Working title: Differentiating subgroups of preschool children at risk for Mathematical Learning Disabilities.

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Abstract

The specific cognitive abilities that contribute to Mathematics Learning Disabilities (MLD) are still under investigation. However, certain abilities have emerged as playing a key role in the development of mathematical abilities, including both domain general and domain specific ones. The current study investigated mathematical abilities in 283 pre-schoolers aged 3 to 5 years old and examined the proportion of children who were considered at risk for MLD, having scored lower than the 35th percentile on the Test of Early Mathematical Abilities. Cluster analysis revealed four subgroups of children at risk for MLD: 1) a weak processing subtype, 2) a subtype with no numerical cognitive deficit, 3) a general MLD subtype, 4) a spatial difficulties subtype. Current findings suggest that children at risk for MLD constitute a very heterogeneous group and stress the importance of domain-general factors for the development of mathematical abilities in preschool years.

An increasing number of studies show that between 5% and 10% of children experience a substantial deficit in at least one area of mathematics (Desoete, Roeyers, & DeClercq, 2004; Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005). This deficit should be considered as a central risk factor as mathematical achievement in school years correlates with educational and financial success later in life, particularly for women (Bynner & Parsons, 2006; Geary, Hoard, Nugent, & Bailey, 2013). This context stresses the importance of identifying the cognitive characteristics of those children with low mathematical skills early on in life in order to intervene as early as possible and put effective educational programmes in place.

Mathematical learning disability: definition

The term Mathematical Learning Disability (MLD) is used when children show a developmental delay or deviance in the acquisition of one or more of mathematical functions (Mazzocco, 2007). MLD is considered a very heterogeneous disorder which may affect different aspects of mathematical learning, including reading and writing numerals, remembering number facts, calculation or mathematical reasoning. Recent studies have explored the cognitive characteristics of the different subtypes of MLD in primary education. Some of these studies used a top-down a priori approach, examining the cognitive profiles of predefined MLD sub-groups (Jordan, Hanich, & Kaplan, 2003; Murphy, Mazzocco, Hanich, & Early, 2007). Other studies have used a data driven classification approach to try and describe the MLD profiles (Bartelet, Ansari, Vaessen, Blomert, 2014; Von Aster, 2000). Both types of studies have confirmed the heterogeneous nature of MLD and at the same time emphasise the complexity of establishing the core deficits that constitute the MLD phenotype.

Although these previous studies have examined which cognitive abilities relate to mathematical difficulties in primary school children with MLD, little is known about the rate of children at risk for MLD in preschool years or what abilities may explain their mathematical difficulties. There is currently debate about what abilities drive mathematical competencies in typically developing (TD) children and it has been suggested that different abilities may be important at different developmental stages. For example, although studies have shown that non-symbolic abilities relate to mathematical achievement early on in life (Mazzocco, Feigenson, & Halberda, 2011a), symbolic abilities are a better predictor of mathematical abilities for children in formal education (Iuculano, Tang, Hall, & Butterworth, 2008; Rousselle & Noël, 2007). As a developmental process needs to be taken into account and it cannot be assumed that the deficit observed in adults is the same deficit in young children (Ansari, 2010), further studies are needed to identify potential subtypes of children at risk of developing MLD before children's entrance into formal education.

Domain-specific and Domain-general precursors of mathematical learning

Research studies in the field of educational and cognitive psychology show that both domain-specific and domain-general abilities predict successful mathematical achievement outcomes in later life (Mazzocco & Thompson, 2005; Passolunghi & Lanfranchi, 2012).

Domain-specific abilities that relate to mathematical abilities include both verbal and non-verbal number-specific cognitive processes. Counting ability, and in particular the knowledge of the number word sequence, seems to be one of the most discriminating and efficient precursors of early mathematics learning (Passolunghi, Vercelloni, & Schadee, 2007; Krajewski & Schneider, 2009). A child who has achieved the cardinality principle (Gelman & Gallistel, 1978) understands that the last word spoken in counting indicates the cardinality of the whole set. Studies focusing on preschool children indicate that understanding the cardinality principle of counting is particularly important for the creation of the link between non-symbolic skills to number symbols (Ansari, Donlan, Thomas, Ewing, Peen, & Karmiloff-Smith, 2003; Le Corre & Carey, 2007).

Another building block for the development of mathematics includes the non-verbal ability to perceive and discriminate approximate large numerosities, supported by the Approximate Number System (ANS). The ANS is another domain-specific ability that has been shown to relate to mathematical skills (Halberda, Mazzocco, Feigenson, 2008). Indeed, some authors suggest that the acquisition of the meaning of symbolic numerals is done by mapping number words and Arabic digits onto the pre-existing approximate number representation (Dehaene, 2001; Piazza, 2010). Research has found a relationship between ANS abilities and mathematical abilities in primary school children and in preschool years (Libertus, Feigenson, & Halberda, 2011; Mussolin, Nys, Leybaert, & Content, 2012). Moreover, longitudinal studies showed that ANS abilities assessed at 3 years old predict general mathematical achievement at 6 years old (Mazzocco et al., 2011a). In line with these findings, research on MLD showed that impaired acuity of the ANS contributes to lower calculation skills and mathematical learning disability in general (Piazza, 2010; Butterworth 2005; Mazzocco, Feigenson, & Halberda, 2011b). Still, other studies have failed to find a relationship between non-verbal ANS abilities and mathematical performance in TD children and in children with dyscalculia (Iuculano et al., 2008; Rousselle & Noël, 2007).

General cognitive abilities (i.e., domain general precursors) also play an important role in the development of mathematical abilities. This is particularly true if we focus on the relation between general cognitive abilities and maths performance in preschool years. Indeed, the importance of domain-general abilities usually diminishes as a consequence of a greater influence of the domain-specific abilities during primary school education (Passolunghi & Lanfranchi, 2012). Amongst general cognitive skills, working memory (WM) is considered a key domain-general predictor of mathematical learning. WM refers to a temporary memory system that allows short-term storage and manipulation of verbal and visuo-spatial information (Baddeley, 1986). WM abilities are related both to early numeracy skills in preschool years and to later mathematical skills (Alloway & Alloway, 2010; Frisovan den Bos, van der Ven, Kroesbergen, & van Luit, 2013). Performing even the simplest mathematical calculation or number comparison task requires the storage of information into memory while it is processed or integrated with the incoming information to perform the task (Kroesbergen, van't Noordende, & Kolkman, 2014). Especially spatial skills and visuo-spatial working memory are strongly related to children's early numeracy ability (Ansari et al, 2003; Kyttala, Aunio, Lehto, van Luit, & Hautamaki, 2003).

Another domain-general cognitive precursor important for the development of mathematics is Processing Speed (Gersten, Jordan, & Flojo, 2005), which is the efficiency and speed of execution of cognitive tasks (see Case, 1985). A number of studies have shown that children with poor mathematical abilities have poor performance in processing speed (Bull & Johnston, 1997; Geary, Hamson, & Hoard, 2000). This means that children with MLD process information more slowly compared to TD peers (Geary, Hoard, Byrd- Craven, Nugent, & Numtee, 2007).

The present Study

Considering the variety of cognitive abilities that can play a role during a child's early mathematical development, it is not surprising that no comprehensive picture has emerged regarding the precursors of mathematical learning. Overall, results in TD children have shown that both domain-general and domain-specific precursors may be important for the development of early mathematical learning.

Although previous studies have examined which cognitive abilities relate to mathematical difficulties in primary school children with MLD (Bartelet et al., 2014; Von Aster, 2000), to our knowledge no study has explored the cognitive subtypes of children at risk for MLD among pre-schoolers using a data-driven approach. The identification of different profiles of children at risk is of great importance for the early identification and remediation of MLD. Key factors in the prognosis for individuals with MLD include the effectiveness of evidence based interventions. Given that the component of math difficulty may vary across individuals and may differ over development, interventions should vary depending on the type(s) of problems encountered.

In the present study, we examined the cognitive characteristics of a sample of pre-school children with low mathematical skills, identifying through a cluster analysis different subtypes of children at risk for MLD. This allowed greater insight into whether being at risk for MLD can be contributed to domain-general or domain-specific difficulties in pre-schoolers.

Method

Participants

To identify children at risk for MLD, 283 preschool children aged 3 to 5 years old (M_{age}= 45.45 months, *SD* = 5.26, 141 girls) attending 14 preschool settings in London and Greater London were included in the screening phase. All children were screened on a standardized test designed to assess mathematical abilities (Test of Early Mathematics Ability – Third Edition, Ginsburg & Baroody, 2003) and on the Picture Similarities subtest of the British Ability Scales (BAS-3; Eliot & Smith, 2011). Children were labelled as "at risk for MLD" if they performed at or below 35th percentile on the Test of Early Mathematics Ability (TEMA-3)[1]. Children with low reasoning skills (T-score <37 on Picture Similarities subtest) were excluded, in order to ensure that children did not perform low on TEMA-3 due to overall reasoning difficulties. All children spoke English at home or performed within the normal rage on the Verbal Comprehension subtest of the BAS (*T* score > 37). Parents did not

[1] Although previous studies usually only consider children who perform below 25th centile on TEMA-3 as MLD children (e.g., Murphy, Mazzocco, Hanich, & Early (2007), these studies included primary school aged children. The TEMA-3 scores from the children screened in the current study showed that TEMA-3 is insensitive at the lower range and that even a high percentile score on TEMA-3 is based on getting just a few items correctly. Based upon the fact that 45% of the total sample of children in the current study scored a raw score of 6 or less on the TEMA-3, where the score range for the age group is 0-32, we opted for a higher percentile cut-off for TEMA-3 (below 35th percentile) to define children at risk for MLD.

report any developmental delays or hearing and vision disabilities. Ten children were excluded from the screening sample as they failed to complete the assessment battery due to refusal to participate (N= 2), illness or long absence (N= 8).

The final sample of children who met the criteria for being at risk for MLD consisted of 71 children[2] (M_{age}= 44.34 months, *SD* = 5.60, 39 girls; $M_{\text{TEMA percentile}}$= 22,9, *SD* = 9,3).

A control group of 47 (M_{age} 45.64 months, *SD* = 5.10, 27 girls; $M_{\text{TEMA percentile}}$= 72,3, *SD* = 16,8) children who obtained TEMA-3 scores at or above the 50th centile was also identified. These children were randomly chosen from each preschool setting.

The socioeconomic status (SES) of the two groups was established using mothers' and fathers' highest level of education, as parental education is considered to be one of the most stable aspects of SES (Sirin, 2005).

Materials

Mathematical screening measure. Test of Early Mathematics Ability – Third Edition is a standardized test to measure children's mathematical abilities. TEMA-3 is normed for use with children aged 3 to 8 years old. TEMA-3 items involve producing finger displays to represent different quantities, counting, and making numerical comparisons as well as counting, reading or writing two-digit numbers, adding or dividing quantities with manipulatives, determining the relative magnitude of symbolic numbers, symbolic arithmetic facts, evaluating addition number sentences, and mental addition with one-digit addends. Test-retest reliability for the TEMA-3 is .93. Our variable of interest was the percentile score to identify children at risk, and raw scores were used to compare the different groups (see footnote 1 for discussion).

[2] This is the equivalent of 26% of the total amount of children screened for MLD risk.

Approximate Number System (ANS). ANS abilities were measured by a magnitude comparison or ANS task in which children were asked to identify which side of the screen showed more dots. There were 48 randomised trials of 0.5, 0.6, 0.7, and 0.8 ratios. Children responded using a touch screen in order to reduce hand-eye co-ordination problems. The number of dots in each array ranged from 5 to 20 and to control for continuous quantity variables, both congruent and incongruent trials were used. In the incongruent trials the dot size and envelope area were negatively correlated with the number of dots, while in the congruent trials the dot size and envelope area were positively correlated with the number of dots (Simms et al., 2015). In each of the experimental trials children saw a fixation point followed by presentation of the stimuli for 1500ms. Children could respond either when the stimuli were visible on the screen, or afterwards up until 5000ms after presentation. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 48. In order to assess whether children could understand the concept of 'more' in a numerical sense, a training task was administrated. The dot displays in the training task were of the ratio 1:3 and included both congruent and incongruent trials. The training task ended when children answered 8 consecutive trials successfully or when 24 trials were administered. In contrast to the experimental task, children received feedback for both correct and incorrect answers (e.g., that is right there are more blue dots than red dots).

Visuo-spatial short-term memory (*VS-STM*). The Pathway Recall task (Lanfranchi et al., 2004) was used to assess visuo-spatial STM abilities. The child was shown a path taken by a small toy frog on a 3 × 3 or 4 × 4 grid. The child had to recall the pathway immediately after presentation by moving the frog from square to square, reproducing the experimenter's moves. The task is composed of eight trials and had four levels of difficulty, depending on the number of steps in the frog's path and dimensions of the chessboard (3×3 in the first level with two steps and 4×4 in the other levels, with two, three, and four steps, respectively). Two trials for each difficulty level were presented. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 8.

Speed of processing. The Naming Speed sub-test from the Phonological Assessment Battery 2 (PhAB2; REF) was used to assess speed of processing skills (RAN). A total of 50 stimuli were presented on one page, and the child was asked to name the stimuli (pictured objects), as quickly as possible without error. Non-standardized total response time (RT) measure was obtained. The reliability of this test is adequate with internal consistency alpha coefficients above .8.

Cardinality. To assess cardinality abilities children were assessed on a Give-a-Number task (Wynn, 1992). In this task children were asked to give the experimenter exactly 1, 2, 3, 4 and 5 beads from a pile. The child was asked to provide each number three times in randomised order. A score of 1 was given for every trial performed correctly. The minimum score was 0 and the maximum was 15.

Procedure

After the head teacher or manager had provided consent to take part, a letter was given to the parents/guardians of each child for individual consent. Parental written consent was obtained for all children as well as children's verbal assent before the start of the study. Trained research assistants carried out the assessments. Each child was assessed individually in a quiet area within the preschool setting. In order to encourage children and keep them motivated, they received stickers at the end of each session.

This study was assessed by the Ethics Committee for the Faculty of Arts and Social Sciences at xxxxx, xx and allowed to proceed.

Data Analyses

We examined the existence of sub-groups within the group of children at risk for MLD using cluster analysis. Cluster analysis is a descriptive, multivariate statistical technique that aims to group individuals that are close together. Performance on the ANS, speed of processing, cardinality and visuo-spatial STM tasks were entered as variables of interest in the cluster analysis. Outliers for each task were excluded. Standardization into *z*-scores was performed prior to the cluster analysis to ensure that differences in measurement scale did not influence the results. The variable scores entered in the analysis were standardized relative to the sample at risk for MLD; therefore the profile description represents performance relative to the average performance of the group at risk, not relative to the norm.

First, we conducted an agglomerative hierarchical clustering approach (Ward's method) to determine the number of optimal clusters. This approach combines the cases into clusters such that the variance within a cluster is minimized. To do so, clusters whose merger increases the overall within-cluster variance to the smallest possible degree are merged (Mooi & Sarstedt, 2011). The result can be described with a dendogram and a plot of the agglomeration coefficients. To establish the initial cluster, the percentage change in the agglomeration coefficients was evaluated and a screen-plot was used to detect a point of inflection. Following the interpretation of the height of the different nodes in the dendogram, a four-cluster solution was judged as the optimal one for producing subgroups in children at risk for MLD. As suggested by Milligan (1980), after the number of clusters and the cluster centroids has been determined with the hierarchical method, a K-means cluster analysis was used in order to reduce the overall within-cluster variation and optimize the results.

To further describe the subtypes identified in the cluster analysis, we compared performance scores for the different clusters to a group of controls on the variables of interest entered in the cluster analysis, on mathematical abilities (TEMA-3), and on the Picture

Similarities subtest of the British Ability Scales (BAS-3). For this purpose, Univariate ANOVA on the unstandardized scores for each of the clustering variables was applied to help describe the clusters. η_p^2 was used as a measure of effect size for the Univariate ANOVA analyses. The criteria of Cohen (1988) were used to classify the effect sizes; small effect: η_p^2 =.01; medium effect: $\eta_p^2 = .06$; and large effect: $\eta_p^2 = .14$. The Bonferroni procedure was used for post hoc comparisons of the means. Such analyses indicated whether and how groups differ on each clustering variable.

Results

From the original sample two children at risk for MLD were removed from the analyses before the standardization of *z* scores, because they were identified as outliers on the speed of processing task.

Description of the clusters

Analyses revealed the following four clusters:

Cluster 1 (n = 10) included children at risk for MLD characterized by average performance in the visuo-spatial STM task (*M z* score = .04; *SD* = .54), low-average performance on cardinality (*M z* score -.92; *SD* = 1.22) and ANS (*M z* score -.79, *SD* =.90) and very weak performance on the speed of processing task (*M z* score = -1.81, *SD* =.61). On the basis of the described profile, this group was assigned the label *weak processing subtype*.

Cluster 2 (n = 33) is the larger subgroup of children at risk for MLD and consisted of children characterized by average performance on all tasks: visuo-spatial STM *M z* score .04, *SD* = .54; cardinality *M z* score = .14, *SD* = .60; ANS *M z* score = -.12, *SD* .68; speed of processing *M z* score .31, SD = .63. As it is not possible to identify a specific cognitive strength or weaknesses in this group compared to the other children at risk for MLD, this group was labelled *general MLD subtype***.**

Cluster 3 (n = 12) consisted of children at risk for MLD with average performance on the speed of processing task (*M z* score = .60; *SD* = .59) and above average performance on the visuo-spatial STM task (*M z* score = .88; *SD* = .66). This group is characterized by strong performance on the domain-specific mathematical tasks considered in this study (cardinality: *M z* score = 1.16, *SD* = .59; ANS: *M z* score = 1.35, *SD* = .60) and was therefore labelled *no numerical cognitive deficit subtype.*

Cluster 4 (n = 14) comprised children at risk for MLD with impaired visuo-spatial STM skills (*M z* score = -1.54, *SD* =. 39) and average performance in the other tasks: cardinality *M z* score =-.67, *SD* = .75; ANS *M z* score = -.30, *SD* .95; speed of processing *M z* score -.04, *SD* = .78. Scoring specifically low on the visuo-spatial STM tasks, this group was assigned the label *spatial difficulties subtype.*

Group Comparisons

Although group comparisons revealed a significant effect for chronological age, $F(4,115) = 2.642$, $p = .037$, $\eta^2_p = .087$, post hoc Bonferroni comparisons did not show any significant differences between the different clusters (all *p*s > .05). There was no significant difference for T-scores on the Picture Similarities subtest between the groups, $F(4,111) = 1.58$, $p = .18$, $\eta^2_p = .054$). As predicted, there was a significant effect for TEMA raw scores, $F(4,115) = 36.863$, $p < .001$, $\eta^2_p = .571$. Post hoc Bonferroni analyses showed that all four cluster groups differed significantly from the control group (all *p*s < .001) but not from one another (all *p*s = n.s.). Table 1 shows the average performance scores for each cluster and the control group for each task.

Table 1 about here

Although we could not calculate any significant differences between the different groups for SES and gender, due to the fact that different groups included different numbers of participants, Table 1 did not show any obvious differences for gender. However, as can be seen in Table 2 a large number of the mothers in Cluster 4 had no formal qualifications whilst those children in Cluster 3 were more likely to have educated mothers.

Table 2 about here

ANS. The ANOVA for performance scores on the ANS task revealed a significant difference between groups, $F(4,111) = 18.91$, $p < .001$, $\eta_p^2 = .40$. Bonferroni-adjusted post-hoc pairwise comparisons indicated that the performance of three of the cluster groups of children at risk for MLD was significantly lower compared to the control group (all *p*s < .001). However, children in Cluster 3 (no numerical cognitive deficit subtype) showed higher average ANS scores compared to the controls (M_{diff} 2.26, $p = .999$).

In addition, considering the difference between the groups at risk for MLD, Cluster 3 (no numerical cognitive deficit subtype) showed higher ANS performance compared to all the other subtypes (all *p*s < .001) while there was no significant difference between the other three groups at risk for MLD.

Speed of processing. There was a significant difference between the groups for speed of processing performance: $F(4,111) = 39.69$, $p < .001$, $\eta_p^2 = .59$. Bonferroni-adjusted post-hoc pairwise comparisons indicated that the control group performed significantly better compared to all the groups at risk (Cluster 1 $p < .001$; Cluster 2 $p = .018$; Cluster 4 $p = .001$), except for the Cluster 3 (no numerical cognitive deficit subtype) (M_{diff} -6.85, p = .999).

Considering the difference between only the groups at risk for MLD, performance for children in Cluster 1 (weak processing subtype) was significantly slower for the speed of processing task compared to all the other at-risk groups (all *p*s < .001), but there was no significant difference between the other at-risk groups.

Visuo-spatial STM. There was a significant difference between the groups for performance on the visuo-spatial STM task, $F(4,111) = 29.79$, $p < .001$, $\eta_p^2 =.52$. Bonferroni-adjusted post-hoc pairwise comparisons indicated that the control group performed significantly better compared to all the groups at risk for MLD (Cluster 1 $p = .003$; Cluster 2 $p <.001$; Cluster 4 $p < .001$), except for the Cluster 3 (no numerical cognitive deficit subtype) (M_{diff} .35, $p = .999$).

Comparisons between the groups at risk for MLD showed that children in Cluster 4 (spatial difficulties subtype) performed significantly lower on the visuo-spatial STM task compared to all the other at-risk groups (all *p*s < .001) and that there were no differences between the other at-risk groups.

Cardinality. The ANOVA for the cardinality scores revealed a significant difference between the groups, $F(4,111) = 29.79$, $p < .001$, $\eta_p^2 = .55$). Bonferroni-adjusted post-hoc pairwise comparisons indicated that the control group performed significantly better compared to all the groups at risk (all *p*s < .001), except for the Cluster 3 (no numerical cognitive deficit subtype) (*Mdiff* .67, $p = .999$).

Considering the difference between the groups at risk for MLD, children in Cluster 3 (No numerical cognitive deficit subtype) outperformed those in all other the clusters (Cluster 1 $p < .001$; Cluster 2 $p = .002$; Cluster *4* $p < .001$). Cluster 2 (general MLD subtype) performed better on the cardinality task compared to Cluster 1 (weak processing subtype) (M_{diff} 4.06, $p =.003$) and Cluster 4 (spatial difficulties subtype) (M*diff* 3.11, $p = .14$). There is no significant difference between Clusters 1 and 4, which both have the lowest cardinality scores (respectively 4.70 and 5.64, $p = .999$).

Discussion

The current study builds on previous studies that have shown mathematical abilities to rely on a wide range of domain-general and domain-specific abilities, and that primary school aged children with MLD form a heterogeneous group that can be sub-divided into different subtypes. The current study is the first to examine individual variability within preschool children who can be classified as at risk for MLD using a data driven approach. In order to examine which factors contribute to preschool children who perform below the 35th centile, we used a cluster analyses and identified 4 sub-types of children who are at risk for MLD.

Within the four sub-types we found two groups that are characterised by domain-general abilities. Children in the spatial difficulties subtype showed lower performance on visuo-spatial abilities whilst those in the weak processing subtype were characterized by impaired speed of processing. This finding is in line with Bartelet and colleagues (2014) who also found a sub-group of children with MLD who had spatial difficulties, as well as with research showing that children's visuo-spatial abilities define their number line abilities, a measure of numerical representations that has been found to relate to mathematical achievement (Simms, Clayton, Cragg, Gilmore, & Johnson, 2016).

In contrast to previous studies of primary school children (Bartelet et al 2014, Von Aster, 2000), we did not find any groups that showed numerical specific deficits (ANS or cardinality) only. Instead, three of the subtypes showed lower performance on the ANS task and give-a-number task compared to control children. Furthermore, children in the no numerical deficit cluster demonstrated even better performance on the ANS task and did not differ from controls in terms of cardinality abilities, despite their very low performance on

TEMA. Although we did not measure all aspects of mathematical ability (e.g., number line abilities or Arabic knowledge), the fact that these children are not impaired on ANS or counting abilities suggests that the mathematical difficulties in this group of children can most likely be attributed to other domain-general difficulties not currently measured, rather than domain-specific ones. For example, Von Aster (2000) found that a sub-sample of children perform low on mathematical achievement tasks due to low verbal abilities. Some of the items on the TEMA include verbal reasoning tasks that require listening to short stories and thus performance on TEMA depends on good language abilities. In order to keep the testing session as short as possible with the young pre-schoolers we did not measure verbal abilities. It is, therefore, possible that the pre-schoolers in the no numerical deficit group have low verbal abilities, which limited their understanding of the questions from the TEMA. Still, the current finding that one group of children did not show any numerical deficits, despite low performance on the TEMA, is in line with the 'no numerical deficit' group in the study by Bartelet and colleagues (2014).

In line with Von Aster (2000), there was one group of children, the general MLD subtype, who performed at or below average on all domain-general and domain-specific tasks. This group of children did not differ from other groups in terms of general reasoning abilities or age, but still performed very low on TEMA. It has been proposed that some children with MLD might not have a single deficit but rather multiple deficits (Dowker, 2005; Henik, Rubinsten & Ashkenazi, 2012; Rubinsten & Henik, 2009; von Aster & Shalev, 2007).

The current results indicate that low performance on TEMA is more often caused by domain-general abilities than domain-specific abilities in pre-schoolers. It can be argued that this outcome is the result of the fact that the items in the TEMA aimed at preschool aged children do not focus on domain-specific knowledge. However, the first six items of the

TEMA include ANS-like items in which the child has to say which side has more dots, as well as items in which the child has to count.

Another interesting finding in the current study is that three out of the four subtypes of children with MLD were found to perform significantly lower on the ANS task compared to control children. The fact that some of these children performed within the TD range on the Give-a-Number-task has been argued to show that ANS abilities cannot explain symbolic number processing deficits (Bartelet et al., 2014). Still, in the current study more than 70% of the children at risk for MLD scored well below the control children on the ANS task (score <30) and this suggests that ANS deficits are a central part of the cognitive profile of pre-schoolers at risk for MLD.

Limitations

Due to the young age of the children we did not assess them on all aspects of mathematical ability and we also did not include a measure of verbal abilities, even though previous studies have shown that language deficits can explain mathematical difficulties in some children with MLD (Von Aster, 2000). Therefore, future studies should further include measures of verbal comprehension abilities as well.

Although the subtypes identified in the current study overlap with those found in previous studies that included primary school age children (Bartelet et al., 2014; Von Aster, 2000), the current findings need to be replicated by future studies as research thus far has used different tasks and study designs. For example, whilst children with general reasoning difficulties were excluded from the current study as well as in the study by Von Aster (2000), they were included in Bartelet et al (2014). Also, the cluster analysis approach includes a subjective description of the different subtypes, which can lead to different interpretations.

Finally we did not examine the effects of SES in detail in our study, but the mothers of those children who did not show any numerical difficulties despite their low performance on TEMA were well educated, whilst half of the mothers of the children in Cluster 4 (spatial difficulties subtype) had no formal qualifications, and this suggests that SES plays a role for some but not all subtypes of children who perform low on standardised mathematical tasks. Further research using larger samples is required to see how low SES affects the different subtypes that can be identified, so that better educational programmes can be developed.

Conclusions

In line with previous studies, the current study has shown that children at risk for MLD include a heterogeneous group made up of different subgroups. However, in contrast to primary school aged children with MLD, pre-schoolers who are at risk for MLD are more likely to have domain-general deficits rather than domain-specific deficits. In addition, most pre-schoolers at risk for MLD also performed low on the ANS task. This shows that the number foundations in pre-schoolers are different to those in primary school years, and that intervention programmes for pre-schoolers need to include training on domaingeneral abilities as well as numerical-specific skills.

References

Simms, V., Gilmore, C., Cragg, L., Clayton, S., Marlow, N. & Johnson, S. (2015). Nature and origins of mathematics difficulties in very preterm children: a different etiology than developmental dyscalculia. *Pediatric Research*, 77(2), 389- xxx.

Murphy, M. M., Mazzocco, M. M., Hanich, L. B., & Early, M. C. (2007). Cognitive characteristics of children with mathematics learning disability (MLD) vary as a function of the cutoff criterion used to define MLD. *Journal of Learning Disabilities*, *40*(5), 458-478.

Ginsburg HP, Baroody AJ. Test of Early Mathematics Ability. 3. Austin, Texas: Pro Ed;

2003.

Eliot, C. D., & Smith, P. (2011). *British Ability Scales: Third Edition*. GL Assessment.

Wynn K (1992) Addition and subtraction by human infants. Nature 358: 749–750

Table 1

Chronological Age (CA) and Performance scores (means and Standard Deviations) for the 4 clusters and the Control group for reasoning ability (Picture Similarities task), non-symbolic comparison (ANS task), Mathematical abilities (TEMA), Rapid Automated Naming (RAN), Visuo-spatial short term memory (VS-STM) and Cardinality.

	Cluster 1 N = 10 (7 Females)		Cluster 2 N = 33 (18 Females)		Cluster 3 N = 12 (6 Females)		Cluster 4 N = 14 (6 Females)		Control Group N=47 (28 Females)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
CA (months)	42.70	5.89	44.45	4.98	48.00	5.51	42.21	6.09	45.64	5.10
Picture Similarity	46.70	7.48	46.33	7.54	46.83	5.39	44.57	5.05	49.17	7.19
TEMA (raw)	2.50	1.72	4.52	1.48	6.42	2.84	3.29	1.82	13.36	5.85

ANS	24.50	4.62	27.91	3.53	35.50	3.12	27.00	4.91	33.23	4.77
RAN	215.70	28.67	116.48	29.28	103.17	27.66	129.50	36.63	96.32	23.14
VS-STM	2.90	.88	3.36	.99	4.25	1.06	.36	.63	4.60	1.72
Cardinality	4.700	4.644	8.758	2.305	12.667	2.270	5.643	2.872	13.340	3.171

Table 2

Overview of Socio-Economic Status (SES) per group as a percentage

Group	No formal qualification	Finished secondary school	Vocational degree	Undergraduate degree	Post-graduate degree	Missing data
Cluster 1	14.3 %	28.6 %	42.9 %	14.3 %	0%	42.9%
Cluster 2	16.7 %	10.0 %	16.7 %	56.7 %	0%	10%
Cluster 3	0.0 %	20.0 %	20.0 %	40.0 %	20%	20%
Cluster 4	50.0 %	0.0 %	20.0 %	20.0 %	10%	40%

Children at risk for MLD

Control	8.9 %	11.1 %	11.1 %	35.6 %	33.3%	4.44%