Number estimation in Down syndrome: Cognition or experience?

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Abstract

Background

The ability to place numbers on a visual "number line" is a hallmark of the understanding of numerical magnitude and it is a strong predictor of mathematical achievement.

Aim

We examined whether the performance in the number line estimation task is more driven by mental age or experience with numbers in a sample of Italian children with Down syndrome (DS).

Method and procedure

Sixty-three children with DS (M_{months}=128.62, *SD*=30.73) and sixty-three typically developing children (M_{months}=54.98, *SD*=6.34) matched one to one for mental age completed number line estimation tasks and other tests to assess their numerical knowledge.

Outcomes and results

No significant differences emerged between the two groups in terms of accuracy of positioning numbers on the 1-10 and 1-20 interval. In addition, the accuracy on the 1-10 interval was related to the ability to recognise numbers, while the accuracy on the 1-20 line was related to the ability to compare magnitudes.

Conclusion and Implication

Results suggest that in individuals with DS the linear mapping of numbers is driven by mental age, but the accuracy of positioning numbers is also shaped by the experience with symbolic numbers. Therefore, the improvement of numerical estimation abilities should be a target of intervention programs.

Keywords: Down Syndrome, number line estimation, number familiarity, cognitive development

Number estimation in Down syndrome: cognition or experience?

Introduction

Down Syndrome (DS) is a neurogenetic condition associated with Intellectual Disability (ID) (Contestabile, Benfenati & Gasparini, 2010). DS is also characterized by physical deficits (e.g., growth delay, flat hypoplastic face with short nose) as well as other medical conditions (e.g., congenital heart disease, thyroid diseases, sleep apnea; Rosser et al., 2018). The behavioral phenotype associated with DS entails weak language skills, whose severity is highly variable, whereby receptive vocabulary results to be stronger than the expressive one (Silverman, 2007 for a review). Conversely, individuals with DS display relatively intact visuo-spatial abilities (Dykens, Hodapp, & Finucane, 2000), although recent research has shown impairments in the visuo-spatial domain, depending on which specific aspect is considered (Yang, Conners, & Merrill, 2014). However, although a typical phenotype is described, the interindividual variability is high (Karmiloff-Smith et al., 2016).

Children with DS exhibit several mathematical difficulties compared to typically developing (TD) individuals matched for chronological (CA) or mental (MA) age (Brigstocke, Hulme, & Nye, 2008). They have reduced ability to process small numerical quantities compared to TD children matched for MA, whereas the ability to discriminate large numerical quantities is in line with MA (Patterson, Girelli, Butterworth & Karmiloff-Smith, 2006; Sella, Lanfranchi & Zorzi, 2013); children with DS can master the counting principles, even though they display a slower and more error-prone enumeration (Onninvello, Lanfranchi & Zorzi, 2019).

Another area of difficulty is numerical estimation. Numerical estimation is a process of translating between alternative quantitative representations, at least one of which is inexact, and at least one of which is numerical (Siegler & Booth, 2015). Numerical estimation tasks are particularly useful for investigating children's numerical development and understanding of numerical magnitudes (Siegler, Thompson & Opfer, 2009; Siegler & Opfer, 2003). A widely-used numerical estimation task is the Number-To-Position (hereafter NTP; Siegler & Opfer, 2003), which involves translating a number into a spatial position on a bounded visual number line. For instance, participants indicate the position of several target numbers on a line representing the numerical interval from 0 to 10.

The pattern of estimates is characterized by a shift from an inaccurate log-like to accurate linear positioning of target numbers as children increase their experience with the presented numerical interval. For instance, when placing numbers on the number line 0-100 interval, preschool children overestimate the position of small numbers and underestimate the position of large numbers (Berteletti, Lucangeli, Piazza, Dehaene & Zorzi, 2010), whereas second graders achieve an accurate mapping (Sella, Berteletti, Lucangeli & Zorzi, 2015; Siegler & Opfer, 2003). The log-like mapping has been attributed to the internal representation of numbers, limited numerical knowledge, or proportional reasoning (Barth & Paladino, 2011; Cohen & Blanc-Goldhammer, 2011; Cohen, Blanc-Goldhammer, & Quinlan, 2018; Cohen & Sarnecka, 2014; Dackermann, Huber, Bahnmueller, Nuerk, & Moeller, 2015; Ebersbach, 2016; Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008; Moeller, Pixner, Kaufmann & Nuerk, 2009; Opfer, Siegler & Young, 2011; Opfer, Thompson & Kiim, 2016; Rouder & Geary, 2014; Sella et al., 2015; Slusser, Santiago & Barth, 2013). Beyond the theoretical accounts, the performance in the NTP task has been repeatedly associated with mathematical skills (Booth & Siegler, 2006, 2008; Sasanguie, De Smedt, Defever, & Reynvoet, 2013; Schneider, Grabner & Paetsch, 2018 for a review).

Few studies have investigated NTP task performance in DS. Lanfranchi, Berteletti, Torrisi, Vianello & Zorzi (2015) compared the performance of adolescents with DS to TD controls matched on MA and CA in the NTP task with 1-10 and 0-100 intervals. In the 1-10 interval, the DS and MA group showed similar accuracy in placing numbers but poorer performance compared to the CA group. All the three groups showed a linear pattern of estimates in the 1-10 interval. In the 0-100 interval, the DS group showed higher accuracy than the MA group, but lower than the CA group. Accordingly, while the majority of children in the CA matched group showed a linear mapping, the majority of children in DS and MA matched groups showed a biased (log-like) mapping. Moreover, the linear mapping in the 1-10 interval was related to visuo-spatial skills in the DS group whereas in the MA group it was related to chronological age, which could be considered a proxy for experience. No significant relationship was found for the 0-100 interval. In a subsequent study by Simms, Karmiloff-Smith, Ranzato, & Van Herwegen (2020), a group of individuals with DS aged between 8 and 49 years was compared to a TD group and a group of individuals with Williams Syndrome matched for MA. The DS group did not differ from the other two groups in terms of accuracy and linearity in both the 0-10 and 0-100 interval. As similarly observed by Lanfranchi et al. (2015), in the DS group there was a significant correlation between the accuracy in placing numbers and visuo-spatial skills for both intervals. In addition, a significant correlation between 0-100 number line estimation and number familiarity (assessed using counting and number recognition tasks) was found. The results of these two studies suggest that children with DS perform in line with MA, relying on a linear mapping of numbers in the interval 1-10. Moreover, for the 1-10 interval the mapping ability seems to be related only to visuo-spatial skills and not to age or number familiarity. In the 1-100 interval, one study reported that individuals with DS outperformed controls matched on MA whereas another reported a similar performance in the two groups. The discrepancy between the results of the two studies might be due to the different age of the DS and MA samples. In the Simms et al. (2020) study the DS sample was older and had a higher MA with respect to the study of Lanfranchi et al. (2015). Consequently, since in both studies TD children were matched for MA, children in Simms et al. (2020) were 1 year older and were attending primary school as compared to the preschoolers in Lanfranchi et al. (2015). In this light, MA children in the study of Simms et al. had more experience with numbers and possibly for this reason their performance was more similar to that of individuals with DS.

The present study aimed at better understanding numerical estimation in individuals with DS and its relation with age, verbal and non-verbal abilities, and other numerical skills. We considered two numerical intervals, 1-10 and 1-20. The former has already been considered in previous studies (e.g., Lanfranchi et al., 2015; Simms et al., 2020), and for this reason we expected to replicate previous findings; that is, children with DS should display a performance comparable to MA controls. The novelty of this study stems from its focus on the 1-20 interval, which is an intermediate number range between the previously considered 1-10 and 0-100 intervals. Previous studies demonstrated that most children with DS show a linear mapping in the 1-10 interval and a logarithmic mapping in the 0-100 interval. Considering the 1-20 interval is therefore crucial to explore the transition between linear and logarithmic mappings. Moreover, we believe it is important to consider the 1-20 interval because this is the quantity range that most school-age children with DS are exposed to at school and during daily life. If the mapping of numbers on the 1-20 interval is primarily related to cognitive functioning, we should expect children with DS to show a performance similar to MA matched controls. Conversely, if experience with numbers modulates numerical estimation abilities, we should expect a higher performance in individuals with DS compared to controls. Indeed, individuals in the DS group in the present study were not just older than the MA group but had much greater exposure to numbers above 10 compared to preschool control children because they attended primary or secondary school. Exploring more in depth the ability to position numbers on a line is important to understand numerical cognition in DS and how best to tailor intervention related to math skills in this population.

Methods

Participants and procedure

Sixty-three children with DS (M_{months}=128.62, *SD*=30.73, range=70–207) from north-eastern Italy took part in the study, after obtaining informed consent from parents and verbal consent from participants. The study was approved by the Ethics Committee for Psychological Research of [blind for review] and it was conducted following the principles of the Declaration of Helsinki. We recruited participants with DS from local associations, which offer support to families of children with intellectual disabilities. The experimenters met each child individually and the tasks were administered in a comfortable and quiet room. A control group of sixty-three TD children (M_{months}=54.98, *SD*=6.34, range=43–68) took part in the study. These children were all attending the kindergarten where they were engaged twice a week in activities with numbers. The two groups were matched one to one on the basis of their raw scores at the Raven's Colored Progressive Matrices (RCPM), a measure of fluid intelligence. According to Kover and Atwood (2013), two groups are adequately matched when both the absolute value of Cohen's d and the variance ratio fall within the field's standards. A Cohen's d of 0.00 reflects well-matched group means; a Cohen's d of 1.00 reflects poorly matched groups. A variance ratio of 1 indicates no difference in variances; a ratio of 2 reflects an unacceptable magnitude of difference in the spread of the distributions. In our case, a Cohen's d of 0.04 and a variance ratio of 1.05 indicated a good matching between the groups. Moreover, a measure of verbal skills that is highly correlated with verbal intelligence, such as the Peabody Picture Vocabulary Test (PPVT-R), was taken. The characteristics of the two groups are reported in Table 1. The DS and TD groups displayed a similar MA in months, as measured by the RCPM, whereas the DS group had lower scores in receptive vocabulary (PPVT-R) and was older compared to the TD group. This pattern of results is coherent with the jagged profile often shown by individuals with DS, with lower verbal abilities than non-verbal ones.

Tasks

Number-To-Position Task (NTP; Berteletti et al., 2010; Siegler & Opfer, 2003). Children were presented with a 20-cm line on a white landscape sheet. The left end of the line was labeled with the number 1 and the right end side was labeled either with 10 or 20. The target number to be positioned was shown on the left upper corner of the sheet. For each interval, there were eight randomly presented target numbers (i.e., 2, 3, 4, 5, 6, 7, 8, 9 for the

1–10 interval; 2, 4, 6, 7, 13, 15, 16, 18 for the 1–20 interval). Every trial, a new number line was presented with a different target number to be placed. The experimenter said: "*Now we are going to play a game with number lines. You can see that this line goes from 1 to 10 (or 20). I will tell you a number and you have to indicate which is the place of this number on the line, as precisely as you can*." The instructions were repeated as many times as needed but no feedback was given. As training trials, children had to place 1 and 10 in the 1-10 line, whereas in the 1-20 line the training trials were 1 and 20. The experimenter named the target numbers every trial. Children drew a vertical mark on the line where they thought the target number should be placed. Some children had difficulties in holding the pencil, so they were asked to point with their finger to the position of the target number on the line and the experimenter made the mark. An index of accuracy on this task was obtained by computing the individual percentage of absolute error ([[|Estimate-Target Number|]/Numerical Interval]*100).

Numerical Intelligence Battery (BIN: Batteria Intelligenza Numerica; Molin et al., 2007). The BIN test assesses several numerical skills, which are the precursors of later mathematical and arithmetical learning. It is composed of four subscales: lexical, semantic, counting, and pre-syntactic.

The lexical subscale assesses the ability to read and write Arabic numbers as well as the ability to connect number-words to the corresponding digits. The subscale is composed of three tasks. In the *Number-Name Correspondence* task, the child is shown a cardboard with three digits and has to indicate the one corresponding to the number-word pronounced by the experimenter, for a total of nine trials. In the *Number Naming* task, the child is shown digits from 1 to 9, one by one, and has to read them. In the *Number Writing* task, the child has to write the numbers (i.e., 3, 1, 4, 2, 5) read aloud by the experimenter.

The semantic subscale measures the ability to compare numerical quantities (i.e., dots and Arabic digits). There are two tasks in this subscale. In the *Dots Comparison* task, the child is shown a cardboard with two sets of dots and has to point to the larger one. There are ten comparisons presented in the following order: 4vs2, 1vs2, 5vs8, 8vs3, 7vs6, 2vs5, 4vs9, 8vs5, 9vs6, 9vs8. In the *Digits Comparison* task, the child has to point to the larger of two Arabic digits presented on a cardboard. There are eleven comparisons presented in the following order: 2vs4, 7vs2, 8vs3, 1vs2, 7vs8, 4vs5, 6vs3, 6vs7, 5vs1, 3vs9, 4vs1.

The counting subscale assesses the ability to recite the number–words sequence forward and backward as well as the knowledge of the order of Arabic digits from 1 to 5. There are four tasks in this subscale. In the *Forward Counting* task, the child has to tell the numbers from 1 to 20. In the *Backward Counting* task, the child has to tell the numbers backwards, from 10 to 1. In the *Digit Seriation* task, the child has to put cardboards with the numbers from 1 to 5 in increasing order. In the *Sequence Completion* task, the child is presented with a visual sequence of digits from 1 to 4, where one or two digit/s is/are missing. The child has to tell the missing digit/s in the sequence. There are five trials in total.

The pre-syntactical scale evaluates the ability to link numbers to sets of dots and to order objects based on their size. The subscale is composed of three tasks. In the *Digit-Dots Correspondence* task, the child has to match a digit by choosing the corresponding number of dots among three sets presented on a cardboard, for a total of 9 trials. In the *One-Many* task, the child is asked to complete six sentences that express a one-to-many relation. For example, "A class is made of many…" and the child should answer "Students" or "Children". In the *Magnitude Ordering* task, the child had first to put five paper baskets in decreasing order of size. Then, four paper balls were ordered from the largest to the smallest in front of the child, who had to place a mid-size ball in the correct place within the sequence. This trial was then repeated with a different mid-size ball to be placed.

For each subscale the number of correct answers was calculated. The total number of correct answers in the battery was used as an index of basic numerical abilities.

Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 1997; Stella, Pizzoli, & Tressoldi, 2000). Children saw a group of four pictures and were required to point to the one best representing what the experimenter named aloud. Items are arranged in order of increasing difficulty. The test indicates different starting points according to the participant's age and the administration has to be interrupted when the children make six mistakes in eight consecutive trials. The age-equivalent score was used as a measure of verbal skills., computed according to the Italian norms (Stella, Pizzioli and Tressoldi, 2000).

Raven's Colored Progressive Matrices (RCPM; Raven, 1998). The RCPM contains three sets of 12 items each, arranged in increasing levels of difficulty. Each item consists of a coloured pattern with a missing portion; below the matrix, six similarly shaped pieces are presented and children have to choose which of them fills the pattern. We used the age-equivalent score as a measure of nonverbal reasoning ability, computed according to the Italian norms (Belacchi, Scalisi, Cannoni and Cornoldi, 2008).

Data analysis

The type of mapping (none, log-like or linear) was first determined for each child. On an exploratory level, the resulting subgroups (separately for DS and TD) were compared for chronological age, age-equivalent scores for RCPM and PPVT-R and the BIN total scores in a series of one-way ANOVAs with type of mapping as factor, and significant effects were further explored with post-hoc t-tests. When the assumption of Sphericity was violated, the Greenhouse–Geisser adjustment was applied to *p*-values (reported as *p*[gg]). Post-hoc t-tests were two-tailed and the *p*-values were corrected for multiple comparisons using the Bonferroni method (i.e., alpha value divided by the number of comparisons). Then, to assess if the accuracy in positioning numbers was in line with mental age in the group with DS, the percentage of absolute error (PAE) was analyzed in a mixed ANOVA with interval [1-10, 1-20] as within-subjects factor and group [DS, TD] as between-subjects factor. Subsequently, correlation analyses were conducted to explore the relationship between numerical cognition, verbal and visuo-spatial intelligence, age, months of school attended and PAE, separately for 1-10 and 1-20 number lines and for both DS and TD groups. Finally, regression analyses with the PAE 1-10 and PAE 1-20 as dependent variables, respectively, and all the subtests of the BIN, chronological age, months of school, the scores of RCPM and PPVT-R as independent variables were carried out separately for the two groups. For each regression model, we calculated the Bayesian Information Criterion (BIC) for all the possible subsets of independent variables. We identified the models with the lower BICs, but that were virtually identical in their precision in fitting the data (i.e., difference in BIC<2; Raftery, 1995). Among these models, we selected the model with fewer independent variables as the best model. Data analysis was run in R, version 4.0.0 (R Core Team, 2016).

Results

Number-to-position task

We identified those children with a compressed (log-like) mapping and those with a linear (accurate) mapping. We fit the linear and logarithmic model on the estimates as a function of target numbers for each participant separately for the two numerical intervals. We classified children as having a non-numerical ("None") mapping when neither model was significant or when the slope of the linear mapping was negative (i.e., children place larger numbers on the left side of the line and small numbers on the right side). When at least one of the models was significant, we classified children as having a linear or logarithmic mapping depending on the highest R^2 (Table 2). Several participants in both groups displayed a non-numerical mapping in the number line task, even in the 1-10 interval. These children most likely had limited numerical knowledge, which prevented them from understanding the aim of the task even with a small numerical interval (Sella, Lucangeli & Zorzi, 2019). Both groups displayed a larger number of children classified as linear than logarithmic in the 1-10 interval, whereas the pattern was reversed in the 1-20 interval. In order to better understand the characteristics of the three groups of children (non-mappers, logarithmic and linear), descriptive statistics for chronological age, age-equivalent scores for RCPM and PPVT-R and the BIN total score were calculated separately for the DS and TD group and compared within each group. Results are reported in table 3. Considering individuals with DS, although the non-mappers group showed lower scores in all the variables considered in comparison to the other two groups (logarithmic and linear mappers), no significant differences emerged for both the 1-10 and 1-20 intervals. This is probably due to the high interindividual variability. In contrast, the TD participants showed reliable differences between groups. In particular, in the 1-10 interval, the non-mappers were younger than those with a linear representation (t=3.44, p=.003, d=0.96) and they had lower age-equivalent scores for RCPM than the group of children with a logarithmic representation (t=3.33, p=.005, d=1.21). Finally, they also had lower BIN total score than the participants with a logarithmic (t=5.02, p<.001, d=1.83) and linear representation (t=4.81, p<.001, d=1.34). In the 1-20 interval, the non-mappers were younger than the children with a logarithmic (t=2.66, p=.03, d=0.75) and a linear representation (t=2.91, p=.02, d=1.00) and their age-equivalent scores for RCPM were lower than the group with a linear representation (t=2.48, p=.05, d=0.85). Finally, they also had lower BIN total scores than children with a logarithmic (t=5.03, p<.001, d=1.43) and a linear representation (t=4.55, p<.001, d=1.57).

We then analyzed the precision in placing numbers on the line using the percentage of absolute error (PAE). We restricted our analysis on the PAE to only those children who displayed at least a significant linear or logarithmic positioning in the interval 1-10 (DS=34; TD=39) as we are sure that these children clearly understood the goal of the task. The two subgroups remained matched in terms of MA, as measured by the RCPM (DS: M=66.03, *SD*=19, range: 39-111; TD: *M*=66.85, *SD*=19.81, range: 30-111; t_{welch}(70.33)=0.18, *p*=.85). Results of the PAE analysis are displayed in Figure 1. In the mixed ANOVA, the main effect of interval reached statistical significance (F(1, 71)=6.37, *p*=.01, η^2_p=0.08). Overall, the absolute error was lower in the 1-10 compared to the 1-20 interval. However the main effect of group (F(1, 71)=0.09, *p*=.77, η^2_p=.001) and the interaction between group and interval were not significant (F(1, 71)=1.39, *p*=.24, η^2_p=0.02).

The relation between number line task and numerical knowledge

We explored the relationship between numerical cognition, verbal and visuo-spatial intelligence, age, months of school attended and PAE, separately for 1-10 and 1-20 number lines. Descriptive statistics for months of schooling and numerical tasks are reported in Table 4. The correlations with confidence intervals are reported in Table 5, separately for the DS and TD groups.

For the number line 1-10, a significant moderate correlation emerged between PAE and *Number-Name Correspondence* in the group with DS, while no correlation emerged in the TD group. For the number line 1-20 a significant moderate correlation was found between PAE and *Digit Comparison*, *Forward Counting* and *Backward Counting* in the group with DS, while a significant moderate correlation was found between PAE and *Number-Name Correspondence* in the TD group. Finally, a moderate significant correlation emerged between PAE in the 1-10 and in the 1-20 number lines in the group with DS but not in the TD one.

Moreover, we ran two regressions with the PAE 1-10 and PAE 1-20 as dependent variables, respectively, and all the subtests of the BIN, chronological age, months of school, the scores of RCPM and PPVT-R as independent variables. Considering DS, the model only including the *Number-Name correspondence* task subtest emerged as the best model (b=-1.8, SE=0.77, *p*=.026, R^2=0.15) in the case of the 1-10 interval. In the number correspondence task, children indicate among three Arabic digits that one that corresponds to the number word said by the experimenter. Conversely, the model only including the *Digit Comparison* task emerged as the best model (b=-2.19, SE=0.81, *p*=.011, R^2=0.19) in the case of the 1-20 interval. In the symbolic number comparison task, children indicate the larger between two Arabic digits. Considering the TD group, the best model was the one only containing the intercept in the case of the 1-10 interval, meaning that none of the BIN tasks was associated with the performance on this interval. Conversely, the model only including the *Number-Name Correspondence* task emerged as the best model (b=-1.79, SE=0.79, *p*=.029, R^2=0.10) in the case of the 1-20 interval.

Discussion

The aim of the present work was to extend previous results on numerical estimation in children with DS using the NTP task. The performance of a large group of children with DS was compared to that of TD children matched for MA. In particular, two numerical intervals were considered: 1-10 and 1-20. The latter interval had never been used before with this population, although this is the numerical range that children are systematically exposed to during school and daily living activities. Our interest was to better characterize the boundaries of the linear mapping in individuals with DS and to assess whether the ability to place numbers on a number line is more driven by MA or by experience with numbers.

First of all, approximately one third of children in both groups showed a non-numerical mapping, which means that they showed neither a compressive (log-like) mapping (with small numbers given more space on the line than larger numbers) nor a linear pattern (with numbers evenly spread across the line). In the TD group these children were younger, with lower non-verbal age equivalent scores (RCPM) and with lower basic numerical abilities with respect to children with a logarithmic or linear positioning of numbers. This is coherent with previous studies showing that TD children between the age of 4 and 6 shift progressively from a non-numerical mapping to a biased log-like and then to a linear one, even for small numerosities (Berteletti et al., 2010; Sella et al., 2017). The results are less straightforward for children with DS. Indeed, although non-mappers showed lower mean chronological and mental age (verbal for the 1-10 line and non-verbal for the 1-20 line) compared to mappers, the difference was only approaching the conventional significance level, and this is probably due to the high interindividual variability. It is possible that other variables, such as home numeracy or school environment might play a role in this variability, and it would be interesting to explore this aspect more in depth in future studies. In any case, we cannot exclude that at least some of those kids did not properly understand the task, although they carried out practice trials as part of the instructions. Finally, it is possible that the well-known problems in sustained attention and executive functions in children with Down syndrome (Lanfranchi et al., 2012) might have had an impact on the performance of those kids.

After excluding children with non-numerical mapping of numbers, DS and TD groups had a similar pattern: a larger number of children was classified as having linear rather than logarithmic mapping in the 1-10 interval, whereas the pattern was reversed in the 1-20 interval. Moreover, both groups showed more errors in the 1-20 interval with respect to the 1-10 interval. These data extend to DS what has already been demonstrated for TD children, that is the development of a linear pattern of numerical estimation for the 1-10 interval preceding the development of a linear pattern for the 1-20 interval (e.g., Berteletti et al., 2010; Sella et al., 2017). Notably, the accuracy in placing numbers was similar in children with DS and in TD children matched for MA, both in 1-10 and 1-20 intervals. These results are in line with previous studies (e.g., Sella et al., 2013; Simms et al., 2020) focusing on the 1-10 interval and extending them to the 1-20 interval. Moreover, considering that the two groups were matched for non-verbal age equivalent scores, these results support the idea that numerical estimation performance in DS is aligned with cognitive development.

Subsequent analyses on the performance of the DS group showed that the ability to position numbers on the 1-10 intervals was related to the ability to recognize written Arabic numbers (Purpura, Baroody & Lonigan, 2013). In contrast, the ability to position numbers on the 1-20 interval showed a moderate correlation with counting (forward and backward) and with the ability of comparing the magnitude of arabic numbers, but only the last one remained significant when considered together in a regression model. No significant relationship was found with CA, months of schooling, verbal and visuo-spatial MA. Parallel analyses on the performance of the TD group showed no predictors for the ability to position numbers on the 1-10 interval, whereas the ability to position numbers on the 1-20 intervals was predicted by the ability to recognize written Arabic numbers. These results are in line with several studies that have shown the relationship between basic number skills and numerical estimation in TD children (Siegler et al., 2009; Laski & Siegler, 2007) and in atypical populations (e.g. Simms et al., 2020). Taken together, our results suggest that if on one hand the development of a linear mapping of numbers and the accuracy of positioning them is driven by MA (as previously demonstrated by Lanfranchi et al., 2015 and Simms et al., 2018), on the other hand these skills are shaped by the knowledge of (and so the experience with) symbolic numbers. These results are very important from an applied point of view: they suggest that extensive experience with quantities and numbers is fundamental for developing numerical estimation abilities even beyond MA. This is even more important because the ability to place numbers on a number line is one of the strongest predictors (among basic number skills) of formal math abilities both in TD (e.g. Schneider et al., 2018, for a review) and in DS (Simms et al., 2018). For this reason, it is very important to work with these children with specific educational tools to foster basic number knowledge, to create a strong basis for subsequent math skills development.

Two previous training studies (Lanfranchi et al., 2021; Sella et al., 2021) showed that “The number race” (Wilson, Dehaene, Pinel, Revkin, Cohen, & Cohen, 2006), an adaptive computerized game developed to foster basic number skills, enhance number sense, cement the links between representation of numbers and automatize number facts, was effective with children with DS not only in improving basic number sense, but also had a transfer effect on the ability to place numbers on a 1-20 number line, which was not directly trained. This finding provides further evidence of a relationship between basic number skills and numerical estimation abilities in DS, thereby supporting the feasibility of numeracy training programs to foster basic number skills in individuals with DS. We are only at the beginning of the discovery of number skills in individuals with DS, a domain that only recently received the attention it deserves, and further studies are needed in order to better understand these processes.

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Declaration of Competing Interest

The authors report no declarations of interest.

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References

Abreu-Mendoza, R. A., & Arias-Trejo, N. (2015). Numerical and area comparison abilities in Down syndrome. *Research in Developmental Disabilities*, *41*, 58-65.

Barth, H. C., & Paladino, A. M. (2011). The development of numerical estimation: evidence against a representational shift. *Developmental Science, 14*(1), 125-135.

Bashash, L., Outhred, L., & Bochner, S. (2003). Counting skills and number concepts of students with moderate intellectual disabilities. *International Journal of Disability, Development and Education*, *50*(3), 325–345.

Belacchi, C., Scalisi, T. G., Cannoni, E., & Cornoldi, C. (2008). *CPM - coloured progressive matrices. standardizzazione italiana.* Firenze: Giunti O.S.

Berteletti, I., Lucangeli, D., Piazza, M., Dehaene, S., & Zorzi, M. (2010). Numerical estimation in preschoolers. *Developmental Psychology*, *46*, 545–551.

Berteletti, I., Lucangeli, D., & Zorzi, M. (2012). Representation of numerical and non-numerical order in children. *Cognition*, *124*(3), 304–313.

Booth, J. L., & Siegler, R. S. (2006). Developmental and individual differences in pure numerical estimation. *Developmental Psychology*, *42*(1), 189–201.

Booth, J. L., & Siegler, R. S. (2008). Numerical magnitude representations influence arithmetic learning. *Child Development*, *79*(4), 1016–1031.

Brigstocke, S., Hulme, C., & Nye, J. (2008). Number and arithmetic skills in children with Down syndrome. *Down Syndrome: Research and Practice.*

Camos, V. (2009). Numerosity discrimination in children with Down syndrome. *Developmental Neuropsychology*, *34*(4), 435-447.

Cohen, D.J., & Blanc-Goldhammer, D. (2011). Numerical bias in bounded and unbounded number line tasks. *Psychonomic Bulletin and Review, 18*, 331–338.

Cohen, D. J., Blanc-Goldhammer, D., & Quinlan, P. T. (2018). A mathematical model of how people solve most variants of the number-line task. *Cognitive Science, 42*, 2621–2647.

Cohen, D. J., & Sarnecka, B. W. (2014). Children's number-line estimation shows development of measurement skills (not number representations). *Developmental Psychology, 50*(6), 1640–1652.

Contestabile, A.; Benfenati, F.; & Gasparini, L. (2010). Communication breaks-Down: from neurodevelopmental defects to cognitive disabilities in Down syndrome. *Progress in Neurobiology*, *91*, 1–22.

Dackermann, T., Huber, S., Bahnmueller, J., Nuerk, H. C., & Moeller, K. (2015). An integration of competing accounts on children's number line estimation. *Frontiers in Psychology, 6*, 884.

Dykens, E.; Hodapp, R.; & Finucane B. (2000). *Genetics and mental retardation syndromes: A new look at behavior and interventions*. Paul H Brookes Publishing.

Dunn, L. M. & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test–III.* Circle Pines, American Guidance Service.

Ebersbach, M. (2016). Development of children's estimation skills: The ambiguous role of their familiarity with numerals. *Child Development Perspectives, 10*(2), 116-121.

Ebersbach, M., Luwel, L., Frick, A., Onghena, P., & Verschaffel, L. (2008). The relationship between the shape of the mental number line and familiarity with numbers in 5- to 9-year old children: Evidence for a segmented linear model. *Journal of Experimental Child Psychology, 99*(1), 1-17.

Karmiloff-Smith, A., Al-Janabi, T., D'Souza, H., Groet, J., Massand, E., Mok, K., …Strydom, A. (2016). The importance of understanding individual differences in Down syndrome. *F1000 Research*, 5.

Lanfranchi, S., Baddeley, A., Gathercole, S., & Vianello, R. (2012). Working memory in Down syndrome: is there a dual task deficit?. *Journal of Intellectual Disability Research*, *56*(2), 157-166.

Lanfranchi, S., Berteletti, I., Torrisi, E., Vianello, R., & Zorzi, M. (2015). Numerical estimation in individuals with down syndrome. *Research in Developmental Disabilities*, *36*, 222-229.

Lanfranchi, S., Onnivello, S., Lunardon, M., Sella, F., & Zorzi, M. (2021). Parent-based training of basic number skills in children with Down syndrome using an adaptive computer game. *Research in Developmental Disabilities*, *112*, 103919.

Laski, E. V., & Siegler, R. S. (2007). Is 27 a big number? Correlational and causal connections among numerical categorization, number line estimation, and numerical magnitude comparison. *Child Development, 78*(6), 1723–1743.

Lefevre, J. A., Jimenez Lira, C., Sowinski, C., Cankaya, O., Kamawar, D., & Skwarchuk, S. L. (2013). Charting the role of the number line in mathematical development. *Frontiers in Psychology*, *4*, 641.

Moeller, K., Pixner, S., Kaufmann, L., & Nuerk, H. C. (2009). Children's early mental number line: Logarithmic or decomposed linear? *Journal of Experimental Child Psychology, 103*(4), 503-515.

Molin, A., Poli, S., & Lucangeli, D. (2007). *BIN 4-6: Batteria per la valutazione dell'intelligenza numerica in bambini dai 4 ai 6 anni*. Erickson.

Muldoon, K., Towse, J., Simms, V., Perra, O., & Menzies, V. (2013). A longitudinal analysis of estimation accuracy, counting skills and mathematical ability across the first school year. *Developmental Psychology*, *49*, 250–257.

Nye, J., Fluck, M., & Buckley, S. (2001). Counting and cardinal understanding in children with Down syndrome and typically developing children. *Down Syndrome: Research and Practice, 7*(2), 68–78.

Onnivello, S., Lanfranchi, S., & Zorzi, M. (2019). Mathematical abilities in down syndrome. In S. Lanfranchi (Ed.), *International review of research in developmental disabilities: State of the art of research on down syndrome* (pp. 257-291, Chapter xiv, 291 Pages) Elsevier Academic Press.

Opfer, J. E., Thompson, C. A., & Kim, D. (2016). Free versus anchored numerical estimation: A unified approach. *Cognition, 149*, 11-17.

Opfer, J. E., Siegler, R. S., & Young, C. J. (2011). The powers of noise-fitting: Reply to barth and paladino. *Developmental Science, 14*(5), 1194-1204.

Paterson, S. J., Girelli, L., Butterworth, B., & Karmiloff-Smith, A. (2006). Are numerical impairments syndrome specific? Evidence from Williams syndrome and Down's syndrome. *Journal of Child Psychology and Psychiatry*, *47*(2), 190-204.

Porter, J. (1999). Learning to count: A difficult task? *Down Syndrome: Research and Practice*, *6*(2), 85–94.

Praet, M., & Desoete, A. (2014). Number line estimation from kindergarten to grade 2: A longitudinal study. *Learning and Instruction, 33*, 19-28.

Purpura, D. J., Baroody, A. J., & Lonigan, C. J. (2013). The transition from informal to formal mathematical knowledge: Mediation by numeral knowledge. *Journal of Educational Psychology*, *105*(2), 453–464.

R Core Team. (2016). *R: A Language and Environment for Statistical Computing*. Vienna, Austria. Retrieved from https://www.R-project.org/

Raftery, A. E. (1995). Bayesian model selection in social research. *Sociological Methodology,* 111–163.

Raven, J., Raven, J.C. & Court, J.H. (1998). *Raven manual, Section 1 (General overview), Section 2 (Coloured Progressive Matrices) and Section 6 (The Crichton Vocabulary Scale).* Oxford Psychologists Press.

Rosser, T. C., Edgin, J. O., Capone, G. T., Hamilton, D. R., Allen, E. G., Dooley, K. J., . . . Sherman, S. L. (2018). Associations between medical history, cognition, and behavior in youth with down syndrome: A report from the down syndrome cognition project. *American Journal on Intellectual and Developmental Disabilities, 123*(6), 514-528.

Rouder, J. N., & Geary, D. C. (2014). Children's cognitive representation of the mathematical number line. *Developmental Science, 17*(4), 525-536.

Sasanguie, D., De Smedt, B., Defever, E., & Reynvoet, B. (2012). Association between basic numerical abilities and mathematics achievement. *British Journal of Developmental Psychology, 30*(2), 344-357.

Sasanguie, D., Göbel, S. M., Moll, K., Smets, K., & Reynvoet, B. (2013). Approximate number sense, symbolic number processing, or number-space mappings: What underlies mathematics achievement? *Journal of Experimental Child Psychology*, *114*(3), 418–431.

Schneider, M., Grabner, R. & Paetsch, J., (2009). Mental Number Line, Number Line Estimation, and Mathematical Achievement: Their Interrelations in Grades 5 and 6. *Journal of Educational Psychology*, *101*, 359-372.

Sella, F., Berteletti, I., Lucangeli, D., & Zorzi, M. (2015). Varieties of quantities estimation in children. *Developmental Psychology*, *51* (6), 758-770.

Sella, F., Berteletti, I., Lucangeli, D., & Zorzi, M. (2017). Preschool children use space, rather than counting, to infer the numerical magnitude of digits: Evidence for a spatial mapping principle. *Cognition, 158*, 56-67.

Sella, F., Lanfranchi, S., & Zorzi, M. (2013). Enumeration skills in Down syndrome. *Research in Developmental Disabilities*, *34*, 3798–3806.

Sella, F., Lucangeli, D., & Zorzi, M. (2018). Spatial and verbal routes to number comparison in young children. *Frontiers in psychology*, *9*, 776.

Sella, F., Lucangeli, D., & Zorzi, M. (2019). Spatial order relates to the exact numerical magnitude of digits in young children. *Journal of experimental child psychology*, *178*, 385-404.

Sella, F., Onnivello, S., Lunardon, M., Lanfranchi, S., & Zorzi, M. (2021). Training basic numerical skills in children with Down syndrome using the computerized game "The Number Race". *Scientific reports*, *11*(1), 1-14.

Siegler, R.S. (2016). Magnitude knowledge: The common core of numerical development. *Developmental Science*, *19*, 341–361.

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development*, *75*(2), 428–444.

Siegler, R. S., & Booth, J. L. (2015). Development of numerical estimation: A review. In Jamie I. D. Campbell (Ed.), *Handbook of mathematical cognition*. Psychology Press.

Siegler, R. S., & Opfer, J. E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science*, *14*(3), 237e243.

Siegler, R. S., & Ramani, G. B. (2009). Playing linear number board games—But not circular ones—Improves low-income preschool- ers' numerical understanding. *Journal of Educational Psychology*, *101*, 545–560.

Siegler, R. S., Thompson, C. A., & Opfer, J. E. (2009). The logarithmic-to-linear shift: One learning sequence, many tasks, many time scales. *Mind, Brain, and Education*, *3*, 143-150.

Silverman, W. (2007). Down syndrome: Cognitive phenotype. *Mental Retardation and Developmental Disabilities Research Reviews*, *13* (3), 228-236.

Simms, V. (2018). Editorial. *British Journal of Developmental Psychology, 36*(2), 151-152.

Simms, V., Karmiloff-Smith, A., Ranzato, E., & Van Herwegen, J. (2020). Understanding number line estimation in Williams syndrome and Down syndrome. *Journal of Autism and Developmental Disorders, 50*(2), 583-591.

Slusser, E., Santiago, R., & Barth, H. (2013). Developmental change in numerical estimation. *Journal of Experimental Psychology: General*, *142*(1), 193-208.

Stella, G., Pizzoli, C., & Tressoldi, P. E. (2000). *PPVT-R, peabody picture vocabulary test–revised.* Omega Edizioni.

Wilson, A. J., Dehaene, S., Pinel, P., Revkin, S. K., Cohen, L., & Cohen, D. (2006). Principles underlying the design of 'The Number Race', an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions, 2*(1), 1-16.

Yang, Y., Conners, F.A., & Merrill E.C. (2014). Visuo-spatial ability in individuals with Down syndrome: Is it really a strength? *Research in Developmental Disabilities*, *35*(7), 1473-1500.

Fig. 1 Percentage of absolute error (PAE; y-axis) as a function of numerical interval (x-axis) separately for the DS (circles) and TD (triangles) considering only children with a significant linear or logarithmic fit in the 1-10 interval. Error bars represent 95% CIs, whereas transparent dots represent individual values

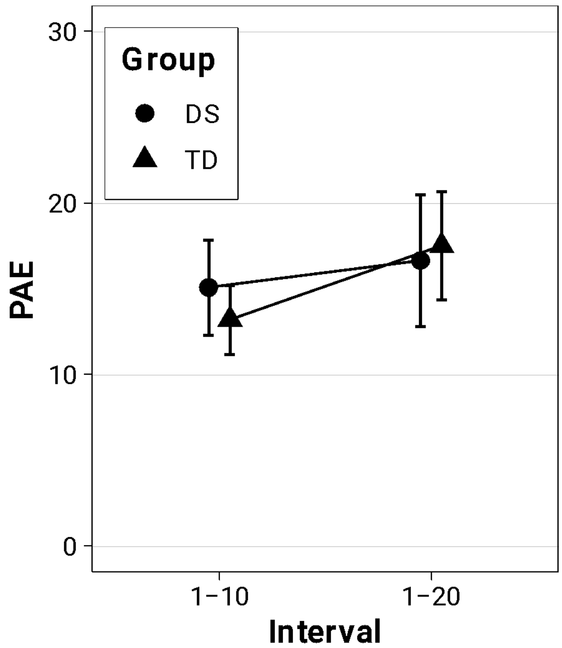

Table 1. Descriptive statistics and statistical testing for chronological and mental age (expressed in months).

	DS	TD	t-test
Chronological age	128.62 (30.73) [70-207]	54.98 (6.34) [43-68]	$t_{welch}(67.26)=18.63$, $p<.001$
RCPM	61.79 (18.18) [30-111]	62.48 (17.7) [30-111]	$t_{welch}(123.91)=0.21$, $p=.83$
PPVT-R	53.22 (24.2) [27-181]	61.19 (19.24) [29-116]	$t_{welch}(117.99)=2.04$, $p=.04$

Table 2. Classification of children's mapping in the two numerical intervals (i.e., 1-10, 1-20) in children with DS and TD.

		Classification		
Group	Interval	None	Logarithmic	Linear
DS	1-10	29	8	26
	1-20	29	20	14
TD	1-10	24	11	28
	1-20	24	26	13

Table 3. Descriptive statistics M(SD) [min-max] for the three groups of mappers.

	DS							
	1-10				1-20			
	None n=29	Logarithmic n=8	Linear n=26		None n=29	Logarithmic n=20	Linear n=14	
BIN total score	66.35 (20.96) [31-102]	59.50 (30.91) [24-105]	76.77 (25.91) [20-105]	$F(2,60)=2.06$ $p=0.14$ $\eta^2_p=0.06$	64.48 (21.62) [31-105]	69.90 (27.89) [24-105]	80.57 (24.68) [20-105]	$F(2,60)=2.05$ $p=0.14$ $\eta^2_p=0.06$
CA	120.17 (27.77) [70-174]	130.88 (37.65) [74-191]	137.35 (30.30) [87-207]	$F(2,60)=2.25$ $p=0.07$ $\eta^2_p=0.09$	118.59 (27.90) [70-174]	137.75 (32.07) [87-191]	135.36 (30.11) [87-207]	$F(2,60)=3.06$ $p=0.05$ $\eta^2_p=0.09$
RCPM	56.83 (16.08) [30-92]	59.50 (13.90) [39-81]	68.04 (20.12) [39-111]	$F(2,60)=2.84$ $p=0.11$ $\eta^2_p=0.07$	56.03 (15.12) [30-92]	67.00 (20.22) [43-111]	66.29 (18.65) [36-99]	$F(2,60)=2.87$ $p=0.07$ $\eta^2_p=0.09$
PPVT-R	45.90 (14.01) [27-86]	63.75 (50.42) [27-181]	58.15 (19.95) [27-103]	$F(2,60)=2.77$ $p=0.07$ $\eta^2_p=0.09$	51.45 (28.52) [27-181]	51.15 (19.16) [27-87]	59.86 (21.07) [37-103]	$F(2,60)=0.67$ $p=0.52$ $\eta^2_p=0.02$
	TD							
	1-10				1-20			
	None n=24	Logarithmic n=11	Linear n=28		None n=24	Logarithmic n=26	Linear n=13	
BIN total score	50.98 (15.83) [26-84]	85.95 (14.57) [56-103]	76.57 (22.86) [26-106]	$F(2,60)=17.11$ $p<.001$ $\eta^2_p=0.36$	50.83 (15.66) [26-84]	78.39 (20.38) [36-103]	81.15 (23.11) [26-106]	$F(2,60)=16.20$ $p<.001$ $\eta^2_p=0.35$
CA	51.71 (6.09) [43-63]	56.18 (4.52) [51-67]	57.32 (6.10) [48-68]	$F(2,60)=6.20$ $p=0.04$ $\eta^2_p=0.17$	51.92 (5.78) [43-63]	56.39 (5.95) [45-67]	57.85 (6.14) [48-68]	$F(2,60)=5.46$ $p=0.007$ $\eta^2_p=0.15$
RCPM	55.38 (10.53) [36-78]	75.36 (19.45) [45-111]	63.50 (19.27) [30-109]	$F(2,60)=5.63$ $p=0.006$ $\eta^2_p=0.15$	57.08 (10.75) [36-78]	62.85 (16.83) [30-99]	71.69 (25.62) [36-111]	$F(2,60)=3.08$ $p=0.05$ $\eta^2_p=0.09$
PPVT-R	54.88 (16.32) [29-89]	63.91 (12.09) [50-86]	65.54 (22.60) [35-116]	$F(2,60)=2.20$ $p=0.12$ $\eta^2_p=0.07$	56.58 (15.71) [29-89]	66.35 (21.81) [30-116]	59.39 (15.71) [29-89]	$F(2,60)=1.72$ $p=0.18$ $\eta^2_p=0.05$

Table 4. Means, standard deviations for months of schooling and numerical tasks for the DS (n=34) and the TD group (n=39).

	DS M(SD) [min-max]	TD M(SD) [min-max]
Months of school	99.82 (31.68) [38-171]	21.00 (5.67) [12-32]
BIN		
Number-Name Correspondence	8.24 (1.69) [2-9]	7.72 (1.89) [2-9]
Number Naming	7.88 (1.93) [2-9]	6.95 (3.03) [0-9]
Number Writing	3.44 (2.26) [0-5]	1.85 (1.99) [0-5]
Dots Comparison	7.53 (2.18) [2-10]	9.33 (1.22) [4-10]
Digit Comparison	8.44 (2.16) [4-11]	8.87 (2.46) [1-11]
Counting Forward	13.79 (7.24) [0-20]	16.82 (4.58) [7-20]
Counting Backward	4.53 (4.95) [0-10]	4.67 (4.40) [0-10]
Digit Seriation	3.03 (2.249) [0-5]	4.08 (1.69) [0-5]
Sequence Completion	3.41 (1.83) [0-5]	3.65 (1.85) [0-5]
Digit-Dots Correspondence	5.91 (2.45) [2-9]	6.85 (2.46) [1-9]
One-Many	2.47 (2.19) [0-6]	3.82 (1.34) [0-6]
Magnitude Ordering	4.03 (2.99) [0-7]	4.42 (2.68) [0-7]
NTP		

1-10	15.07 (7.97) [3.53-40.62]	13.19 (6.22)
1-20	16.65 (10.98) [2.44-49.1]	17.52 (9.70)

Table 5 Correlations with confidence intervals for the group with DS (n=34) and the TD group (n=39). Correlations for the group with DS are reported below the median line (white part); correlations for the TD group are reported above the median line (gray part).Values in square brackets indicate the 95% confidence interval for each correlation.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. CA	-	.56**	.55**	1.00**	.45**	.53**	.60**	.25	.58**	.48**	.61**	.41**	.58**	.53**	.25	.29	-.17	-.27
		[.30, .74]	[.29, .74]	[1.00, 1.00]	[.16, .67]	[.26, .73]	[.36, .77]	[-.07, .53]	[.32, .76]	[.19, .69]	[.36, .78]	[.11, .65]	[.32, .76]	[.26, .72]	[-.07, .52]	[-.03, .56]	[-.46, .16]	[-.54, .05]
2. PPVT-R MA	.29	-	.41**	.56**	.18	.10	.42**	.34*	.37*	.15	.44**	.23	.40*	.11	.56**	.41**	-.20	-.04
	[-.05, .57]		[.11, .65]	[.30, .74]	[-.14, .47]	[-.22, .40]	[.12, .65]	[.02, .59]	[.06, .61]	[-.18, .44]	[.15, .66]	[-.10, .51]	[.09, .63]	[-.21, .41]	[.29, .74]	[.11, .64]	[-.48, .13]	[-.35, .28]
3. CPM MA	.21	.28	-	.55**	.29	.32*	.48**	.27	.47**	.52**	.49**	.25	.37*	.44**	.10	.38*	-.11	-.18
	[-.14, .51]	[-.06, .57]		[.29, .74]	[-.03, .55]	[.00, .58]	[.19, .69]	[-.05, .54]	[.19, .69]	[.25, .72]	[.20, .70]	[-.07, .52]	[.07, .62]	[.14, .66]	[-.22, .40]	[.07, .62]	[-.41, .21]	[-.47, .15]
4. Months of school attended	1.00**	.29	.21	-	.45**	.53**	.60**	.25	.58**	.48**	.61**	.41**	.58**	.53**	.25	.29	-.17	-.27
	[1.00, 1.00]	[-.05, .57]	[-.14, .51]		[.16, .67]	[.26, .73]	[.36, .77]	[-.07, .53]	[.32, .76]	[.19, .69]	[.36, .78]	[.11, .65]	[.32, .76]	[.26, .72]	[-.07, .52]	[-.03, .56]	[-.46, .16]	[-.54, .05]
5. BIN Number-Name correspondence	.48**	.36*	.25	.48**	-	.83**	.45**	.04	.47**	.70**	.48**	.45**	.60**	.53**	.03	.39*	-.06	-.35*

	[.17, .70]	[.03, .62]	[-.10, .54]	[.17, .70]		[.70, .91]	[.16, .67]	[-.28, .35]	[.18, .68]	[.49, .83]	[.20, .69]	[.16, .67]	[.35, .77]	[.26, .72]	[-.29, .34]	[.08, .63]	[-.37, .26]	[-.60, -.04]
6. BIN Number Naming	.49**	.40*	.23	.49**	.82**	-	.46**	.20	.64**	.68**	.55**	.67**	.68**	.68**	.06	.42**	-.02	-.25
	[.18, .71]	[.07, .65]	[-.12, .53]	[.18, .71]	[.67, .91]		[.16, .67]	[-.12, .49]	[.41, .80]	[.46, .82]	[.28, .74]	[.46, .82]	[.46, .82]	[.46, .82]	[-.26, .37]	[.12, .65]	[-.34, .29]	[-.52, .07]
7. BIN Number Writing	.51**	.49**	.19	.51**	.54**	.66**	-	.13	.36*	.49**	.53**	.47**	.41*	.30	.25	.29	-.15	-.31
	[.21, .72]	[.18, .71]	[-.16, .49]	[.21, .72]	[.25, .75]	[.42, .82]		[-.19, .43]	[.04, .60]	[.21, .70]	[.26, .73]	[.18, .69]	[.10, .64]	[-.02, .56]	[-.07, .52]	[-.03, .55]	[-.44, .18]	[-.57, .00]
8. BIN Dots Comparison	.47**	.54**	.23	.47**	.56**	.38*	.47**	-	.64**	-.05	.39*	.33*	.53**	.35*	.23	.41**	-.29	-.03
	[.15, .70]	[.25, .75]	[-.12, .53]	[.15, .70]	[.27, .75]	[.05, .64]	[.15, .70]		[.40, .79]	[-.36, .27]	[.09, .63]	[.02, .59]	[.26, .72]	[.04, .60]	[-.09, .51]	[.11, .64]	[-.56, .02]	[-.34, .29]
9. BIN Digit Comparison	.47**	.54**	.44**	.47**	.47**	.57**	.51**	.56**	-	.34*	.59**	.61**	.75**	.75**	.33*	.55**	-.14	-.19
	[.16, .70]	[.25, .74]	[.12, .68]	[.16, .70]	[.15, .70]	[.29, .76]	[.21, .72]	[.27, .76]		[.03, .59]	[.34, .77]	[.36, .78]	[.56, .86]	[.57, .86]	[.02, .58]	[.28, .74]	[-.44, .18]	[-.48, .13]
10. BIN Counting Forward	.50**	.53**	.46**	.50**	.54**	.69**	.74**	.55**	.77**	-	.47**	.27	.42**	.42**	.01	.18	-.16	-.22
	[.19, .71]	[.23, .74]	[.14, .69]	[.19, .71]	[.25, .74]	[.46, .83]	[.53, .86]	[.26, .75]	[.58, .88]		[.19, .69]	[-.05, .54]	[.12, .65]	[.12, .65]	[-.30, .33]	[-.15, .47]	[-.45, .16]	[-.50, .10]
11. BIN Counting Backward	.47**	.58**	.52**	.47**	.32	.48**	.65**	.48**	.72**	.79**	-	.40*	.56**	.42**	.26	.53**	-.05	-.18

	[.15, .69]	[.30, .77]	[.22, .73]	[.15, .69]	[-.02, .59]	[.17, .70]	[.40, .81]	[.17, .70]	[.51, .85]	[.62, .89]		[.09, .63]	[.30, .75]	[.12, .65]	[-.06, .53]	[.25, .72]	[-.36, .27]	[-.47, .14]
12. BIN Digit Seriation	.39*	.40*	.68**	.39*	.34*	.34	.39*	.41*	.66**	.67**	.69**	-	.58**	.62**	.25	.48**	.08	-.08
	[.06, .64]	[.07, .65]	[.45, .83]	[.06, .64]	[.01, .61]	[-.00, .61]	[.06, .65]	[.08, .66]	[.41, .81]	[.42, .82]	[.47, .84]		[.33, .76]	[.38, .78]	[-.07, .52]	[.20, .69]	[-.24, .39]	[-.38, .24]
13. BIN Sequence Completion	.46**	.46**	.60**	.46**	.44**	.55**	.71**	.43*	.59**	.83**	.69**	.72**	-	.65**	.35*	.46**	-.25	-.22
	[.15, .69]	[.15, .69]	[.32, .78]	[.15, .69]	[.12, .68]	[.27, .75]	[.49, .85]	[.11, .67]	[.31, .77]	[.68, .91]	[.45, .83]	[.51, .85]		[.42, .80]	[.04, .60]	[.17, .68]	[-.52, .07]	[-.50, .10]
14. BIN Digit-Dots Correspondence	.45**	.44**	.66**	.45**	.51**	.55**	.43*	.46**	.62**	.68**	.63**	.60**	.78**	-	.22	.46**	-.06	-.31
	[.14, .69]	[.12, .68]	[.41, .81]	[.14, .69]	[.21, .72]	[.26, .75]	[.11, .67]	[.14, .69]	[.35, .79]	[.45, .83]	[.37, .80]	[.33, .78]	[.60, .88]		[-.11, .50]	[.17, .68]	[-.36, .26]	[-.57, .01]
15. BIN One-Many	.49**	.59**	.62**	.49**	.25	.36*	.49**	.47**	.52**	.60**	.64**	.70**	.66**	.55**	-	.33*	.08	.09
	[.18, .71]	[.31, .77]	[.36, .79]	[.18, .71]	[-.10, .54]	[.02, .62]	[.18, .71]	[.15, .70]	[.22, .73]	[.32, .78]	[.38, .80]	[.47, .84]	[.42, .82]	[.26, .75]		[.02, .59]	[-.24, .38]	[-.23, .39]
16. BIN Magnitude Ordering	.59**	.55**	.47**	.59**	.45**	.57**	.67**	.38*	.65**	.68**	.73**	.66**	.76**	.58**	.65**	-	-.00	-.18
	[.31, .77]	[.26, .75]	[.16, .70]	[.31, .77]	[.13, .68]	[.29, .76]	[.42, .82]	[.05, .64]	[.41, .81]	[.44, .83]	[.52, .86]	[.42, .82]	[.56, .87]	[.30, .77]	[.41, .81]		[-.32, .32]	[-.47, .15]
17. NTP 1-10	-.25	-.12	-.30	-.25	-.38*	-.30	-.13	-.13	-.31	-.28	-.21	-.21	-.12	-.33	-.19	-.17	-	.209

	[-.54, .10]	[-.44, .23]	[-.58, .05]	[-.54, .10]	[-.64,-.05]	[-.58, .04]	[-.45, .22]	[-.45, .21]	[-.59, .03]	[-.57, .06]	[-.51, .14]	[-.51, .14]	[-.44, .23]	[-.60, .01]	[-.50, .16]	[-.48, .18]		[-.01,.49]
18- NTP 1-20	-.33	.01	-.18	-.33	-.28	-.32	-.21	-.21	-.43*	-.40*	-.35*	-.27	-.17	-.31	-.15	-.16	.54**	-
	[-.60, .01]	[-.33, .35]	[-.49, .17]	[-.60, .01]	[-.56, .07]	[-.59, .02]	[-.51, .14]	[-.51, .14]	[-.67, -.11]	[-.65,-.07]	[-.61,-.01]	[-.55, .08]	[-.48, .18]	[-.59, .03]	[-.46, .20]	[-.48, .18]	[.25, .74]	

Note. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.