM would predict additional variance in
mathematics attainment when the other variables were present in the model was partially supported as only verbal WM significantly predicted additional variance. Attention behaviour was also a significant predictor of mathematical performance.

The findings relevant to the relationship between GA and the other study variables (aim one), and domain-general predictors of mathematical attainment (aim two) will be discussed in relation to relevant theories and literature. Future research directions will be suggested.

**Relationship between GA and other study variables (Aim 1)**

MLPT children obtained IQ scores in the average range but significantly lower than term children. This difference could not be accounted for by differences in SES as found in previous studies (e.g., Kerstjens et al., 2011; Odd et al., 2012). Unlike many previous studies, no differences were found between MLPT and term children on behavioural or cognitive variables (Kerstjens et al., 2011; Mulder et al., 2009; Talge et al., 2010; van Baar et al., 2009).

The correlation between GA and IQ was of medium strength (Cohen, 1992). GA was not significantly correlated with any aspect of STM, WM, or attentional control, or with mathematical attainment. This remained the case when IQ was controlled. There are two possible explanations for this: 1) by 6- to 8-years-old MLPT children have ‘caught up’ with their peers across the domains measured in this study; 2) the exclusion of very low birth weight children (less than 1500 grams) and those with medical complications, and the relatively high SES of the children, compared to previous studies, acted as protective factors against the potential negative consequences of MLPT birth.
Longitudinal studies of MLPT children have found evidence that their cognitive development ‘catches up’ with their term peers over time. For example, difficulties with mathematics and attention that were present in MLPT children at 3- to 5-years-old were no longer present at 5- to 7-years-old (Caravale et al., 2005; Caravale et al., 2012; Chan & Quigley, 2014; Quigley et al., 2012). It is possible, therefore, that the MLPT children in this study had achieved term levels of functioning at the time of the study although they may have had difficulties when they were younger.

Low birth weight has been associated with poorer academic outcomes in MLPT children, with children who weigh less than 1500 grams having an increased risk of reading, spelling, and mathematics difficulties (Kirkegaard et al., 2006). The relatively high mean birth weight in the MLPT group in this study may have been a protective factor against the neurodevelopmental difficulties found in children born at lower birth weight (Breeze & Lees, 2007; Roberts, Bellinger, & McCormick, 2007). The exclusion of children with severe co-morbid medical difficulties, may also have reduced the likelihood of finding differences in performance between MLPT and term children as higher levels of medical complications have been associated with more cognitive and academic difficulties (de Jong et al., 2012). The relatively high SES of the MLPT children in this study, compared to previous studies, may also have been a protective factor due to there being fewer environmental barriers to the children achieving their full potential (Hackman & Farah, 2009; Roberts et al., 2007).

In the regression model of mathematical attainment, GA significantly moderated the relationship between attentional switching and mathematical attainment, with attentional switching only being significantly related to mathematical attainment in term children. As IQ was not significantly correlated
with attentional switching this finding cannot be explained by attentional switching and mathematical attainment having a shared relationship with IQ. In the current study this may be due to the relatively high WM load of the task used to measure attentional switching (Creature Counting from the TEA-Ch, Manly et al., 1999). This may confound the results, therefore, it would be helpful for future studies to use other measures of attentional switching which do not have a high WM component. It is also possible that the MLPT children’s attentional switching ability was not as well developed as the term children’s. Although there was not a significant difference between the groups on this task, it may be that the MLPT children’s attentional switching ability was not as efficient as the term children’s meaning it was not as useful when completing the mathematical tasks. This significant moderation finding needs to be replicated and explored further in future studies.

**Domain-general predictors of mathematical attainment (Aim 2)**

When IQ, GA, STM and WM variables were added into the model only verbal WM significantly predicted additional variance in mathematical attainment. This finding may reflect the children’s high use of verbal strategies, such as counting, which draw heavily on verbal WM resources, to complete the mathematical tasks (Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Hecht, 2002). It may also reflect the children’s use of mental arithmetic, which requires verbal WM resources to maintain intermediate results, to complete calculations (DeStefano & LeFevre, 2004). As IQ was already present in the model this suggests that the verbal WM tasks used in this study are measuring something different to the tasks measuring IQ.

STM variables did not predict any additional variance in mathematical attainment when all other variables were present in the model, including IQ.
This is consistent with previous research that suggests that although STM processes are useful for mathematical attainment they do not contribute any additional variance when WM and IQ are also present in the model (Alloway & Alloway, 2010; Vanbinst, Ghesquière, & de Smedt, 2015). The lack of significant correlation between mathematical attainment and STM variables when IQ was controlled suggests that the relationship between STM abilities and mathematical attainment may be due to their shared relationship with IQ. This could be taken to support previous findings that STM is one cognitive ability that underlies IQ (Hornung et al., 2011). Another view is that STM systems are related to domain-specific abilities, which are then related to mathematical attainment. STM systems have been found to be indirectly related to mathematical attainment via number knowledge, numerical magnitude comparisons, and number line estimation (Krajewski & Schneider, 2009; Simmons, Willis, & Adams, 2012; Vanbinst et al., 2015; Vukovic et al., 2014). It would be helpful for future studies to include both domain-specific and domain-general predictors to investigate this further.

Visuospatial WM was not a significant predictor of mathematical attainment, when all other variables were included in the model, contrary to many previous studies (e.g., Bull, Espy, & Wiebe, 2008; Szűcs et al., 2014). As this study used well-validated tasks to measure visuospatial WM it seems unlikely that this finding was due to insensitivity of the tasks (e.g., Gathercole & Pickering, 2000). Rather, it may be that visuospatial WM was less relevant to the mathematical tasks administered in this study than verbal WM. Presenting mathematical calculations aurally, as in the current study, predisposes individuals to recruit verbal rather than visuospatial WM systems (Logie, Gilhooly, & Wynn, 1994). In addition, two of the three verbal WM tasks in this
study involved numbers (counting span and backward digit recall). Some have suggested that measures which use numbers are more strongly related to mathematical ability than measures which do not (Raghubar et al., 2010). Not all studies, however, have found this association (Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013). Another possibility is that the relationship between visuospatial WM and mathematical attainment can be explained by their shared relationship with IQ. This could be due to the tasks used to measure IQ in this study. Matrix reasoning particularly draws on visuospatial WM abilities and has previously been found to help explain the relationship between IQ and WM abilities (Harrison, Shipstead, & Engle, 2015).

Unlike some previous studies SES was not related to mathematical attainment (Cowan, 2008; Pina et al., 2014). This could be attributed to the use of a different measure of SES in this study which encapsulated deprivation from a number of influences at a neighbourhood level, rather than focusing on parental education. It may be, however, that rather than having a direct relationship with mathematical attainment, SES moderates the relationship between domain-general predictors and mathematical attainment. Future research could explore this possibility in more detail.

When the attentional control variables were added into the model, after IQ and GA, only attention behaviour predicted significant additional variance in mathematical attainment. This may be because attentive behaviour allows children to better access learning opportunities resulting in higher test scores (de Jong, 1993). In this study there were no significant correlations between any of the attentional control variables and IQ, suggesting that the contribution of attentional processes to mathematical attainment is not due to a shared relationship with IQ.
It was surprising that executive attention was not a significant predictor of mathematics attainment as previous studies have found a strong relationship between these two abilities (Commodari & Di Blasi, 2014; LeFevre et al., 2013). Previous studies have found that executive attention does not predict mathematical attainment in 6-year-olds but does in 8- to 10-year-olds (Commodari & Di Blasi, 2014; LeFevre et al., 2013). This may reflect the development of attentional processes during childhood. Some attentional processes, such as simple motor inhibition, are fully developed by 6-years-old (Klenberg, Korkman, & Lahti-Nuuttila, 2001; Steele et al., 2012), while more complex skills, such as executive attention, continue to develop into adolescence (Klenberg et al., 2001). The executive attention abilities of the children in the current study, therefore, may not have been sufficiently developed to be useful when completing mathematical tasks.

**Strengths and limitations of the study**

Strengths of the current study were the use of a wide range of tasks to measure each cognitive ability, the consideration of IQ and SES as confounding variables, and the investigation of the relationship between domain-general abilities and mathematics in a novel population (MLPT children).

A limitation of the study is that prenatal factors relevant to MLPT birth, such as maternal illness during pregnancy, were not measured. It is possible that these factors are related to childhood cognitive development independently of the neurological changes related to MLPT birth. Additionally, although this study attempted to reduce the risk of biasing the MLPT sample towards children with a greater degree of post-natal complications, data on this was not collected. It is possible that some MLPT children, particularly those for whom hospital records were not available, had more post-natal complications than
others. This reduces the generalisability of the findings. It would be helpful for future research to measure these variables to more accurately characterise the participants.

Another limitation is the cross-sectional design which limits conclusions about the causal relationships between domain-general predictors and mathematical attainment. It is possible that the domain-general abilities which significantly predict concurrent mathematical ability are not the same as those which predict future mathematical ability. Indeed, previous findings in term children that different aspects of WM and STM are important at different chronological ages suggests that this is likely to be the case (McKenzie, Bull, & Gray, 2003). The domain-general abilities found to be important for mathematical attainment in this study, therefore, can only be generalised to children of a similar age. Longitudinal studies involving MLPT children would be helpful in further exploring the relationships between mathematical attainment and domain-general abilities in this population.

In addition, there are many other factors which may contribute to the prediction of mathematical attainment in children, such as reading and language ability (Fuchs et al., 2006), children’s attitudes to mathematics (Dowker, 2005), and educational factors, such as characteristics of the child’s teacher. This study also did not include any domain-specific factors, which may moderate the relationship between domain-general abilities and mathematical attainment (e.g., Vukovic et al., 2014). This study, therefore, does not provide a comprehensive account of the cognitive abilities which contribute to mathematical attainment in MLPT and term children.
Clinical implications

Overall, the findings of this study do not suggest that all MLPT children have cognitive and academic difficulties. Thorough assessment, therefore, is needed to identify any difficulties a MLPT child may experience. The need for assessment is supported by the significant moderation analysis finding that attentional switching was only significantly related to mathematical attainment in term children. This suggests that the developmental trajectory for attentional switching in MLPT children may not be the same as that for term children. Routine follow-up of MLPT children would provide an opportunity for these children’s cognitive and academic development to be monitored and appropriate interventions implemented in a timely manner.

Previous studies have found that early interventions with preterm children can have a positive impact on their cognitive abilities. For example, in their review Orton et al. (2009) found that preventative interventions, such as developmental education packages (Avon Premature Infant Project, 1998), parenting support, and child development centre services (McCarton et al. 1997) increased the developmental quotient scores of preterm infants who had received the intervention compared to preterm infants who had received standard follow-up. The impact of these interventions appears to be sustained into school-age (McCarton et al., 1997). As the current study found that even low risk MLPT children obtain lower IQ scores, albeit in the average range, than term children, further research into these preventative interventions with MLPT children could be helpful for improving cognitive outcomes in these children.

The findings related to the domain-general predictors of mathematical attainment suggest that domain-general training programs which aim to improve mathematical attainment, such as WM training (e.g., Holmes, Gathercole, &
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Dunning, 2009), may be useful. Research which has investigated the
effectiveness of WM training in very preterm children (less than 28 weeks GA)
has shown some promising results (e.g., Grunewaldt, Løhaugen, Austeng,
Brubakk, & Skranes, 2013) but the effect of this on mathematical attainment has
not been explored. Any domain-general intervention that aims to improve
mathematical attainment, however, needs to take into account the relationships
between the domain-general processes and specific aspects of mathematical
performance. For example, in typically developing primary school children,
Simmons et al. (2012) found that performance on central executive tasks
predicted unique variance in addition accuracy, while visuospatial STM
predicted unique variance in number writing and judgements of symbolic
magnitude. Verbal STM contributed unique variance to multiplication accuracy.
A WM training intervention, therefore, aiming to improve mathematical
performance would need to ensure that the tasks on which the child is trained
are relevant for the aspect of mathematical performance that the intervention is
aiming to improve.

Conclusion

In this study GA was significantly correlated with IQ but was not a
significant predictor of mathematical attainment. These findings suggest that
higher SES and birth weight, and lower levels of co-morbid medical conditions
may serve as protective factors against the potential negative consequences of
MLPT birth. GA did significantly moderate the relationship between attentional
switching and mathematical attainment. This may reflect the different rates of
cognitive development in MLPT and term children. This finding, however, needs
to be replicated in future studies.
Mathematical attainment was significantly predicted by IQ, attention behaviour, and verbal WM. The specific role of verbal WM may be due to the nature of the WM and mathematics tasks used in this study. The inclusion of domain-specific abilities in the model could, however, moderate the relationships between WM, STM and mathematical attainment. The age of the participants in the study was also important for explaining why some aspects of attentional control were not significant predictors of mathematical attainment. The shared relationship between some of the domain-general abilities, IQ and mathematical attainment could explain some of the findings but not all.

Overall, this study suggests that investigating the cognitive underpinnings of mathematical attainment in MLPT and term children may be helpful for informing the identification of children with mathematical difficulties and implementing appropriate interventions.
References


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Appendices

Appendix A – Initial contact letter

Appendix B – Parent information sheets – preterm and term versions

Appendix C – Child information sheets – preterm and term versions

Appendix D – Consent to be contacted form

Appendix E – Advertisements placed on the University of Exeter website and in a staff newsletter

Appendix F – Initial contact letter, parent and child information sheets sent to parents of eligible children at a local school

Appendix G – Demographic information questionnaire

Appendix H – Parental consent form

Appendix I – Child assent form

Appendix J – NHS ethics approval letter

Appendix K – R&D ethics approval letter

Appendix L – School of Psychology ethics committee approval letter

Appendix M – Details of amendments made to protocol and ethical approvals

Appendix N – Order in which non-significant interactions and predictors were removed from the regression model

Appendix O – Instructions for authors of Pediatrics journal

Appendix P – Dissemination statement
Dear parent/guardian of

I am writing to provide you with some information about a research study that we are supporting. I am contacting you because your child was born at the Royal Devon and Exeter Hospital and is now aged between 6 and 8 years old.

The study, “Working memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention”, is being conducted by Emma Matthews, Trainee Clinical Psychologist, supervised by Dr Anna Adlam (University of Exeter) as part of her Doctorate in Clinical Psychology qualification. The study aims to investigate the impact of memory and attention on maths ability in children born prematurely as well as children born at term. I have enclosed the information sheet for the study along with an information sheet for your child to read to help you make a decision about whether you would like to participate in the study.

If you would like to find out more about the study, please contact Emma Matthews using one of the following ways:

- Complete the enclosed consent to share contact details form and return this to Emma at the address provided.
- Contact Emma directly via email on em358@exeter.ac.uk.
- Contact Emma via the research group voicemail: 01603 59 1507
- Register your interest online via www.exeter.ac.uk/ccnr/getinvolvedmaths

I would like to take this opportunity to inform you that your decision to participate in this research is voluntary. Your decision to participate, or not, will not affect the care that you might receive from members of the clinical team or other services in the future.

Thank you for taking the time to consider this request.

Yours sincerely

Dr Richard Tomlinson
Consultant Paediatrician
Please keep this sheet for your reference. You can take your time to read this information and I will be available if you want to ask any questions during or after you have read the information below.

Aims of the study

The aim of the study is to investigate the thinking skills that are related to maths performance. In particular this study will focus on working memory and attention. Working memory is the ability to store information for a short period of time while completing a task, for example working out a maths sum in your head. It is important for learning many skills and research has shown that children’s abilities in this area can be related to their maths skills. How well a child can pay attention to tasks they need to complete when there are distractions is called attentional control and it has been shown to be related to working memory performance. So this study is asking if attentional control is also related to maths performance in children. The study will look at these relationships in both children born prematurely and those born at term to see if these skills are linked in a similar way on both groups of children.

This study has been granted full ethical approval by the NHS Research Ethics Committee (East of Scotland Research Ethics Service (EoSRES) Rec 1; reference 14/ES/1033) and by the School of Psychology ethics committee at the University of Exeter. The study is being completed in collaboration with Dr Vaughan Lewis on the Neonatal Unit at the Royal Devon and Exeter Hospital. No clinical details other than gestational age at delivery have been shared.

Why has my child been invited to take part?

For this study I am interested in children who were born between 32 weeks and 36 weeks gestation. From medical records we can see that your child was born in this period and is now between 6 and 8 years old.

Maths is a core area of learning for children at the beginning of their school lives. Research has shown that a child’s ability at maths at a young age can affect their performance in other areas, such as reading, and learning of other skills and academic subjects. If we can find out what thinking skills contribute to maths performance we can try and put appropriate interventions in place to help
children who may be struggling in those areas and so improve their maths ability. However, we need to know what skills are related to maths performance in order to know what those interventions might be.

**What will my child be asked to do?**

Your child will be asked to complete some activities which look at your child’s intellectual ability, working memory, attentional control and maths ability. The tasks will require your child to answer questions about words, look at pictures, complete some maths problems and do some activities on a computer. The computer tasks involve your child looking at pictures and listening to words and trying to remember different aspects of what they have been shown. Some of the tasks will involve your child paying attention to pictures and making decisions as quickly as they can. The session should not take longer than 90 minutes.

To thank your child for participating they will be given a small gift, such as a sheet of stickers.

**Do I have to do anything?**

You will be asked to complete two short questionnaire about your child’s memory abilities and about their general behaviour at home.

**Does my child have to take part?**

No. It is up to you to decide if you would like your child to take part in the study. If you agree we will go through an information sheet with your child to check that they are happy to take part. If you or your child decide that you do not want to take part in the research at any time they do not have to. Your child will be given opportunities to say if they do not wish to continue with the research.

**What are the possible disadvantages and risks of taking part?**

Being part of this research involves you and your child giving up your time to complete these activities. If your child becomes tired during the session they can take regular breaks. In the unlikely event that your child becomes upset or distressed in any way the assessments will be stopped immediately.

Some children do not enjoy these activities and may find them difficult or upsetting to complete. If this is the case your child will be given the opportunity to take a break or to stop completing the activities.

As a result of taking part in this research you may find out that your child has some difficulties with working memory and/or maths that you did not know about before. This can be upsetting. If this is the case you will be informed of this and information will be provided about where you can get further help and support for your child.
What are the possible benefits of taking part?

The results of this study should help us to know more about what thinking skills are important for maths performance. This will help us to work out what interventions may be helpful for children who have difficulties with maths or have difficulties in these thinking skills in order to improve their performance.

If you would like a research report to be written about your child’s performance on the working memory and maths tasks you can ask for this on the consent form provided at the assessment session. You can also ask to receive a summary of the research results by circling the appropriate option at the bottom of the same consent form. You will be reminded of this at the assessment session.

What will happen to the data?

This research is being conducted by Emma Matthews, Trainee Clinical Psychologist at the University of Exeter, under the supervision of Dr Anna Adlam, Senior Lecturer at the University of Exeter. The research is being completed to fulfil the requirements of the University of Exeter Doctorate in Clinical Psychology.

In accordance with University of Exeter Open Research Exeter policy, the thesis will also be stored electronically at the University of Exeter, and will be accessible online (open access). The study findings might also be written up for publication in research journals and presented at conferences. The published journal article will also be available online (open access, University of Exeter). These research reports and presentations will not contain any identifiable information about your child as the results will only be presented as a group.

All study results (data) will be anonymised and securely stored electronically at the University of Exeter. In accordance with the University of Exeter Open Research Exeter, the anonymised data will be available online (open access) through the Open Research Exeter database.

Expenses

As this research is being conducted as part of my Doctorate in Clinical Psychology I am unable to reimburse any travel costs you may incur attending the session with your child.

You can withdraw your child from this study at any time and you do not need to give a reason for this. Withdrawing from the study will not affect any current or future services your child may receive. The research is due to be submitted to the university on the 5th May 2015, therefore for practical reasons if you decide that you would rather that your child’s information was not included in the project it would be appreciated if you would contact Emma Matthews by 30th March 2015 by email on em358@exeter.ac.uk or write to Emma Matthews, Doctorate in Clinical Psychology, Washington Singer, Laboratories, Perry Road, Exeter, EX4 4QG.
Please keep this sheet for your reference. You can take your time to read this information and I will be available if you want to ask any questions during or after you have read the information below.

Aims of the study

The aim of the study is to investigate the thinking skills that are related to maths performance. In particular this study will focus on working memory and attention. Working memory is the ability to store information for a short period of time while completing a task, for example working out a maths sum in your head. It is important for learning many skills and research has shown that children’s abilities in this area can be related to their maths skills. How well a child can pay attention to tasks they need to complete when there are distractions is called attentional control and it has been shown to be related to working memory performance. So this study is asking if attentional control is also related to maths performance in children. The study will look at these relationships in both children born prematurely and those born at term to see if these skills are linked in a similar way on both groups of children.

This study has been granted full ethical approval by the NHS Research Ethics Committee (East of Scotland Research Ethics Service (EoSRES) Rec 1; reference 14/ES/1033) and by the School of Psychology ethics committee at the University of Exeter. The study is being completed in collaboration with Dr Vaughan Lewis on the Neonatal Unit at the Royal Devon and Exeter Hospital. No clinical details other than gestational age at delivery have been shared.

Why has my child been invited to take part?

For this study I am interested in children who were born at term so that I can compare them to children who were born prematurely. From medical records we can see that your child was born between 2007 and 2009 and is therefore eligible to take part.

Maths is a core area of learning for children at the beginning of their school lives. Research has shown that a child’s ability at maths at a young age can affect their performance in other areas, such as reading, and learning of other skills and academic subjects. If we can find out what thinking skills contribute to maths performance we can try and put appropriate interventions in place to help children who may be struggling in those areas and so improve their maths
ability. However, we need to know what skills are related to maths performance in order to know what those interventions might be.

**What will my child be asked to do?**

Your child will be asked to complete some activities which look at your child’s intellectual ability, working memory, attentional control and maths ability. The tasks will require your child to answer questions about words, look at pictures, complete some maths problems and do some activities on a computer. The computer tasks involve your child looking at pictures and listening to words and trying to remember different aspects of what they have been shown. Some of the tasks will involve your child paying attention to pictures and making decisions as quickly as they can. The session should not take longer than 90 minutes.

To thank your child for participating they will be given a small gift, such as a sheet of stickers.

**Do I have to do anything?**

You will be asked to complete two short questionnaire about your child’s memory abilities and about their general behaviour at home.

**Does my child have to take part?**

No. It is up to you to decide if you would like your child to take part in the study. If you agree we will go through an information sheet with your child to check that they are happy to take part. If you or your child decide that you do not want to take part in the research at any time they do not have to. Your child will be given opportunities to say if they do not wish to continue with the research.

**What are the possible disadvantages and risks of taking part?**

Being part of this research involves you and your child giving up your time to complete these activities. If your child becomes tired during the session they can take regular breaks. In the unlikely event that your child becomes upset or distressed in any way the assessments will be stopped immediately.

Some children do not enjoy these activities and may find them difficult or upsetting to complete. If this is the case your child will be given the opportunity to take a break or to stop completing the activities.

As a result of taking part in this research you may find out that your child has some difficulties with working memory and/or maths that you did not know about before. This can be upsetting. If this is the case you will be informed of this and information will be provided about where you can get further help and support for your child.
What are the possible benefits of taking part?

The results of this study should help us to know more about what thinking skills are important for maths performance. This will help us to work out what interventions may be helpful for children who have difficulties with maths or have difficulties in these thinking skills in order to improve their performance.

If you would like a research report to be written about your child’s performance on the working memory and maths tasks you can ask for this on the consent form provided at the assessment session. You can also ask to receive a summary of the research results by circling the appropriate option at the bottom of the same consent form. You will be reminded of this at the assessment session.

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All study results (data) will be anonymised and securely stored electronically at the University of Exeter. In accordance with the University of Exeter Open Research Exeter, the anonymised data will be available online (open access) through the Open Research Exeter database.

Expenses

As this research is being conducted as part of my Doctorate in Clinical Psychology I am unable to reimburse any travel costs you may incur attending the session with your child.

You can withdraw your child from this study at any time and you do not need to give a reason for this. Withdrawing from the study will not affect any current or future services your child may receive. The research is due to be submitted to the university on the 5th May 2015, therefore for practical reasons if you decide that you would rather that your child’s information was not included in the project it would be appreciated if you would contact Emma Matthews by 30th March 2015 by email on em358@exeter.ac.uk or write to Emma Matthews, Doctorate in Clinical Psychology, Washington Singer, Laboratories, Perry Road, Exeter, EX4 4QG.
INFORMATION SHEET FOR CHILDREN

Memory, maths and attention in children

You can read this sheet by yourself or you can ask me or your mum or dad to read it with you. You can ask questions about anything on this sheet or about anything else you are not sure about.

What is research?

Research is a way we try to find out the answers to questions. Before any research is allowed to happen it has be checked by a group of people called a Research Ethics Committee. They make sure that the research is fair. Your project has been checked by the National Health Service Research Ethics Committee.

Why is this project being done?

I am trying to find out why some children find maths, like counting or doing sums, hard but some children find it easy. We think that your memory and your attention, that is how well you can pay attention to things without being distracted by something else, might be linked to how easy or hard you find maths.

Some children are born before the doctors think they are going to be born. When this happens the baby is called a premature baby. We want to find out how good children who were premature babies are at maths and how their memory and attention is linked to how well they can do maths. We are then going to see how they compare to children who were not premature babies to see if there are any differences in how memory, attention and maths link together in children who were premature and those who were not.

Why have I been asked to take part?

You have been invited to take part in this study because you were a premature baby and you are now between 6 and 7 years old.

All together I am going to see 60 children including you, 30 children who were premature babies and 30 children who were not premature babies.
Do I have to take part?

No. It is up to you. You don’t have to take part in this research if you don’t want to. Deciding not to take part is ok. I will ask you for your assent and I will give you a copy of this information sheet for you to keep. You can stop taking part at any time during the research without giving a reason. If you are not sure about taking part after you have read this information you can talk to your mum or dad to help you decide.

What will happen to me if I take part?

You will only need to come here once. So after today you won’t need to come back. I am going to ask you to do some maths puzzles, tell me the meanings of some words and look at some patterns. I am also going to ask you to play some games on the computer. The session today should not take more than 90 minutes.

Might anything about the research upset me?

You might find some of the games and puzzles easy but you might find some of them hard. It can make you sad if something is hard for you. All children will find some of the games and puzzles hard and you can tell me if you want a break.

It doesn’t matter if you get any answers wrong. I would just like you to do your best. I will tell you what to do for each game or puzzle and you can ask me questions if you are not sure.

Will anyone else know how I did?

I will tell your mom or dad about the things you find easy or hard if they want me to.

Will joining in help me?

Joining in might not help you but what we find out from this research might help children who find maths hard because we will be able to think about things that might help them.

What if I don’t want to do the research anymore?

If at any time you don’t want to do the research anymore, just tell me or your parents. We will not be cross with you.

Do you understand what I am asking you to do?

Would you like to ask me any questions?
Memory, maths and attention in children

You can read this sheet by yourself or you can ask me or your mum or dad to read it with you. You can ask questions about anything on this sheet or about anything else you are not sure about.

What is research?

Research is a way we try to find out the answers to questions. Before any research is allowed to happen it has be checked by a group of people called a Research Ethics Committee. They make sure that the research is fair. Your project has been checked by the National Health Service Research Ethics Committee.

Why is this project being done?

I am trying to find out why some children find maths, like counting or doing sums, hard but some children find it easy. We think that your memory and your attention, that is how well you can pay attention to things without being distracted by something else, might be linked to how easy or hard you find maths.

Some children are born before the doctors think they are going to be born. When this happens the baby is called a premature baby. We want to find out how good children who were premature babies are at maths and how their memory and attention is linked to how well they can do maths. We are then going to see how they compare to children who were not premature babies to see if there are any differences in how memory, attention and maths link together in children who were premature and those who were not.

Why have I been asked to take part?

You have been invited to take part in this study because you were not a premature baby and you are now between 6 and 7 years old.

All together I am going to see 60 children including you, 30 children who were premature babies and 30 children who were not premature babies.

Do I have to take part?

No. It is up to you. You don’t have to take part in this research if you don’t want to. Deciding not to take part is ok. I will ask you for your assent and I will give you a copy of this information sheet for you to keep. You can stop taking part at
any time during the research without giving a reason. If you are not sure about taking part after you have read this information you can talk to your mum or dad to help you decide.

**What will happen to me if I take part?**

You will only need to come here once. So after today you won’t need to come back. I am going to ask you to do some maths puzzles, tell me the meanings of some words and look at some patterns. I am also going to ask you to play some games on the computer. The session today should not take more than 90 minutes.

**Might anything about the research upset me?**

You might find some of the games and puzzles easy but you might find some of them hard. It can make you sad if something is hard for you. All children will find some of the games and puzzles hard and you can tell me if you want a break.

It doesn’t matter if you get any answers wrong. I would just like you to do your best. I will tell you what to do for each game or puzzle and you can ask me questions if you are not sure.

**Will anyone else know how I did?**

I will tell your mom or dad about the things you find easy or hard if they want me to.

**Will joining in help me?**

Joining in might not help you but what we find out from this research might help children who find maths hard because we will be able to think about things that might help them.

**What if I don’t want to do the research anymore?**

If at any time you don’t want to do the research anymore, just tell me or your parents. We will not be cross with you.

Do you understand what I am asking you to do?

Would you like to ask me any questions?
PARENT/GUARDIAN CONSENT TO CONTACT FORM

Working memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention

Researcher: Emma Matthews

Please return this form to: Emma Matthews, Doctorate in Clinical Psychology, Washington Singer Laboratories, Perry Road, Exeter, EX4 4QG.

Please initial boxes

1. I have received information about the above study.

2. I consent to be contacted by Emma Matthews about my child taking part in this research.

3. I am aware that I can contact Emma Matthews to ask any further questions about the study and that I will be given more information about the study before consenting for my child to participate.

4. I understand that my contact details will be kept confidential and will not be shared outside of the research team.

5. I understand that I and my child are under no obligation to take part in this study.

Please include your contact details below and return to the address at the top of this form.

Child’s name_____________________________________

Address_________________________________________

_________________________________________________________________________

_________________________________________________________________________

Contact telephone number___________________________

Email address_____________________________________

Preferred contact method (telephone, email, post)_______________________________

Name of parent/guardian___________________________________
Advertisements placed on the University of Exeter website and in a staff newsletter

**Advertisement for University of Exeter website** - [http://www.exeter.ac.uk/research/takepart/](http://www.exeter.ac.uk/research/takepart/)

**Research study**
Postgraduate clinical psychology research project

Trainee Clinical Psychologist Emma Matthews is looking for 6 to 8 year olds who were born at term or between 32 and 36 weeks gestation to take part in her postgraduate research project.

Emma is investigating the thinking skills that are related to maths performance in children, particularly memory and attention. Volunteers will be asked to complete one 1.5 hour session where they will be asked to complete a variety of puzzles and games. Parents/guardians will be asked to complete some brief questionnaires about their child.

Sessions can be arranged at a convenient time for you, including weekends and evenings.

Recruitment will end in February 2015 (approximately).

If you are interested please sign up using the online form [here](http://www.exeter.ac.uk/ccnr/getinvolvedmaths) or contact Emma directly (this will be a hyperlink which will allow people to email Emma directly).

**Advertisement for University of Exeter faculty newsletter**

**Research study volunteers**
Postgraduate Trainee Clinical Psychologist, Emma Matthews, is looking for volunteers for her research project investigating the thinking skills that are related to maths performance in children, particularly memory and attention. Emma is particularly interested in the link between these skills in children born prematurely. Young volunteers are required between the ages of 6 and 8 years, who were born at term or between 32 and 36 weeks gestation, to complete one 1.5 hour session where they will be asked to complete a variety of puzzles and games. Parents/guardians will be asked to complete some brief questionnaires about their child. If you have a child aged 6-8 years and you are interested in finding out more about this study please contact Emma (this will be a link which will allow interested people to email Emma directly) or register your interest using [this online form](http://www.exeter.ac.uk/ccnr/getinvolvedmaths).
Initial contact letter

Dear parent/guardian,

We are writing to invite you and your child to participate in some research which is being conducted in conjunction with the Neonatal unit at the Royal Devon and Exeter Hospital. You have been contacted because your child is aged between 6 and 8 years old.

The study “Working memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention”, is being conducted by Emma Matthews, Trainee Clinical Psychologist, supervised by Dr Anna Adlam (University of Exeter) as part of my Doctorate in Clinical Psychology qualification. The study aims to investigate the impact of memory and attention on maths ability in children born prematurely as well as children born at term. We have enclosed the information sheet for the study along with an information sheet for your child to read to help you make a decision about whether you would like to participate in the study.

If you would like to find out more about the study, then please let Emma Matthews know in one of the following ways:

- Complete the enclosed consent to share contact details form and return this to Emma at the address provided.
- Contact Emma directly via email on em358@exeter.ac.uk.
- Contact Emma via the research group voicemail: 01603 59 1507
- Register your interest online via www.exeter.ac.uk/ccnr/getinvolvedmaths

Your decision to participate in this research is completely voluntary. Your decision to participate, or not, will not affect any care or support you might need from the Royal Devon and Exeter Hospital or University of Exeter in the future.

Thank you for taking the time to consider this request.

Yours sincerely

[Signature]
PARENT/GUARDIAN CONSENT TO CONTACT FORM

Working memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention

Researcher: Emma Matthews

Please return this form to: Emma Matthews, Doctorate in Clinical Psychology, Washington Singer Laboratories, Perry Road, Exeter, EX4 4QG.

Please initial boxes

6. I have received information about the above study.

7. I consent to be contacted by Emma Matthews about my child taking part in this research.

8. I am aware that I can contact Emma Matthews to ask any further questions about the study and that I will be given more information about the study before consenting for my child to participate.

9. I understand that my contact details will be kept confidential and will not be shared outside of the research team.

10. I understand that I and my child are under no obligation to take part in this study.

Please include your contact details below and return to the address at the top of this form.

Child’s name_____________________________________

Address__________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

MATHEMATICAL ATTAINMENT IN MLPT AND TERM CHILDREN

Parent information sheet

Please keep this sheet for your reference. Take your time to read this information and feel free to contact me using the details on the letter enclosed with this sheet if you would like to ask any questions.

Aims of the study

The aim of the study is to investigate the thinking skills that are related to maths performance. In particular, this study will focus on working memory and attention. Working memory is the ability to store information for a short period of time while completing a task, for example working out a maths sum in your head. It is important for learning many skills and research has shown that children’s abilities in this area can be related to their maths skills. How well a child can pay attention to tasks they need to complete when there are distractions is called attentional control and it has been shown to be related to working memory performance. So this study is asking if attentional control is also related to maths performance in children. The study will look at these relationships in both children born prematurely and those born at term to see if these skills are linked in a similar way in both groups of children.

This study has been granted full ethical approval by the NHS Research Ethics Committee (East of Scotland Research Ethics Service (EoSRES) Rec 1; reference 14/ES/1033) and by the School of Psychology ethics committee at the University of Exeter. The study is being completed in collaboration with Dr Vaughan Lewis from the Neonatal Unit at the Royal Devon and Exeter Hospital.

Why has my child been invited to take part?

For this study I am interested in children who were born between 32 weeks and 36 weeks gestation or were born at term (between 37 and 42 weeks gestation) and are now between 6 and 8 years old so that I can compare them to children who were born prematurely.

Maths is a core area of learning for children at the beginning of their school lives. Research has shown that a child’s ability at maths at a young age can
affect their performance in other areas, such as reading, and learning of other skills and academic subjects. If we can find out what thinking skills contribute to maths performance we can try and put appropriate interventions in place to help children who may be struggling in those areas and so improve their maths ability. However, we need to know what skills are related to maths performance in order to know what those interventions might be.

**What will my child be asked to do?**

Your child will be asked to complete some activities which look at your child’s intellectual ability, working memory, attentional control and maths ability. The tasks will require your child to answer questions about words, look at pictures, complete some maths problems and do some activities on a computer. The computer tasks involve your child looking at pictures and listening to words and trying to remember different aspects of what they have been shown. Some of the tasks will involve your child paying attention to pictures and making decisions as quickly as they can. The session will take approximately 2 hours.

To thank your child for participating they will be given a small gift, such as a sheet of stickers.

**Do I have to do anything?**

You will be asked to complete two short questionnaires about your child’s memory abilities and about their general behaviour at home.

**Does my child have to take part?**

No. It is up to you to decide if you would like your child to take part in the study. If you agree we will go through an information sheet with your child to check that they are happy to take part. If you or your child decide that you do not want to take part in the research at any time they do not have to. Your child will be given opportunities to say if they do not wish to continue with the research.

**What are the possible disadvantages and risks of taking part?**

Being part of this research involves you and your child giving up your time to complete these activities. If your child becomes tired during the session they can take regular breaks. In the unlikely event that your child becomes upset or distressed in any way the assessments will be stopped immediately.

Some children do not enjoy these activities and may find them difficult or upsetting to complete. If this is the case your child will be given the opportunity to take a break or to stop completing the activities.

As a result of taking part in this research you may find out that your child has some difficulties with working memory and/or maths that you did not know about before. This can be upsetting. If this is the case you will be informed of this and information will be provided about where you can get further help and support for your child.

**What are the possible benefits of taking part?**

The results of this study should help us to know more about what thinking skills are important for maths performance. This will help us to work out what
interventions may be helpful for children who have difficulties with maths or have difficulties in these thinking skills in order to improve their performance.

If you would like a research report to be written about your child’s performance on the working memory and maths tasks you can ask for this on the consent form provided at the assessment session. You can also ask to receive a summary of the research results by circling the appropriate option at the bottom of the same consent form. You will be reminded of this at the assessment session.

**What will happen to the data?**

This research is being conducted by Emma Matthews, Trainee Clinical Psychologist at the University of Exeter, under the supervision of Dr Anna Adlam, Senior Lecturer at the University of Exeter. The research is being completed to fulfil the requirements of the University of Exeter Doctorate in Clinical Psychology.

In accordance with University of Exeter Open Research Exeter policy, the thesis will also be stored electronically at the University of Exeter, and will be accessible online (open access). The study findings might also be written up for publication in research journals and presented at conferences. The published journal article will also be available online (open access, University of Exeter). These research reports and presentations will not contain any identifiable information about your child as the results will only be presented as a group.

All study results (data) will be anonymised and securely stored electronically at the University of Exeter. In accordance with the University of Exeter Open Research Exeter, the anonymised data will be available online (open access) through the Open Research Exeter database.

**Expenses**

As this research is being conducted as part of my Doctorate in Clinical Psychology I am unable to reimburse any travel costs you may incur attending the session with your child.

**You can withdraw your child from this study at any time and you do not need to give a reason for this.** Withdrawing from the study will not affect any current or future services your child may receive. The research is due to be submitted to the university on the 5th May 2015, therefore for practical reasons if you decide that you would rather that your child’s information was not included in the project it would be appreciated if you would contact Emma Matthews by 30th March 2015 by email on em358@exeter.ac.uk or write to Emma Matthews, Doctorate in Clinical Psychology, Washington Singer, Laboratories, Perry Road, Exeter, EX4 4QG.
Memory, maths and attention in children

(Researcher: Emma Matthews, supervised by Dr Anna Adlam)

You can read this sheet by yourself or you can ask your mum or dad to read it with you. You can ask questions about anything on this sheet or about anything else you are not sure about.

What is research?

Research is a way we try to find out the answers to questions. Before any research is allowed to happen it has be checked by a group of people called a Research Ethics Committee. They make sure that the research is fair. Your project has been checked by the National Health Service Research Ethics Committee.

Why is this project being done?

I am trying to find out why some children find maths, like counting or doing sums, hard but some children find it easy. We think that your memory and your attention, that is how well you can pay attention to things without being distracted by something else, might be linked to how easy or hard you find maths.

Some children are born before the doctors think they are going to be born. When this happens the baby is called a premature baby. We want to find out how good children who were premature babies are at maths and how their memory and attention is linked to how well they can do maths. We are then going to see how they compare to children who were not premature babies to see if there are any differences in how memory, attention and maths link together in children who were premature and those who were not.

Why have I been asked to take part?

You have been invited to take part in this study because you are now between 6 and 8 years old. You might have been a premature baby or you might not have been.

All together I am going to see 60 children including you, 30 children who were premature babies and 30 children who were not premature babies.

Do I have to take part?

No. It is up to you. You don’t have to take part in this research if you don’t want to. Deciding not to take part is ok. I will ask you for your assent and I will give
you a copy of this information sheet for you to keep. You can stop taking part at any time during the research without giving a reason. If you are not sure about taking part after you have read this information you can talk to your mum or dad to help you decide.

**What will happen to me if I take part?**

You will only need to see a researcher for one session. I am going to ask you to do some maths puzzles, tell me the meanings of some words and look at some patterns. I am also going to ask you to play some games on the computer. The session today will take about 2 hours.

**Might anything about the research upset me?**

You might find some of the games and puzzles easy but you might find some of them hard. It can make you sad if something is hard for you. All children will find some of the games and puzzles hard and you can tell me if you want a break.

It doesn’t matter if you get any answers wrong. I would just like you to do your best. I will tell you what to do for each game or puzzle and you can ask me questions if you are not sure.

**Will anyone else know how I did?**

I will tell your mum or dad about the things you find easy or hard if they want me to.

**Will joining in help me?**

Joining in might not help you but what we find out from this research might help children who find maths hard because we will be able to think about things that might help them.

**What if I don’t want to do the research anymore?**

If at any time you don’t want to do the research anymore, just tell me or your parents. We will not be cross with you.

Do you understand what I am asking you to do?

Would you like to ask me any questions?
Appendix G

Demographic information questionnaire

Demographic questionnaire

Please tick boxes where appropriate

1) Child’s date of birth (dd/mm/yy):

……………………………………………………………………………………

2) Child’s gender:

Female □ Male □

3) Child’s gestational age at birth:

……………………………………………………………………………………

4) Birth weight:

……………………………………………………………………………………

5) Was your child a multiple birth, e.g. a twin or a triplet?

Yes □ No □

6) Postcode of your child’s primary home:

……………………………………………………………………………………

7) What is your child’s first language?

……………………………………………………………………………………

8) Does your child have any difficulties with hearing or vision?

Yes □ No □

If yes please give details…………………………………………………………

……………………………………………………………………………………

9) Does your child have any motor difficulties?

Yes □ No □

If yes please give details…………………………………………………………

……………………………………………………………………………………

10) Does your child have a history or current diagnosis of any of the following
conditions? (please tick any that apply)

Cerebral palsy □ Learning disability □
Epilepsy □

11) Highest level of education completed- Mother:

Primary school □ Secondary school □ College (16-18) □
Further training □ Undergraduate degree □ Postgraduate degree □
(E.g. NVQ)

Other (Please state)

Thank you for taking your time to complete this questionnaire
Appendix H
Parental consent form

CONSENT FORM

Working memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention

Please answer the following questions to the best of your knowledge

1. I confirm that I have read and understand the information sheet dated 11.08.14 (version 5) for the above study and I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. □

2. I understand that my child’s participation is voluntary and that I am free to withdraw my child from the study at any time without giving a reason and without my medical care or legal rights being affected. □

3. I understand that all data will be anonymised and the resulting data set, thesis and journal publications will be available to the public through Open Research Exeter. □

4. I agree for my child to take part in the above study. □

____________________  ______________
Name of child           Child’s date of birth

____________________  ____________________  ____________
Name of parent giving consent  Date  Signature

____________________  ____________________  ____________
Name of person taking consent  Date  Signature

When completed: 1 for parent and 1 for researcher site file.

Would you like to receive:
• a clinical research report detailing your child’s performance on the working memory assessment? Yes/No
• a written summary of the study results? Yes/No

Address to which you would like the report and/or results summary to be sent:
Appendix I
Child assent form

ASSENT FORM FOR CHILDREN

Working memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention

Please circle yes or no after each statement. You can ask your mum or dad to help you.

Has somebody explained this project to you? Yes/No
Do you understand what this project is about? Yes/No
Have you asked all the questions you want? Yes/No
Have you had your questions answered in a way you understand? Yes/No
Do you understand that it’s OK to stop taking part at any time? Yes/No
Are you happy to take part? Yes/No

If any answers are ‘no’ or you don’t want to take part, don’t sign your name!

If you do want to take part, you can write your name below

Your name ________________________________

Date_____________________________________

The researcher who explained this project to you needs to sign too:

Print name________________________________

Sign_____________________________________

Date_____________________________________

Thank you for your help.
Appendix J

NHS ethics approval letter
Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at [http://www.htaforum.nhs.uk](http://www.htaforum.nhs.uk).

Where a NHS organisation’s role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations.

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Ethical review of research sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see ‘Conditions of the favourable opinion’).

Approved documents

The documents reviewed and approved were:

<table>
<thead>
<tr>
<th>Document</th>
<th>Version</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covering letter on headed paper [Covering letter]</td>
<td>2</td>
<td>17 June 2014</td>
</tr>
<tr>
<td>Evidence of Sponsor insurance or indemnity (non NHS Sponsors only) [University of Exeter evidence of insurance]</td>
<td></td>
<td>16 August 2013</td>
</tr>
<tr>
<td>IRAS Checklist XML [Checklist_26062014]</td>
<td></td>
<td>26 June 2014</td>
</tr>
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<td>1</td>
<td>07 April 2014</td>
</tr>
<tr>
<td>Letters of invitation to participant [Initial Contact Letter]</td>
<td>5</td>
<td>01 July 2014</td>
</tr>
</tbody>
</table>
Non-validated questionnaire [Demographic information questionnaire] 2 06 June 2014
Participant consent form [Parent/guardian consent form] 2 04 April 2014
Participant consent form [Child assent form] 1 04 April 2014
Participant information sheet (PIS) [Parent information sheet] 4 06 May 2014
Participant information sheet (PIS) [Child information sheet] 3 06 May 2014
REC Application Form [REC_Form_26062014] 25 June 2014
Research protocol or project proposal [Project proposal submitted to University of Exeter] 7 21 January 2014
Summary CV for Chief Investigator (CI) [Emma Matthews summary CV - chief investigator]
Summary CV for supervisor (student research) [Dr Anna Adiam (project supervisor) brief CV]
Validated questionnaire [Strengths and Difficulties Questionnaire - age 4-16 parental report]
Validated questionnaire [Working Memory Questionnaire for Parents]

Membership of the Proportionate Review Sub-Committee

The members of the Sub-Committee who took part in the review are listed on the attached sheet.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

□ Notifying substantial amendments
□ Adding new sites and investigators
□ Notification of serious breaches of the protocol
□ Progress and safety reports
□ Notifying the end of the study

The HRA website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance/

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee's best wishes for the success of this project.
14/ES/1033: Please quote this number on all correspondence

Yours sincerely

pp
Mrs Sandra Forbes
Vice-chair

eoros.tayside@nhs.net

Enclosures: List of names and professions of members who took part in the review
"After ethical review – guidance for researchers"

Copy to: Ms Gail Seymour
Lynda Garcia, Royal Devon and Exeter NHS Foundation Trust
Appendix K

R&D ethics approval letter

Miss Emma Matthews
Trainee Clinical Psychologist
Washington Singer Laboratories
Perry Road
Exeter
EX4 4QG

Royal Devon and Exeter Hospital (Wonford)
Barrack Road
Exeter
EX2 5DW

Tel: 01392 411611

RESEARCH AND DEVELOPMENT
DIRECTORATE

Direct Dial: 01392 406933
Direct Fax: 01392 403012
Email: rde-tr.Research@nhs.net
Ref: CB/R&D/CG

Date: 30th July 2014

Dear Emma

Study Title: Working memory, attentional control and mathematics performance in moderate to late preterm children: implications for intervention

R&D No: 1504075
MREC Ref: 14/ES/1033

I have reviewed the Trust R&D file for the above named study, which has received approval from the appropriate regulatory bodies, and I am happy to give approval on behalf of the Royal Devon & Exeter NHS Foundation Trust (RD&E).

The documents approved for use in this study are those approved by ethics, these are detailed on a separate sheet.

As named Investigator for this research that is being undertaken at the RD&E, it is your responsibility to manage and conduct this study in accordance with:

- The requirements of the Research Governance Framework for Health and Social Care (2006) and Medicines for Human Use (Clinical Trials) Regulations 2004 (if applicable).
- ICH-GCP (Good Clinical Practice) – It is mandatory for those staff who will be consenting participants into this study to have undertaken GCP and to ensure it is updated every 2 years.
- The Data Protection Act 1998 which details the eight principles of ‘good information handling’.
- R&D Standard Operating Procedures (SOPs) and Trust policies which are available on the Trust Intranet site

As Lead Investigator for this research, you are required to ensure study specific duties are appropriately delegated and clearly documented on the study Delegation Log. This guarantees clarity of roles and must be signed and dated by each individual on the study and yourself as Lead Investigator.

Safety Reporting

Guidance on the classification of Adverse Events/Reactions (AEs/ARs) / Serious Adverse Events/Reactions (SAEs/SARs) and Suspected Unexpected Serious Adverse Reactions (SUSARs) and the requirements for reporting to the sponsor can be found in the study protocol. For RD&E sponsored studies this is also detailed in the sponsorship letter. All safety events that involve RD&E...
patients, that require reporting to the Sponsor, must also be reported by fax to the R&D Office within 24 hours of becoming aware of the event, using the appropriate Trust R&D fax template which can be found on the Adverse Event Reporting pages of the R&D intranet site (http://iwm.exe.nhs.uk/welcome/directories/research-and-development/rd-administration/adverse-event-reporting/).

Progress Reporting
You are required to submit regular recruitment updates to the R&D Office, as well as annual progress reports to Ethics, MHRA (where applicable) and R&D. Please note that new government and Trust targets require you to have recruited your first patient within 30 days of the date of Trust Approval and to have recruited your target number of participants within the time frame stipulated on your SSI form (Time to Target).

Monitoring and Audit
Your study may be monitored by the Sponsor and selected for audit by the R&D Office (where RD&E is not the Sponsor) and Regulatory Authorities at any time. The team involved in conducting this research must ensure full co-operation with any requests from any of these bodies. Action may be taken to suspend research if it is found to not be conducted in accordance with the protocol and all applicable regulations.

Archiving
Upon completion of this Research an End of Study Report must be submitted to the Regulatory Authorities (this will be done by the CI) and a copy submitted to the R&D Office. All studies must be archived appropriately and in accordance with the applicable Law. Where RD&E is the Sponsor or where the Sponsor has delegated archiving to the Investigator team, it is your responsibility to contact the R&D Office to discuss appropriate archiving arrangements.

Any publications arising from the Research conducted at this site must be sent to the R&D Office as part of the ongoing Research Governance Process.

You should be aware that the Trust accepts no responsibility for the provision of any study drug outside of Clinical Trials and specifically would not fund the continuing prescription of any therapy once the trial has concluded unless there is a written agreement.

Trust Approval is for the duration of the study, as specified in your SSI form. If you have received an Honorary Contract or Letter of Access in order to conduct the above research at this Trust, it is important that you check the termination date on these documents and if applicable contact the R&D Office to extend the document end date.

We wish you every success with your study.

Yours sincerely

[Signature]

Martin Cooper
Medical Director

CC: Dr Richard Tomlinson
Enc: Approved Documents
Appendix L

School of Psychology ethics committee approval letter

To: Emma Matthews
From: Cris Burgess
CC: Anna Adlam
Re: Application 2013/547 Ethics Committee
Date: October 9, 2014

The School of Psychology Ethics Committee has now discussed your application, 2013/547 – Working memory, attentional control and mathematics performance in moderate to late preterm children – implications for intervention. The project has been approved in principle for the duration of your study.

The agreement of the Committee is subject to your compliance with the British Psychological Society Code of Conduct and the University of Exeter procedures for data protection (http://www.ex.ac.uk/admin/academic/datapro/). In any correspondence with the Ethics Committee about this application, please quote the reference number above.

I wish you every success with your research.

Cris Burgess
Chair of Psychology Research Ethics Committee
## Appendix M

Details of amendments made to protocol and ethical approvals

<table>
<thead>
<tr>
<th>Amendment number</th>
<th>Summary of changes</th>
<th>Date approved by NHS REC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clarified completion of demographic questionnaire by parents. Added the child’s home as an assessment location. Informed ethics committee of arrangements to allow the experimenter to access the neonatal database information, and additional recruitment pathway through electronic advertisements.</td>
<td>10th September 2014</td>
</tr>
<tr>
<td>2</td>
<td>Change to wording on parent consent form.</td>
<td>22nd September 2014</td>
</tr>
<tr>
<td>3</td>
<td>Clarified which tasks would be used to measure attentional control and the length of the assessment session.</td>
<td>24th October 2014</td>
</tr>
<tr>
<td>4</td>
<td>Extended the maximum age for participants from 7 years, 11 months to 8 years, 11 months. Changed inclusion criteria to include children born as multiples.</td>
<td>7th November 2014</td>
</tr>
</tbody>
</table>

All amendments were approved by the RD&E research and development department on the 18th November 2014. The School of Psychology Ethics committee approved all amendments on 16th December 2014.
Appendix N

Order in which non-significant interactions and predictors were removed from the regression model

1. Interaction between GA and verbal STM
2. Interaction between GA and IQ
3. Interaction between GA and visuospatial WM
4. Interaction between GA and verbal WM
5. Interaction between GA and visuospatial STM
6. Interaction between GA and executive attention
7. Interaction between GA and divided attention
8. Executive attention
9. Verbal STM
10. Divided attention
11. Interaction between GA and attention behavior
12. Visuospatial STM
13. Visuospatial WM
Appendix O

Instructions for authors of Pediatrics journal

Regular Article – Pediatrics author guidelines

Abstract length: 250 words or fewer (structured, as noted below)

Article length: 3,000 words or fewer.

Regular Articles are original research contributions that aim to inform clinical practice or the understanding of a disease process. Regular Articles include but are not limited to clinical trials, interventional studies, cohort studies, case-control studies, epidemiologic assessments, and surveys. Components of a Regular Article include:

What’s Known on This Subject; What This Study Adds

These brief summaries are each limited to 40 words. Please use precise and accurate language in paragraph form (i.e., not bullet points). For manuscripts accepted as Regular Articles, these summaries will become a highly visible part of your published paper, with prominence on the first page. Moreover, these summaries will be highlighted and presented in other areas of the journal, namely Pediatrics Digest. It is therefore paramount that you use language of the same calibre as the rest of your paper.

Structured Abstract (four paragraphs with headings in boldface type; single-spaced)

The abstract should consist of: Background (or Objectives, or Background and Objectives), Methods, Results, and Conclusions. The Objective should clearly state the hypothesis; Methods, inclusion criteria and study design; Results, the outcome of the study; and Conclusions, the outcome in relation to the hypothesis and possible directions of future study.
For the body of your article, follow this general outline:

- **Introduction**
  
  A 1- to 2-paragraph introduction outlining the wider context that generated the study and the hypothesis.

- **Patients and Methods**
  
  This section should detail inclusion criteria and study design to ensure reproducibility of the research. All studies that involve human subjects must be approved or deemed exempt by an official institutional review board; this should be noted here.

- **Results**
  
  This section should give specific answers to the aims or questions stated in the introduction. The order of presentation of results should parallel the order of the methods section.

- **Discussion**
  
  The section should highlight antecedent literature on the topic and how the current study changes the understanding of a disease process or clinical situation, and should include a section on the limitations of the present study.

- **Conclusion**
  
  A brief concluding paragraph presenting the implications of the study results and possible new research directions on the subject.

General submission instructions (including cover letter, title page requirements, contributors' statement page, journal style guidance, and conflict of interest statements) apply to Regular Articles.
Figures, Tables, and Supplementary Material

Figures

Authors should number figures in the order in which they appear in the text. Figures include graphs, charts, photographs, and illustrations. Each figure should be accompanied by a legend that does not exceed 50 words. Abbreviations previously expanded in the text are acceptable. If a figure is reproduced from another source, authors are required to obtain permission from the copyright holder, and proof of permission must be uploaded at the time of submission.

Figure arrays should be clearly labeled, preassembled, and submitted to scale. Figure parts of an array (A, B, C, etc.) should be clearly marked in capital letters in the upper left-hand corner of each figure part.

Technical requirements for figures

The following file types are acceptable: TIFF, EPS, and PDF. Color files must be in CMYK (cyan, magenta, yellow, black) mode.

Style for figures

Readers should be able to understand figures without referring to the text. Avoid pie charts, 3-dimensional graphs, and excess ink in general. Make sure that the axes on graphs are labeled, including units of measurement, and that the font is large enough to read. Generally delete legends or other material from the graph if it makes the picture smaller. Color graphs should be interpretable if photocopied in black and white.

Tables

Tables should be numbered in the order in which they are cited in the text and include appropriate headers. Tables should not reiterate information presented in the Results section, but rather should provide clear and concise
data that further illustrate the main point. Tabular data should directly relate to the hypothesis. Table formatting should follow the current edition of the *AMA Manual of Style*.

**Style for tables**

Tables should be self-explanatory. Avoid abbreviations; define any abbreviations in footnotes to the table. Avoid excess digits and excess ink in general. Where possible, rows should be in a meaningful order (e.g., descending order of frequency). Provide units of measurement for all numbers. In general, only one type of data should be in each column of the table.

**Presentation of Numbers and Statistics**

- Results in the abstract and the paper generally should include estimates of effect size and 95% confidence intervals, not just P-values or statements that a difference was statistically significant.
- Statistical methods for obtaining all P-values should be provided
- Units of independent variables must be provided in tables and results sections if regression coefficients are provided
- Authors should avoid expressing effect sizes in the form of highly derived statistics.

Equations should be typed exactly as they are to appear in the final manuscript. The following table, adapted from the guidelines for authors for the *Annals of Internal Medicine* by editors of *Medical Decision Making*, shows how to present certain percentages and some statistical measures:
<table>
<thead>
<tr>
<th>Reporting</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentages</td>
<td>Report percentages to one decimal place (i.e., xx.x%) when sample size is greater than or equal to 200. To avoid the appearance of a level of precision that is not present with small samples, do not use decimal places (i.e., xx%, not xx.x%) when sample size is less than 200.</td>
</tr>
<tr>
<td>Error Measures</td>
<td>Report confidence intervals, rather than standard errors, when possible. Use &quot;mean (error measures)&quot; rather than &quot;mean ± error measure&quot; notation. Except when one-sided tests are required by study design, such as in noninferiority trials, all reported P values should be two-sided. In general, P values larger than 0.01 should be reported to two decimal places, those between 0.01 and 0.001 to three decimal places; P values smaller than 0.001 should be reported as P [is less than sign]0.001. Notable exceptions to this policy include P values arising in the application of stopping rules to the analysis of clinical trials and genetic-screening studies. Use the word trend when describing a test for trend or dose-response.</td>
</tr>
<tr>
<td>P values</td>
<td></td>
</tr>
</tbody>
</table>
Appendix P

Dissemination statement

The results of this study will be disseminated to interested parties through feedback, journal publication and presentation.

**Dissemination to participants**

All parents of participants who opted to receive a summary of the results on the consent form and provided their contact details will be informed of the results of the study. The head teacher of the school from which some participants were recruited and the two field collaborators will also be sent a summary of the results. The proportionate review sub-committee of the East of Scotland Research Ethics Service and the RD&E Research and Development team will be sent a summary of the study findings and be informed that the study is now complete.

**Journal Publication**

I intend to submit edited versions of the literature review and empirical paper to a peer-reviewed journal (Pediatrics) in August 2015.

**Presentation**

I will be presenting the findings of the study to Trainee Clinical Psychologists, staff and other interested parties at the University of Exeter in June 2015. I will also be presenting the findings to the paediatric medical team at the RD&E.