RAN AND LEARNING DISABILITIES: IS THERE A SPECIAL CONNECTION BETWEEN MATHEMATICAL DIFFICULTIES AND RAPID AUTOMATIZED NAMING?

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This study examined whether children with mathematical difficulties (MD) show poor performance in rapid automatized naming (RAN), and whether the severity of the MD is associated with RAN performances. Previous studies have shown that RAN is a significant predictor for mathematical abilities, but the understanding of the association between mathematics and RAN are still inconsistent, and not a lot of research has investigated the relationship between RAN and mathematics in children with MD. In addition, this study researched whether RAN is related to math problems only when there is an overlapping reading difficulty or are deficits in rapid serial naming also related to the single MD. In the current study, 336 children from a Finnish clinical database were divided into groups, based on their scores on mathematical and reading fluency measures, and RAN tasks (numbers, letters, and objects). This study found that RAN deficits are very common among children with MD; 43.94% had a RAN numbers deficit, 50.89% had a RAN letters deficit and 49.19% exhibited a deficit in RAN objects. This is clearly more than the expected 7% in a normative sample (with a cutoff score of 1.5 SD below the reference group mean). This finding suggests that poor mathematical fluency is related to poor RAN task performance. Cross-tabulation and χ^2 test revealed that children with severe MD (mathematical fluency test z-score below -2.5 SD) were more likely to have a deficit in RAN numbers and letters than children who had moderate MD (mathematical fluency test z-score between -2.5 SD and -1.5 SD). The severity of the MD was not statistically significantly associated with the performance of the RAN objects task, although it approached significance. This finding suggests that deficits in naming written symbols (numbers and letters) indicate more difficult problems in math. The deficit of naming objects seems to be associated with different levels of math difficulties, indicating that this task is not able to differentiate between different severity levels in MD. The last cross-tabulation and χ^2 test showed that children with MD+RD were more likely to have a deficit in RAN numbers and letters than children with the single MD. Differently, children with both MD and RD, and children with the single MD did not differ statistically significantly in their RAN objects performance. These results showed that comorbid RD increases the number of children having deficits in RAN numbers and letters. In contrast, object naming seems to require some additional process that are central in math difficulties with or without comorbid reading difficulties. This additional process could be the ability recall conceptual information from memory, and children with MD might show problems in this additional process. Overall, RAN could be a useful tool in pinpointing what are the cognitive processes behind single MD and RD and the comorbid MD+RD. This could help to tailor intervention programs for both the isolated learning disabilities and for the comorbid type.

Keywords: mathematical disability, reading disability, comorbidity, RAN and mathematical disability, alphanumeric and non-alphanumeric RAN

JYVÄSKYLÄN YLIOPISTO

Psykologian laitos

GAIANI, ANNIKA: RAN ja oppimisvaikeudet: Onko matematiikan vaikeuksien ja nopean sarjallisen nimeämisen välillä erityinen yhteys?

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Tässä tutkimuksessa tutkittiin, onko matematiikan vaikeuksista (MV) kärsivillä lapsilla, myös ongelmia nopean sarjallisen nimeämisen (RAN) testissä. Tämän lisäksi tarkasteltiin, vaikuttaako matematiikan sujuvuusvaikeuden vakavuusaste numeroiden, kirjainten ja esineiden ongelmien määrään RAN-testissä. Aikaisemmat tutkimukset ovat osoittaneet, että RAN on merkittävä ennustaja matemaattisille kyvyille, mutta ymmärrys matematiikan ja RAN:n välisestä yhteydestä on edelleen epäjohdonmukainen, ja RAN:n yhteyttä matematiikkaan ei ole myöskään tutkittu paljon niillä lapsilla, joilla on MV. Lisäksi tutkittiin, liittyykö RAN matematiikan ongelmiin vain silloin, kun MV:n kanssa esiintyy päällekkäisyyttä lukemisen vaikeuksien (LV) kanssa, vai liittyykö nimeämisongelma myös puhtaaseen matemaattiseen ongelmaan. Tutkimusotos perustuu suomalaiseen kliiniseen aineistoon, ja tutkimukseen valikoitui 336 lasta. Otos jaettiin ryhmiin matematiikan ja lukemisen sujuvuustestien sekä RAN-tehtävien (numerot, kirjaimet ja esineet) pisteiden perusteella. Havaittiin, että RAN-ongelmat ovat yleisiä lapsilla, joilla on MV; 43.94 %:lla oli ongelmia RAN-numeroissa, 50.89 %:lla oli ongelmia RAN-kirjaimissa ja 49.19 %:lla esiintyi ongelmia RAN-esineissä. Tämä määrä on selvästi enemmän kuin väestöllisesti odotettu 7 % (raja-arvona käytettiin 1.5 KH vertailuryhmän keskiarvon alapuolella). Tämä tulos viittaa siihen, että huono matemaattinen sujuvuus on yhteydessä huonoon suoritukseen RAN-tehtävissä. Ristiintaulukointi ja $\chi 2$-testi paljastivat, että ne lapset, joilla oli vakavampaa matematiikan sujuvuuden vaikeutta (määritettiin, mikäli matematiikan sujuvuustestin z-pistemäärä oli alle -2.5 KH) oli myös enemmän ongelmia RAN-numeroissa ja -kirjaimissa verrattuna lapsiin, joilla oli lievempää matematiikan sujuvuuden vaikeutta (määritettiin, mikäli matematiikan sujuvuustestin z-pistemäärä oli -2.5 KH:n ja -1.5 KH:n välillä). Tilastollisesti merkitsevää yhteyttä ei löytynyt MV:n vakavuuden ja RAN-esineiden välillä, vaikkakin tulos oli lähellä merkitsevyyttä. Tämä havainto voi tarkoittaa sitä, että kirjoitettujen symbolien (numeroiden ja kirjainten) nimeämisongelmat viittaavat vaikeampiin matemaattisiin ongelmiin. Ongelmat esineiden nimeämisessä puolestaan ovat yhteydessä eritasoisiin matematiikan vaikeuksiin, joten esineiden nimeämisen testi ei näyttäisi erottelevan MV:n eri vakavuustasoja. Tulokset osoittivat myös, että niillä lapsilla, joilla oli sekä MV että LV, oli myös enemmän ongelmia RAN-numeroissa ja -kirjaimissa mutta ei RAN-esineissä. Näyttäisi siltä, että komorbiditeetti lisää ongelmia RAN-numeroissa ja -kirjaimissa, mutta ei RAN-esineissä. Nämä havainnot voidaan tulkita siten, että RAN-esinetehtävien suorittaminen vaatii jonkinlaisia kognitiivisia lisäprosesseja, jotka ovat keskeisiä matematiikan ongelmissa, joko LV:n kanssa tai ilman. On ehdotettu, että yksi tällainen lisäprosessi voisi olla kyky palauttaa mieleen käsitteellistä tietoa muistista ja lapset, joilla on MV, saattavat osoittaa ongelmia juuri tässä lisäprosessissa. Kaiken kaikkiaan RAN voisi olla hyödyllinen työkalu tutkittaessa kognitiivisia prosesseja, jotka liittyvät yksinomaan MV:iin, LV:iin sekä komorbidiryhmään. Tämä puolestaan voisi auttaa räätälöimään interventio-ohjelmia sekä yksittäisiin oppimisvaikeuksiin että komorbidi häiriöihin.

Avainsanat: matematiikan vaikeus, lukemisen vaikeus, komorbiditeetti, RAN ja matemaattiset oppimisvaikeudet, alfanumeerinen ja ei-alfanumeerinen RAN

CONTENTS

1 INTRODUCTION

Various academic skills are needed at school, such as reading, writing and mathematical skills. Specific learning disorders incorporate difficulties in all academic skills mentioned above (DSM-5, APA, 2013). In addition, fluency in both mathematical and reading abilities is argued to be crucial for the later development of academic skills, however, research investigating the factors underlying the development of both mathematical and reading fluency is still limited (Koponen et al., 2016). Both reading and calculation involve serial processing; the former includes the serial phonemic assembly of letter sounds whilst the latter involves the serial recitation of number words (Koponen et al., 2019). Naming speed deficits have been found to be present in children with reading disabilities (RD); for example, reading speed is related to rapid naming (Bowers, 1995). A vast amount of studies have concentrated on the connection between RD and rapid naming, and it has been argued that rapid serial naming (assessed with rapid serial naming tests, RAN) is a good predictor of later reading fluency (Holopainen, Ahonen, & Lyytinen, 2001; Landerl & Wimmer, 2008). Recent research has also found a connection between RAN and fluent calculation skills (Koponen, Aro, Räsänen & Ahonen, 2007; Koponen, Mononen, Räsänen & Ahonen, 2006, Korpipää et al., 2017), but the studies regarding the association of RAN with mathematical fluency difficulties has been scarce so far. This study concentrated on mathematical disability (MD) by investigating whether children with poor mathematical fluency have RAN deficits. In addition, this study explored whether the severity of the MD is associated with RAN performances, and whether RAN performance is related to math problems, only when there is an overlapping RD, or are the deficits in rapid serial naming also related to the single MD.

1.1 Terminology and prevalence

The terminology varies in the literature when talking about learning disorders and learning disabilities (LDs). One definition for LDs, introduced by the National Joint Committee on Learning Disabilities (1990), proposes that the term LD can be used for a heterogeneous group of neurologically based disorders that are manifested through problems in the use and acquisition of reading, writing, reasoning, mathematical abilities, speaking and listening. The subsets of LDs include mathematical disability (MD) and reading disability (RD) (Pennington, 2008). The diagnostic classification used in Finland is the International Statistical Classification of Diseases (ICD-10). ICD-10 describes LDs to be specific developmental disorders regarding scholastic skills (ICD-10, World Health Organization, 2004). Developmental disorders can be categorised into domain-specific contents, such as dyslexia, which refers to a specific RD and dyscalculia, which refers to a specific MD (ICD-10, World Health

Organization, 2004). For the present study the terms MD, RD, and MD+RD are used, with the last one referring to the comorbid LD subtype.

The prevalence of specific learning disorder, according to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5, APA, 2013) varies from 5 to 15% among school aged children. Epidemiological studies have found a prevalence rate of 3–7% for MD and 4–9% for RD (DSM-5, APA, 2013). Research on LD have long been concentrating on RD, although it has been shown that RD is more likely to occur with MD than without (Dirks, Spyer, van Lieshout, & de Sonneville, 2008). The comorbidity rates vary from 11 to 70% with children who have either MD or RD (Koponen et al., 2018; Landerl & Moll, 2010)

1.2 MD and RAN

A person with MD may have difficulties with, for example, learning number facts, counting, estimating number quantities, doing math calculations, measurement, and problem-solving strategies (Cortiella & Horowitz, 2014). Although the prevalence of RD and MD is roughly the same, MD has a much lower public profile compared to RD (Goswami, 2008), even though MD's consequences seem to be at least as severe as the consequences of RD (Beddington et al., 2008). MD is likely to be a heterogeneous group, and this study concentrated on investigating MD fluency problems, that is, calculation fluency consisting of the fluent use of counting strategies, including the strategy for the retrieval of these counting strategies from long-term memory (Barrouillet & Fayol, 1998). Although it is known that for later development of academic skills fluent calculation skill is very important, the attention in investigating the fluency in mathematics is limited (Koponen et al., 2016). In the first stage of development of fluent calculation ability, one needs to serially recite number words, which requires the serial processing of information, and at a later stage, there is a shift towards the processing and retrieval of information from long-term memory, for example, the retrieval of arithmetic facts needed in calculation (Koponen et al., 2016). The most typical cognitive feature of calculation dysfluency is the problem with the retrieval and storage of these calculation strategies and facts (Landerl, Bevan, & Butterworth, 2004).

Recent research has investigated the relationship between naming speed and mathematical fluency. One process that is involved in naming speed, is the ability to retrieve the name of a symbol, and it can be measured with a task called rapid automatized naming (RAN) (Wolf et al., 2002). RAN tests the ability to name an array of familiar visual stimuli as quickly as possible (Vander Stappen & Reybroeck, 2018). An association has been found between calculation fluency and RAN (Hecht, Torgesen, Wagner, & Rashotte, 2001; Koponen, Aunola, Ahonen, & Nurmi, 2007; Koponen, Georgiou, Salmi, Leskinen, & Aro, 2017), and RAN has been found to be a reliable predictor of later arithmetic calculation skill, after controlling for, for example, memory and phonological awareness, among typically developing children (Koponen et al., 2013, 2016). In addition, there is a study that has found a relation between MD and RAN (Donker, Kroesbergen, Slot, Van Viersen, & De Bree, 2016). In order to better elucidate the relationship between RAN and mathematics, Koponen et al. (2017) did a meta-analysis in which a positive and statistically significant (r = .37) relationship was found between them. The relationship was stronger between RAN and measures of math fluency than RAN and math accuracy measures. This meta-analysis concluded that RAN is in fact a strong correlate of mathematics, especially of math fluency, and a possible underlying cognitive mechanism behind this relationship could be that both RAN and mathematical fluency need rapid access to and retrieval of phonological representations from long-term memory. Also, Landerl et al. (2004) hypothesised that retrieval processing difficulties could be an underlying deficit in MD, and that the serial nature of the retrieval process could be a common process connecting RAN and calculation fluency.

There are, however, inconsistencies in studies investigating the relation between RAN and mathematics; some studies have shown correlations between mathematical skills and RAN (Koponen et al., 2007, 2013, 2016; Swanson & Kim, 2007) whereas other studies, like the one conducted by Niklas and Scheider (2013), found a weak correlation between mathematical skills and RAN. Some studies question the role of RAN in mathematics with the finding that RAN's predictive variance in mathematical fluency is mostly explained by working memory and processing speed (Georgiou, Tziraki, Manolitsis, & Fella, 2013). These inconsistencies could explain why the correlation between RAN and mathematics was only .37 in the study by Koponen et al. (2017). A possible reason, as to why the conclusions regarding the relationship between RAN and mathematics are indefinite and findings are mixed, might be due to how MD is measured in studies. In some studies, the math outcome measure was mathematical accuracy (Niklas & Schneider, 2013; Swanson, 2007) whilst in others it was mathematical fluency (Georgiou, Parrila, Cui, & Papadopoulos, 2013; Koponen et al. 2013, 2016). Another possible reason for variation in previous findings could be the fact that studies use different cut-off criteria when determining whether a child has MD or not, and the severity levels in MD differ between studies.

In the present study, further investigation was made as to whether children with MD fluency problems showed RAN deficits. Previous research has mostly investigated the relationship between RAN with reading and mathematical fluency with unselected samples, which have included participants with a limited percentage of diagnoses. In this study, the focus of this relationship was with a clinical sample of children diagnosed with LDs, to further understand the factors predicting and identifying difficulties related to fluency deficits. In the meta-analysis by Koponen et al. (2017) it was found that RAN correlated more strongly with fluency math outcomes than with accuracy math outcomes. For this reason, in the present study, the type of math outcome used was mathematical fluency. Furthermore, due to different cut-off criteria used in the previous studies, in this study, in addition to investigating whether children with MD fluency problems showed deficits in their RAN performances, it was investigated whether the severity level of the MD had an effect on the children's RAN performances.

1.3 Alphanumeric RAN, non-alphanumeric RAN and comorbidity of MD and RD

With RAN, a distinction has been made between the naming of objects (non-alphanumeric RAN) and the naming of letters and numbers (alphanumeric RAN) (Denckla & Rudel, 1974). Donker et al. (2016) argued that it is important to concentrate on the type of symbols (numbers, letters, objects) that the participants have to name in the RAN task, since the required cognitive processes are different for different symbols. Therefore, it is important to make a distinction between alphanumeric and non-alphanumeric RAN. Donker et al. (2016) highlighted that the relationship between RAN and mathematics could be affected by the type of RAN task that is used. For this relationship, different hypothesis have been proposed; one is that the relationship is related to the use of the numeric stimuli used in RAN tasks, i.e. numbers or quantities (Landerl et al., 2004, Landerl, Fussenegger, Moll, & Willburger, 2009). However, there are also alternative views suggesting that RAN mathematics relation is more complex, and for example, the found relation between object naming and math could be related to conceptual processing needed both in naming objects as well as in processing numerical information in math (Donker et al., 2016). If the former hypothesis was to be true, then RAN numbers would show a stronger relationship with mathematical fluency compared to letters and objects, and if the latter hypothesis was to be true, clear differences between different stimulus (numbers, letters and objects) might not be found since both symbolic and non-symbolic processing of quantities is required in math (Koponen et al., 2017).

Studies on the relationship between RAN and RD have a long history. RAN tasks have been found to be excellent diagnostic indicators of RD, and many studies have replicated the finding that children with RD show a RAN deficit (de Jong & van der Leij, 1999; Di Filippo et al., 2006; Georgiou et al., 2013; Georgiou, Parrila & Kirby, 2009; Wimmer, Mayringer, & Landerl, 1998). Children with RD have been found to show deficits in both alphanumeric and non-alphanumeric RAN (Donker et al., 2016). The investigations regarding the different types of RAN tasks could help elucidate the similarities and differences that lie behind MD and RD. In the present study, RAN tasks with different stimuli (numbers, letters, objects) were used to investigate whether there are retrieval difficulties typical for MD or whether the retrieval difficulties can be explained with comorbid RD (i.e., MD+RD).

At the moment, there are two different hypotheses regarding how MD and RD profiles differ or are similar with respect to alphanumeric and non-alphanumeric RAN deficits. One hypothesis is that there is a difference between alphanumeric and non-alphanumeric RAN in the performances of children with MD and RD. This hypothesis is supported by the finding by Donker et al. (2016) who discovered that the RD group was impaired in both alphanumeric and non-alphanumeric task, although literacy skills were more strongly correlated with alphanumeric RAN performance compared to non-alphanumeric RAN performance. Differently, the MD group showed deficits only on the non-alphanumeric RAN task, and mathematical skills did not correlate with alphanumeric RAN. In this same study, it was found that the MD+RD group was impaired in both the alphanumeric and non-alphanumeric RAN. A plausible interpretation proposed for these findings was that performance on alphanumeric and non-alphanumeric RAN need common underlying processes, but that the performance on the non-alphanumeric RAN needs an additional process (Donker et al., 2016). The additional process required by non-alphanumeric RAN could be the recalling of conceptual information from memory, and children with MD could show problems, not only in the retrieval of numbers, but also in conceptual processing (Donker et al., 2016). According to this hypothesis, it could be predicted that children with MD show deficits in RAN objects. On the other hand, difficulties in the alphanumeric RAN could be caused by a deficit in phonological processing of stimuli that are presented visually, and this deficit is common in children with RD (Wimmer & Schurz, 2010). Differently, children with MD do not always have deficits in phonological skills (Koponen et al., 2013), which could explain the weaker association between alphanumeric RAN and MD. This hypothesis would suggest that children with MD would show similar deficits in both alphanumeric RAN and non-alphanumeric RAN or show a more prominent deficit in non-alphanumeric RAN. Lastly, the comorbid MD+RD group would show more deficits in all RAN tasks (numbers, letters, objects) compared to the children with only the single MD.

A different hypothesis is that MD is related to a specific deficit in numerical processing, whereas a phonological deficit is present in RD (Landerl et al., 2004; Landerl et al., 2009). This so called “number module account” for MD predicts that people with MD will show problems in tasks in which access to the cognitive representation of numerosities is required (Landerl et al., 2009). Similarly, Willburger, Fussenegger, Moll, Wood, and Landerl (2008) found that children with RD had deficits with all the RAN tasks, whereas children with MD showed a specific deficit with RAN quantities (a task in which children were asked to name the number of triangles in each string), and were found to be as good as the control group in naming letters and objects. The researchers argued that these findings point to a possibility that RAN deficit in children with RD are due to a general naming speed deficit, whereas for children with MD, a RAN deficit is caused by a defective number module. For the comorbid group, it was found that RAN deficits were additive, meaning that this group showed the sum of the deficits found in the single MD and in the single RD groups. Also, Landerl et al. (2009) found that in the MD+RD group, the deficits in the RAN tasks were additive, and that the comorbid group showed more marked deficits compared to the single MD and RD groups. In line with this hypothesis is the finding by Araújo, Reis, Petersson, and Faísca (2015) who found that reading was more strongly associated with alphanumeric RAN compared to non-alphanumeric RAN. This hypothesis would suggest that children with MD would show a specific deficit in RAN numbers rather than in RAN letters and objects. The MD+RD group would show more deficits in all RAN tasks compared to the children with the single MD.

1.4 This study

Since there are still contradicting and inconclusive results regarding the relationship between MD, RD and RAN, this study further examined associations between MD and different types of RAN tasks, and whether the severity of MD or comorbid RD were associated with RAN deficits. For this study, RAN was assessed using three RAN tasks: numbers, letters (alphanumeric RAN), and objects (non-alphanumeric RAN). The aim of the study was to find further support as to whether children with MD showed poor performance in RAN, and whether the severity of the MD deficit was associated with RAN performances. In addition, this study researched whether RAN is related to math problems only when there is an overlapping reading difficulty or are deficits in naming also related to the single MD, thus helping to clarify the relationship between RAN with the single MD and with MD+RD.

The first research question was: *'What percentage of children with MD, which was defined by mathematical fluency problems, have deficits in RAN numbers, letters and objects?'* In previous studies, RAN has been shown to have a connection with mathematical fluency (e.g. Donker et al., 2016; Koponen et al., 2007, 2017). Thus, the assumption in this research was that the percentage of RAN deficits is higher in the MD group compared to the population average.

The second research question was: *'Is poor performance in RAN numbers, letters or objects associated with the severity level of the MD (when the criterion for moderate MD was a mathematical fluency test z-score between -2.5 SD and -1.5 SD and for severe MD was a z-score below -2.5 SD)?'* Contradictory results still exist on the relationship of RAN numbers, letters and objects with MD, thus, no specific predictions were made about how the severity level of the MD affects RAN performances.

The third research question was: *'Is poor performance in RAN numbers, letters or objects associated with the type of learning disability (single MD, comorbid MD+RD)?'* Based on previous findings there are contradictory findings as to whether MD is associated with a more general, conceptual processing difficulty (Donker et al., 2016) or whether MD is related with a core deficit in processing numerosities (Landerl et al., 2004, 2009). Based on both hypotheses, it is predicted that the MD+RD group will show additive deficits compared to the single MD in all the RAN tasks. Based on the hypothesis that MD is associated with a more general, conceptual processing difficulty, it is predicted that children with MD will not show clear differences in their RAN numbers, letters and objects performances or that they would show a more prominent deficit in RAN objects. Differently, based on the hypothesis that MD is related to a deficit in processing numerosities, children with MD will show more prominent deficits in RAN numbers.

2 METHOD

2.1 Procedure and Participants

The clinical archival data that were used in this study have been collected and saved gradually to a database between 1985-2016 and include information from over 1200 school aged children. These children were referred to the Clinic for Learning Disorders (CLD) for evaluation of learning disabilities. The CLD is upheld by the Family Guidance Centre of Jyväskylä and the Niilo Mäki Institute (NMI), which focuses in research, as well as assessment, and interventions for children with learning disabilities. Child's difficulties in learning are normally first recognised at school, after which the child is referred to the CLD for a more extensive neuropsychological assessment. Informed consent is given by the parents to use the data for research purposes.

All children in the database who could be identified as having MD, or both MD and RD were included in the present study for further analyses. The criterion for MD was that the child had a z-score of at least 1.5 standard deviation (SD) below the reference group mean in the mathematical fluency measure (see below the description of the mathematical fluency measure, RMAT). Likewise, RD was identified if the child's z-score was at least 1.5 SD below the reference group mean in the reading fluency measures, which are described below. A child was allocated in the MD+RD group if he/she had a z-score of at least 1.5 SD below the reference group mean in both the mathematical and reading fluency measures. The z-scores were computed based on the Finnish normative data.

The original data contained 1218 children, but for this study only the children who had completed the RMAT test (n=643) (Räsänen, 2004) were included, as RMAT is a time limited test, and therefore taps into deficits in calculation fluency (see below). Of those 643 children, there were 336 children with MD (i.e., RMAT z-score below -1.5 SD), and they formed the sample of the present study. Of those 336 children, 159 had a severe form of MD (i.e., RMAT z-score below -2.5 SD) and 183 had also comorbid RD (i.e., RMAT and reading fluency measure z-score below -1.5 SD). A more detailed description of the sample characteristics is given in Table 1. Finnish was the mother tongue of all the children, and they all attended either primary or secondary schools in Finland.

2.2 Measures

Mathematical and reading fluency measures. Mathematical fluency was assessed with the RMAT – A Mathematical Achievement Test (Räsänen, 2004). RMAT is a time-limited (10 minutes) pen and paper test during which the child completes as many basic arithmetical operations as possible, up to

55 operations. The mathematical items consist of algebra tasks, arithmetic operations, fractions, decimals, and measurement. RMAT test is normed for 9 to 12-years old, and the Cronbach alpha reliability was reported to be from 0.92 to 0.95, depending on the grade level (Räsänen, 2004).

Reading fluency was measured with different reading fluency tests, all age-normed and developed in Finland. The test used to assess reading fluency has changed during the years when the children attended the CLD, and therefore the reading fluency measure used in the present study was the one available for the child. If the Lukilasse test score was available, it was used. If Lukilasse score was not available, the score of the ÄRPS test was then used. If ÄRPS score was not available, the score from the Misku test was used. Lastly, if Misku test score was not available, the score of the Markkinat test was used. The first reading fluency measure was Lukilasse's (Häyrinen, Serenius-Virve & Korkman, 1999) subtest in which the participant was asked to read as correctly and as fluently as possible the words shown in the word list (max 90 words). The measure was the amount of words read in 45 seconds. The second reading fluency measure used was the ÄRPS (Äänekoski Reading Performance Scale, Niilo Mäki Institute, 1992-2004) reading skills test battery. This test was developed for second to fourth grade children. The third reading fluency measure was the Misku test (Niilo Mäki Insititute, 1992-2004). This text-reading task is normed for 8- to 12-year-old children. The test consists of the child reading aloud a one-page story as correctly and quickly as possible. The reading speed measure is the time taken to complete the test. The fourth measure used was the Markkinat word list reading task (Niilo Mäki Institute, 1992-2004), in which the participant is asked to read 13 words as fluently and as correctly as possible. The measure is the time it takes to complete the task. For the reading tests measures, reliability coefficients are given for the Lukilasse word list reading test only. For this test, in normative sample, the coefficients reported ranged between 0.94–0.98, depending on the school grade (Häyrinen et al., 1999).

Measure of naming speed. Rapid naming test (RAN; Ahonen, Tuovinen, & Leppäsaari, 1999; Denckla & Rudel, 1974) was used to assess rapid automatized naming with three RAN versions with different stimuli: numbers (2, 4, 6, 7, 9), letters (O, A, S, T, P) and objects (car, house, fish, pen, ball). Each item was repeated in a pseudorandom order so that no individual item was repeated successively. Matrices of 50 items were used, in which five stimuli were presented ten times. The child was instructed to name each stimuli as correctly and as quickly as possible. The outcome score used was the time it took for the child to read the card. A z-score of at least -1.5 SD below the reference group mean was used as the cut-off score for RAN deficit separately in numbers, letters, and objects.

2.3 Statistical Analyses

SPSS Statistics 26 was used to run all the statistical analyses used in this study. The independent variables were the z-scores obtained by the children in the RMAT and in the reading fluency measure. The dependent variable were the z-scores obtained in the RAN numbers, letters, and objects tasks.

The data was first checked for normality and screened for outliers and missing values. The RMAT was normally distributed and did not include any outliers. Differently, the distribution of the reading fluency variables, RAN numbers, letters and objects variables had strong negative skewness and included multiple extreme outliers and missing values. The reading fluency measure was missing from 48 children, RAN numbers was missing from 10 children, RAN letters was missing from 1 child, and RAN objects was missing from 159 children. The outliers were manually moved to the tails to improve the normality of the data, and the order of the participants was maintained. The cut-off point for the outliers was determined using stem-and-leaf plots for each variable. For the reading fluency measure, a total of 46 values, with a score under -7.57, were moved to the tail. For RAN numbers, 26 values, with a score under -5.80, were moved to the tail. For RAN letters, 27 values, with a score under -6.20, were moved to the tail. For RAN objects, a total of 19 values, with a score under -5.10 were moved to the tail. After these corrections, all measures used for analyses were normally distributed and contained no extreme outliers.

Children were divided into two groups based on their RMAT score: the children with MD had a RMAT score below -1.5 SD, and children without MD had a RMAT score above -1.5 SD. Only the children with MD were included in the final sample. Children were also divided into two groups separately in each RAN task in numbers, letters and objects; children who had a RAN deficit (a z-score below -1.5 SD) and children who did not have a RAN deficit (a z-score above -1.5 SD). Before the analyses, the demographic information of the data was checked, and a Pearson correlation was conducted between RMAT, reading fluency, RAN numbers, RAN letters and RAN objects in order see how RAN was related to mathematical and reading fluency.

To answer the first research question, it was analysed what percentages of children with MD (n=336) had a deficit in RAN numbers, letters, and objects.

To answer the second research question, cross-tabulation, and chi-square test of independence ($\chi 2$ test) were used to find out whether the proportions of the deficit in RAN numbers, letters and objects were associated with the severity of the MD. For this test, the children were divided into two groups based on their RMAT score: children with severe MD (a z-score below -2.5 SD, n=159) and children with moderate MD (a z-score between -2.5 SD and -1.5 SD, n=177).

To answer the third research question, cross-tabulation and $\chi 2$-test were conducted in order to find out whether the proportions of deficit in RAN numbers, letters and objects were associated with the type of learning disability (either the single MD or MD+RD). For this test, a group division was made between children who had both MD and RD (a z-score below -1.5 SD in both RMAT and reading fluency measure, n=183) and children who had the single MD (a z-score below -1.5 SD in RMAT, n=153). The MD group in this research question included children with both severe and moderate MD.

In the analyses mentioned above, the number of children vary according to the RAN task (numbers, letters, objects) since not all children did all the RAN tasks. All the analyses and findings were verified with the sample comprising children with no missing data, and the same results were obtained.

3 RESULTS

Demographic information of the sample is shown in Table 1 and Table 2. In all the groups there were more boys than girls, and the children had a relatively low FSIQ score since the age-average mean score is 100.

Table 1. Characteristics of the sample with the group means (M) and standard deviations (SD). MD group (n=336) includes severe MD (n=159) and MD+RD (n=183).

	MD (n=336)				Severe MD (n=159)				MD+RD (n=183)			
	Boys (n=205)		Girls (n=131)		Boys (n=94)		Girls (n=65)		Boys (n=112)		Girls (n=71)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Age[a]	123.56	15.70	121.47	15.88	123.49	18.40	123.20	16.91	124.03	16.37	119.89	14.53
Grade	3.62	1.25	3.63	1.13	3.61	1.05	3.42	1.01	3.70	1.07	3.68	1.0
FSIQ score	88.24	10.45	88.80	11.00	86.89	10.49	88.03	11.64	86.90	9.56	89.32	9.95

Note. FSIQ score = Full scale IQ score. [a] = months

Table 2. RAN performance of the sample with group means (M) and standard deviations (SD).

	RAN numbers deficit (n=261)				RAN letters deficit (n=314)				RAN objects deficit (n=203)			
	Boys (n=177)		Girls (n=84)		Boys (n=206)		Girls (n=108)		Boys (n=144)		Girls (n=59)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Age[a]	128.44	16.00	125.85	15.89	126.83	15.29	126.53	16.3	125.17	15.56	124.37	16.30
Grade	3.64	1.44	3.81	1.37	3.68	1.42	3.81	1.44	4.15	1.31	4.15	1.20
FSIQ score	87.26	10.70	86.78	10.60	87.30	10.55	88.94	11.00	86.61	11.67	88.68	10.35

Note. FSIQ score = Full scale IQ score. [a] = months

Pearson Correlations were conducted between RMAT, reading fluency, RAN numbers, RAN letters, and RAN objects. This descriptive analysis was conducted to see how different RAN tasks are related to mathematical and reading fluency. All correlations are reported in Table 3. RMAT was weakly, positively correlated with RAN numbers, letters, and objects, indicating that those children with a lower RMAT score showed slower RAN performances. Reading fluency had a moderate, positive correlation with RAN numbers and letters, and a weak, positive correlation with RAN objects, indicating that those children with a lower reading fluency score showed slower RAN performances. As shown in Table 3, the number of children vary according to the RAN task (numbers, letters, objects) since not all children did all the RAN tasks. All the analyses and findings were verified with the sample comprising children with no missing data, and the same results were obtained.

Table 3. Pearson Correlations, significance values and number of children between RMAT, reading fluency, RAN numbers, letters, and objects in children with MD (n=336).

		Reading fluency	RAN numbers	RAN letters	RAN objects
RMAT		.01	.18**	.20**	.15*
	n	302	330	336	246
Reading fluency			.35**	.45**	.23**
	n		296	302	215
RAN numbers				.79**	.55**
	n			330	242
RAN letters					.55**
	n				246

Note. * = Correlation is significant at the 0.05 level, ** = Correlation is significant at the 0.01 level.

The first research question was what percentage of children with MD fluency problems had a deficit in RAN numbers, letters, and objects. In our sample, 43.94% of children with MD had a RAN numbers deficit, 50.89% had a RAN letters deficit, and 49.19% exhibited a deficit in RAN objects. About 7% would be expected in a normative sample with the cut-off criterion of -1.5 SD, which was used in this study.

The second research question concerned whether children with moderate MD differed from the severe MD group in their RAN performances. All results are shown in Table 4. A significant relation between the severity of MD and RAN numbers was observed, $\chi 2$ (1, N = 145) = 4.41, p = .04. Children with severe MD were more likely to have a deficit in RAN numbers than children who had moderate MD, as 50.00% of children with severe MD and 38.51% of those with moderate MD exhibited a deficit in RAN numbers. Similarly, a statistically significant association between the severity of MD and RAN letters was observed, $\chi 2$ (1, N = 171) = 5.87, p = .02. Children with severe MD were more likely to have a deficit in RAN letters than children who had moderate MD. 57.86% of children with severe MD and 44.63% of those with moderate MD exhibited a deficit in RAN letters. Differently, there was a non-significant association between the severity of MD and RAN objects, $\chi 2$ (1, N = 121) = 3.60, p = .06. In our sample, 55.75% of children with severe MD and 43.61% of those with moderate MD exhibited a deficit in RAN objects. The severity of the MD seemed to be associated with the performance of RAN numbers and letters, since children who had a more severe MD performed worse in the RAN numbers and letters tasks than children with moderate MD. Differently, the severity of the MD was not statistically significantly associated with the performance of the RAN objects task, although it approached significance.

Table 4. Cross-tabulation between severe MD and moderate MD with RAN numbers, letters and objects deficit and no deficit.

			Severe MD	Moderate MD
RAN numbers	Deficit	Count	78	67
		%	50.00	38.51
		Adjusted Stand. Residual	2.1	-2.1
	No deficit	Count	78	107
		%	50.00	61.49
		Adjusted Stand. Residual	-2.1	2.1
RAN letters	Deficit	Count	92	79
		%	57.86	44.63
		Adjusted Stand. Residual	2.4	-2.4
	No deficit	Count	67	98
		%	42.14	55.37
		Adjusted Stand. Residual	-2.4	2.4
RAN objects	Deficit	Count	63	58
		%	55.75	43.61
		Adjusted Stand. Residual	1.9	-1.9
	No deficit	Count	50	75
		%	44.25	56.39
		Adjusted Stand. Residual	-1.9	1.9

The third research question investigated whether children with the single MD differed from the MD+RD group in their RAN performances. All results are reported in Table 5. A statistically significant association between the type of learning disability and RAN numbers was observed, χ^2 (1, N = 126) = 10.38, p = .001. Children with MD+RD were more likely to have a deficit in RAN numbers than children with the single MD; 50.00% of children with MD+RD and 31.03% of those with MD exhibited a deficit in RAN numbers. There was a significant relationship between the type of learning disability and RAN letters, χ^2 (1, N = 149) = 33.88, p < .001. Children with MD+RD were more likely to have a deficit in RAN letters than children with the single MD; 62.84% of children with MD+RD and 28.57% with MD exhibited a deficit in RAN letters. Lastly, there was a non-significant association between the type of learning disability and RAN objects, χ^2 (1, N = 106) = 3.18, p = .08. In this sample, 54.26% of children with MD+RD and 41.86% of those with MD exhibited a deficit in RAN objects. Thus, the type of learning disability seemed to influence the performance of RAN numbers and letters, since more of those children with comorbid problems also had deficits in RAN letters and numbers. Differently, the type of learning disability did not seem to have such a strong effect on the performance of the RAN objects task. Children with both MD and RD, and children with the single MD did not differ statistically significantly in their RAN objects performance.

Table 5. Cross-tabulation between MD+RD and the single MD with RAN numbers, letters and objects deficit and no deficit. The MD group included children with both severe and moderate MD.

			MD+RD	MD
RAN numbers	Deficit	Count	90	36
		%	50.00	31.03
		Adjusted Stand. Residual	3.2	-3.2
	No deficit	Count	90	80
		%	50.00	69.97
		Adjusted Stand. Residual	-3.2	3.2
RAN letters	Deficit	Count	115	34
		%	62.84	28.57
		Adjusted Stand. Residual	5.8	-5.8
	No deficit	Count	68	85
		%	37.19	71.43
		Adjusted Stand. Residual	-5.8	5.8
RAN objects	Deficit	Count	70	36
		%	54.26	41.86
		Adjusted Stand. Residual	1.8	-1.8
	No deficit	Count	59	50
		%	45.74	58.14
		Adjusted Stand. Residual	-1.8	1.8

4 DISCUSSION

4.1 Aim of the study and results

The aim of this study was to investigate to what extent children with MD, more specifically children with mathematical fluency problems, show deficit in RAN. In addition, it was investigated whether the severity of the MD is associated with RAN performances and whether RAN is related to math problems only when there is an overlapping reading difficulty or are deficits in rapid serial naming also related to the single MD.

In this research, it was found that about half of the sample with MD had deficits in all RAN tasks, confirming the assumption that poor mathematical fluency is related to RAN deficit, as about seven percent of children would be expected to show deficits with the cut-off criterion of -1.5 SD, which was used in this study. For the second research question, regarding whether the severity of the MD is associated with RAN deficit, it was found that children who had a more severe MD performed worse in the RAN numbers and letters tasks than children with moderate MD. Differently, the severity of the MD was not statistically significantly associated with the performance of the RAN objects task, although it approached significance. This finding suggests that deficits in naming written symbols (numbers and letters) indicate more difficult problems in math. The deficit of naming objects seems to be associated with different levels of math difficulties, indicating that this task is not able to differentiate between different severity levels in MD. For the third research question, it was found that children with MD+RD were more likely to have a deficit in RAN numbers and letters, but not in RAN objects, compared to the children with the single MD. Deficit in naming written symbols was related especially to comorbid disabilities in math and reading, whereas deficit in naming object did not so clearly distinguish a single math disability from comorbid disabilities, but seemed to be related to math in general.

4.2 MD and RAN

The present study found that RAN deficit is very common among children with MD; 43.94% had a RAN numbers deficit, 50.89% had a RAN letters deficit and 49.19% exhibited a deficit in RAN objects. The prevalence of a RAN deficit among children with MD was several times higher than expected, based on used -1.5 SD cut-off score, which among normal population would mean that approximately 7% of children would be expected to have the deficit. Thus, the assumption that the percentage of RAN deficits is higher in the MD group compared to the population average, was confirmed, indicating that children with poor mathematical fluency skills do show a RAN task deficit. This finding is in line with the research conducted by Donker et al. (2016) who found that MD is associated with RAN deficits. These findings suggest that RAN and mathematical skills, specifically mathematical fluency, are related, and that rapid serial naming is not only a reading-specific cognitive ability (Koponen et al., 2013).

Although MD was associated with RAN deficit, the correlation results from this data showed that the strength of the linear relationship between RAN and mathematics was low. Koponen et al. (2013) found that the correlation of RAN with mathematical fluency was lower in dyslectics than in non-dyslectics, but in particular there was no correlation between reading and RAN in dyslectics. The correlation results found in both the present study and in the study of Koponen et al. (2013) may be related, for example, to the fact that the MD and RD groups are not homogeneous, but several subgroups can be found in them, and only some of these subgroups show a RAN deficit. Thus, it could be deducted that one should not solely rely on correlative analyses, since this could give an inaccurate interpretation of the relationship between MD and RAN. Further research should pay more attention to the MD and RD subgroups used, in order to better pinpoint which of these subgroups show a RAN deficit.

This study did confirm that mathematical fluency is related to RAN, as found by, for example Koponen et al., (2007), and research has tried to find out which factors explain the connection between RAN and mathematical fluency. One such factor could be how visually presented stimuli are learned and retrieved quickly from long-term memory (Koponen et al., 2013, 2017). To calculate fluently, a fast and fluent retrieval of a number word sequence is needed to make the association between the answer and the problem in long-term memory stronger (Koponen et al., 2007). The problems in storing and accessing verbal information in long-term memory could lead to difficulties in retrieving arithmetical facts (Räsänen & Ahonen, 1995), and fluent single-digit calculation ability has been found to be affected by how fast the serial naming ability was in Grade 4 (Koponen et al., 2007). In a study examining the predictors of the covariance between arithmetic and reading fluency, Koponen et al. (2019) discovered that a latent factor, which they named as serial retrieval fluency (SRF), was the strongest predictor for this shared variance. In addition, they found that articulation speed, working memory and processing speed explained around half of the variance of SRF. These underlying cognitive mechanisms could be some of the potential factors explaining the relationship between mathematical fluency and RAN.

4.3 Severity of MD and RAN

The present study found that children who had a more severe MD performed worse in the RAN numbers and letters tasks than children with moderate MD, but the severity of the MD was not statistically significantly associated with the performance of the RAN objects task, although it approached significance. Thus, no clear conclusions were able to be made regarding how the severity level of the MD affects RAN performances. However, these findings do suggest that deficits in naming numbers and letters indicate more difficult problems in math, whereas the deficit of naming objects seems to be associated with different levels of math difficulties, indicating that this task is not able to differentiate between different severity levels in MD.

To my knowledge, no previous studies have examined how the severity level of the MD has an effect on the performance on RAN tasks. For reading, it has been found that RAN is more strongly associated with reading, especially when children have a low perfomance on reading (Savage & Frederickson, 2005). In the meta-analysis, Koponen et al. (2017) hypothesised that a possible reason why the relationship between mathematics and RAN is not different between well and poor performing children could be due to the fact that the samples in studies are usually heterogenous. In the present study, MD was determined with a specific cut-off criterion, but nonetheless, the naming of objects was not clearly related to the level of difficulty in mathematics, while the naming of numbers and letters was. It seems that difficulties in written symbols (numbers and letters) indicate more problems in mathematics, while the naming of objects was not clearly related to the level of difficulty in mathematics. This finding suggests that RAN objects task might not be able to differentiate between different severity levels in MD, although caution needs to be taken when making this conclusion, since the association between the severity of the MD and RAN objects task performance approached significance. Thus, further research is needed to confirm this finding.

4.4 Comorbidity of RD, the single MD and RAN

The relationship between the type of RAN task used and the type of learning disability was investigated in the third research question, and it was found that children with MD+RD were more likely to have a deficit in RAN numbers and letters, but not in RAN objects, compared to the children with the single MD. This finding suggests that having comorbid RD increases the possibility of having deficits in naming written symbols (numbers and letters) but not in naming objects. Compared with previous research, this is partly in line with the findings of Donker et al. (2016) and Landerl et al. (2004, 2009), who concluded that the comorbid group does show additive deficits compared to the single deficit. However, this was the case only in the RAN numbers and letters tasks, whereas the frequency of RAN object deficits was not significantly larger among children with comorbid reading disabilities (MD+RD) than among children with the single MD. This finding shows that the deficit in the RAN objects task is seen in children with MD, whether they have comorbid RD or not. This result is in line with the study of Donker et al. (2016) who found that the MD group showed deficits in the non-alphanumeric RAN tasks. These results suggest that MD is more likely associated with a general, conceptual processing difficulty, rather than MD being related to a deficit in processing numerosities, as suggested by Landerl et al. (2004, 2009), or that RAN-math association is purely explained by comorbid reading disability.

There seems to be a stronger connection between reading fluency abilities and the capacity of naming numbers and letters than naming objects. Araújo et al. (2015) did indeed find that reading has a strong connection with alphanumeric RAN, and Koponen et al. (2017) found that the performance of alphanumeric RAN has a stronger relationship with reading ability compared to RAN objects. This could explain why RD increases the chances of a child having deficits with RAN numbers and letters. In both reading and alphanumeric RAN, one does not require conceptual processing, like RAN objects task does, and since reading is normally tested with decoding and recognition tasks, instead of comprehension tasks, RAN numbers and letters could be more reliable predictors of reading than RAN objects (Koponen et al., 2017). Donker et al. (2016) hypothesised that children with RD may show deficits in phonological processing, and that it is the phonological processing deficit that is evident in RAN letters and numbers, since these tasks include a print-to-sound translation of phonology and ortography. Differently, in math calculations, there seems to be a need of both phonological and conceptual information, when solving mathematical problems (Koponen et al., 2017). The performance of RAN objects requires conceptual processing skills, phonological access and general naming abilities, whereas RAN numbers and letters tasks only require general naming abilities and phonological access (Donker et al., 2016). Following this line of thought, it could be hypothesised that children with RD have more problems in phonological access and general naming abilities since they perform poorly in RAN numbers and letters, whereas children with MD could show similar deficits in all RAN tasks because both phonological and conceptual skills are needed in mathematics. This latter assumption is supported by Koponen et al. (2017), who found that math had equally strong associations with both alphanumeric and non-alphanumeric tasks. In addition, as supported by the results of this study, the association between mathematics and RAN does not seem to be specific for numbers since the MD group did also show deficits in RAN objects. Object naming seems to require cognitive processes that are central in math fluency difficulties with or without comorbid difficulties in reading. One such cognitive process needed in RAN objects task could be the recalling of conceptual information from memory, and this cognitive process could also be needed in processing numerical information in math (Donker et al., 2016).

It seems that the use of alphanumeric and non-alphanumeric RAN could help to clarify the similarities and differences between MD and RD. At a neuronal level, it has been found that reading and RAN letters and numbers tasks activate similar neural systems in the brain, and these neuronal networks include the motor-sequencing/articulatory areas (Cummine, Chouinard, Szepesvari, & Georgiou, 2015). In addition, RAN letters and numbers have been found to activate different regions compared to RAN objects, with the former activating ventral–lexical and dorsal–sub-lexical streams and the latter activating ventral–lexical regions (Cummine, Szepesvari, Chouinard, Hanif, & Georgiou, 2014). The network activated by alphanumeric RAN is similar to the network that is activated by reading, and RAN objects activate neural systems that are involved in conceptual processing (Cummine et al., 2014). These neuronal findings are in line with the studies that did find literacy to be more strongly associated with alphanumeric RAN compared to non-alphanumeric RAN (Donker et al., 2016; Heikkilä, Närhi, Aro, & Ahonen, 2009) and with the present study, since the comorbid RD increased the number of children having deficits in RAN numbers and letters. However, further studies are required in pinpointing the difficulties in children with the single MD and MD+RD, in order to better understand the cognitive and neural processes involved in these learning difficulties.

4.5 Strengths and limitations

A strength of this study is that the sample used was a clinical sample. The sample size was large and both MD and RD were reliably assessed in a clinic with an extensive neuropsychological examination. In some other studies investigating the relationship between RAN and MD, like Koponen et al. (2016), the sample consisted of a population-based sample. In order to understand the relationship between RAN and MD, not only theoretically, but also clinically, it is important to investigate this relationship in a clinical sample, in order to see whether this phenomenon could be seen not only in typically developing children but also in children with a learning disability. In addition, both math and RAN performance were assessed on the same assessment process. This could also be regarded as a strength of this study since correlations between two measures that are taken at the same measurement point are argued to be stronger than correlations between two measures that are taken at different time points (Koponen et al., 2017).

However, there are limitations concerning the sample chosen for this study. The sample in this study was not homogenous, since it included children with different diagnoses, such as ADHD and milder forms of learning disabilities. The differing results concerning the relationship between RAN and MD could result from the fact that the samples used in studies vary a lot, and thus more attention needs to be paid when choosing the samples. Samples chosen also vary depending on the cut-off scores used. In this study, the cut-off score for both MD and RD was -1.5 SD which is approximately the same as the 7th percentile. This same cut-off criterion was used in, for example Heikkilä et al.'s (2009) study. In previous studies, different cut-off scores have been used, for example 35th percentile (Salihu, Aro, & Räsänen, 2018), 25th and 10th percentile (De Weerdt, Desoete, & Roeyers, 2013). For RAN, Waber, Wolff, Forbes and Weiler (2000) concluded that the optimal cut-off score could be -1.0 SD, and for this study a cut-off score of -1.5 SD was used. The differing of the cut-off criteria could also be a reason why there are different kinds of relationships found between RAN and learning disabilities, and thus, further investigations on the optimal cut-off score criteria for RAN and MD are needed. Another limitation includes the use of RMAT as a measure of mathematical fluency. Although being a time-limited test, it comprises tasks requiring procedural knowledge in addition to those tapping more into fast retrieval skills. Perhaps, RMAT is not the best measure for the detailed modeling of the relationship between RAN and MD, and for the understanding of the underlying mechanism of this relationship. As Koponen et al. (2013) point out, in the future, more experiential design is needed. Caution needs to be taken also if generalising these findings across other languages, since the Finnish's transparent ortography needs to be considered (Torppa et al., 2007).

4.6 Pedagogical implications and further studies

The results of this study point to the possibility that there are differences between MD and RD that would be important to take into account when, for example, tailoring interventions and when making a clearer picture of the risk and protective factors of the individual with learning disabilitis (Landerl et al., 2009). The differences in MD and RD, as shown in their different performances in RAN tasks, would suggest that there could be the need for qualitatively different intervention programs for MD and MD+RD groups. Based on the findings of this study, it would be useful to focus the intervention with MD children in tasks that tap onto conceptual processing and rapid serial naming skills. This study also confirmed that children with MD show a RAN deficit. Early interventions in MD are important, thus RAN could be a useful diagnostic tool, that can be already used in kindergarden, in order to find out whether a child is at risk of developing problems in mathematics (Koponen et al., 2019; Korpipää et al., 2017). In order to confirm the validity and the specificity of RAN as a diagnostic tool for MD, further studies are needed to elucidate the relationship between RAN and MD, and also the similarities and differences between MD and RD. Longitudinal studies are needed to get better insight into the developmental pathways of both MD and RD, and also to better understand the developmental patterns that RAN has with various cognitive skills (Donker et al., 2016).

4.7 Conclusions

The present study showed that children with poor mathematical fluency skills had a RAN deficit, which confirms the results of previous studies arguing that RAN is a strong correlate for mathematical fluency. No clear conclusions were able to be deducted from the results of this study about whether the severity of the MD influences RAN performances, although children who had severe MD performed worse in the RAN numbers and letters tasks, but not in the RAN objects task, compared to the children with moderate MD. This suggests that deficits in naming numbers and letters indicate more difficult problems in math, whereas the deficit of naming objects seems to be associated with different severity levels in MD. This study did show that the relationship between MD and RAN is affected by RD, since the comorbidity worsens the performance of RAN numbers and letters, but not the performance of RAN objects. Deficit in naming numbers and letters was related especially to comorbid disabilities in math and reading, whereas deficit in naming object did not so clearly distinguish a single math disability from comorbid disabilities but seemed to be related to math in general. The nature of the mathematics-RAN relationship is still unclear, thus, more studies about whether the severity of the MD and comorbidity with RD affect the relationship between mathematical fluency and RAN, are needed, in order to pinpoint which moderators affect this relationship. A clearer picture is also needed on the differences and similarities between MD and RD, and RAN could be a useful tool in elucidating these questions.

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