# Training arithmetical skills when finger counting and working memory cannot be used: A single case study in a child with cerebral palsy.

## Abstract:

Children with cerebral palsy (CP) are at greater risk of mathematical learning disabilities due to associated motor and cognitive limitations. However, there is currently little evidence on how to support the development of arithmetic skills within such a specific profile. The aim of this single-case study was to assess the effectiveness of a neuropsychological rehabilitation of arithmetic skills in NG, a 9-year-old boy with CP who experienced math learning disability and cumulated motor and short-term memory impairments. This issue was explored combining multiple-baseline and changing-criterion designs. The intervention consisted of training NG to solve complex additions applying calculation procedures with a tailor-made computation tool. Based on NG's strengths, in accordance with evidence-based practice in psychology, the intervention was the result of a co-construction process involving N, his NG's parents and professionals (therapist and researchers). Results were analysed by combining graph visual inspections with non-parametric statistics for single-case designs (NAP-scores). Analyses showed a specific improvement in NG's ability to solve complex additions, which maintained for up to three weeks after intervention. The training effect did not generalize to his ability to perform mental additions, and to process the symbolic magnitude.

**Keywords:** case-control study; evidence-based practice; mathematical cognition; neurological disorders; learning disabilities; developmental age; motor disorders

## Introduction

Cerebral Palsy (CP) is a permanent neurodevelopmental disorder caused by brain injuries that occur during the perinatal period or in the first months of life. Movements and postures of children and adolescents with CP are particularly affected and are often associated with neuropsychological disturbances such as intellectual disability (Reid et al., 2018), visuo-perceptual impairment (Schmetz et al., 2019) or attentional and executive difficulties (Craig et al., 2019). Academic achievement also appears to be affected (Gillies et al., 2018), with a significant proportion of children exhibiting specific learning disabilities (Frampton et al., 1998).

From the very beginning, children with CP exhibit poor number sense. They showed a lower ability to compare the number of elements in a set (de Freitas Feldberg et al., 2021), to rapidly estimate small numerosities (i.e. reduced subitizing range; Arp & Fagard, 2005) and to count (Lecointre & Camos, 2004). All of these basic numerical skills have been identified as precursors to future arithmetic skills in typically developing children (Jordan et al., 2009; Krajewski & Schneider, 2009; Watts et al., 2014) as well as in children with CP (Van Rooijen et al., 2015). At school they struggle with mathematics (Critten et al., 2018) and have been found to be less efficient in solving small additions and subtractions, especially when enrolled in special education (Jenks et al., 2007; Jenks, de Moor, et al., 2009; Jenks, van Lieshout, et al., 2009).

Typically, children learn to calculate through the implementation of finger counting strategies (Björklund et al., 2019) before giving way to mental computation with no concrete support (Jordan et al., 2008). Such a level of competence requires powerful working memory resources. Otherwise, it is impossible for the child to perform the task without fingers, or to solve complex arithmetical problems involving multiple resolution steps and the maintenance of intermediate results (LeFevre et al., 2005). Finger use also supports the development of the base ten system and provides a concrete support for number composition (Crollen & Noël, 2015; Roesch & Moeller, 2015). Fine finger movements are also required when using manipulatives, which are frequently provided as a concrete support within the classroom when teaching mathematical concepts (for meta-analysis see Carbonneau et al., 2013). These elements explain why fine motor skills prove to be a good predictor of typical arithmetic development (Asakawa & Sugimura, 2014).

With regards to this typical developmental sequence, the cognitive profile of children with CP involves several risk factors that could cumulatively contribute to the emergence of mathematics learning disabilities. First, they often suffer from fine motor skill impairments (Arnould et al., 2007), which puts them in a poor condition to use their fingers effectively. Moreover, they are more prone to visuo-spatial processing deficit and eye-hand coordination problems (Stadskleiv et al., 2018), resulting in difficulty to implement early quantification processes such as subitizing (Arp & Fagard, 2005) and counting abilities (Camos et al., 1998). Finally, children with CP often experience working memory impairment (Stadskleiv et al., 2018), leaving them with a long-lasting dependence on finger-based strategies and/or concrete support (Peng et al., 2015). In children with CP a substandard working memory was found to be predictive of mathematics learning disabilities (Jenks et al., 2012; Van Rooijen et al., 2016). However, their severe fine motor impairments usually prevent the efficient use of finger-counting or manipulatives, with no other options than solving calculation mentally with an overloaded working memory, which drastically increases the risk of errors.

To date, many mathematical interventions have been conducted in children and adolescents with learning disabilities (Jitendra et al., 2018) but only a handful have been set up specifically for children with CP. To the best of our knowledge, only two training studies have been conducted in children with CP: one targeted the child's motivation to improve arithmetic problem solving (Sheehey et al., 2017) while the other focused on the implementation of an interactive geometry software computer program to enhance angle knowledge (Shaw et al., 1998). To date, no study has ever examined how to enhance and support the development of arithmetic procedures in children with CP, in particular, those who cumulate motor and working memory impairment.

### ***Current Study***

The current study examined the effectiveness of an arithmetic procedural training with a specific equipment in a 9-year-old boy with spastic diplegia named NG. He experienced mathematical learning disabilities resulting in a persistent inability to calculate. In the context of his pathology, NG cumulated different risk factors including short-term memory and fine motor skills impairments, which prevented him from using finger-counting strategies or manipulatives to reduce working memory load during computation.

In accordance with Evidence-Based Practice (EBP), the intervention was designed to meet the needs of NG, using an equipment tailored to his abilities. This intervention is grounded in the four pillars of EBP: research, clinical expertise, patient characteristics and organizational context (McCurtin & Clifford, 2015) which were used as the guidelines in the co-construction process involving NG's parents, researchers and a speech therapist.

The main objective of the present intervention was to enable NG to solve Tens/Units + Tens/Units complex additions with carrying (e.g. 34+49), using a suitable equipment. Combining multiple-baseline and changing-criterion designs, the three main issues addressed in this single-case experimental study concerns (1) the training effectiveness, (2) the training specificity and (3), the generalization effects. First, training effectiveness should manifest as an improvement in NG's ability to solve complex additions accurately with his specific equipment. Second, training specificity should demonstrate that improvement in arithmetic problem solving is attributable to the training and not to general cognitive development. Finally, generalization effects should translate into an improvement in numerical tasks that were not directly trained but were nevertheless related to the intervention (i.e. ability to calculate with no equipment and Arabic number comparison).

## Method

### *Design*

The three issues were addressed using a combination of multiple-baseline and changing-criterion designs. In a changing-criterion design the training effectiveness is demonstrated when the target behaviors change positively throughout the different stages of the intervention. Here, the training was divided into five stages of increasing difficulty, in order to steer NG towards solving an increasing number of computational procedures. Altogether, these five stages were designed to enable NG to implement the complex procedures necessary to solving complex additions on his own. The transition from one stage to the next was determined by the achievement of a success criterion (i.e. at least 90% success rate during at least three consecutive training sessions), which required continuous repeated measures of the child's progress. Accordingly, problem solving accuracy was assessed daily by NG's mother using a three-point scale: (a) wrong response, 0 point; (b) right answer with assistance, 1 point; (c) right answer without assistance, 2 points. Assistance was considered from the first help of the adult, whether it was to orally guide NG in his reasoning or to support him in the handling of tools. Daily problem solving success rate was reported on evaluation sheets communicated to the therapist. During weekly therapy sessions the decision to move to the next stage was taken by the researchers and the speech therapist, in concertation with NG's mother, when the success criterion was reached, and if NG's fluency was deemed sufficient (i.e. absence of hesitation and slow response time). When NG met the success criterion several days before a weekly therapy session, consolidation sessions were conducted with a mix of calculations from the previous stages until the day of the therapy session, in order to keep him motivated.

In addition to the changing-criterion design, multiple-baseline design was conducted resulting in an assessment of several behaviors in NG, at different time points. In order to assess the intervention effects (i.e. training effectiveness, training specificity and generalization effects), baselines were conducted at three time points: (1) pre-test (= three days before the first training session), (2) post-test (= the day after the last training session), and (3) follow-up (= three weeks after the post-test session). Each baseline was repeated a minimum of three times at each time point. The sessions, conducted by the main investigator, took place in the family home setting, in the presence of NG's parents. Due to his attention deficit/ hyperactivity disorder, each assessment session was spread over two days, in blocks of tasks administered in 15- to 20-minute sessions. Instructions and items were presented on a computer except for the working memory task for which the instructions were given orally.

Before beginning data collection, NG and his parents were informed about the objectives of the research, the methodology and the training procedure. NG's parents completed an informed consent form and the child gave oral consent. This research project was approved by the local ethic committee (reference number 2021-090).

## *Case report*

NG is a French-speaking boy aged 9 years and 4 months. He is an only child and lives alone with his parents. The family's socioeconomic status, collected using the International Standard Classification of Occupation (ISCO-08; International Labour Organization [ILO], 2008) is high, with both parents reporting intellectual and scientific occupations. NG has congenital spastic diplegia and microcephaly (brain lesion site unknown) associated with an attention-deficit/ hyperactivity disorder and a speech disorder. Despite use of Methylphenidate the sustained attention window remains limited.

After a first year of mainstream schooling, NG was enrolled in a special education school for children with motor disabilities, where he follows an individualized curriculum. Although delayed, NG exhibited better reading and writing skills than his classmates. In contrast, teachers noted great difficulties with mathematics and reported a significant and persistent delay in number sense development and calculation skills. Three years of unsuccessful instruction had led to NG developing severe anxiety in the mathematical learning situation, as reported by both teachers and parents. Faced with math avoidance, anxiety and (sometimes) oppositional behavior, teachers no longer knew how to approach new mathematical concepts with him.

A complete neuropsychological assessment was conducted before starting the intervention (Table 1). Motor latencies and fine motor skills assessment confirmed that NG had slower motor reaction times and a severe impairment in manual dexterity. Fluid reasoning and verbal comprehension were in the normal range[1] and were identified as strengths in NG's general cognitive profile, whereas visuo-spatial abilities were impaired. The assessment of working memory showed that verbal and visuo-spatial short-term memory skills were impaired while central executive remained in the normal range. NG was able to encode and store information in long-term memory but had difficulties in organizing his speech in a free recall session due to his speech disorder. Visual and auditory selective attention were in the normal range. Finally, lexical knowledge and reading comprehension development corresponded to the level expected in the second grade of elementary school[2].

The assessment of the mathematical cognition development (Table 2) confirmed the presence of mathematics learning disabilities. Knowledge of number sequence and counting skills could be considered as strengths. In contrast, the processing of Arabic number magnitude and the understanding of the numerical inclusion relationship was delayed. Arithmetical processing was severely delayed. Additions and subtractions with Arabic numbers were unsuccessful as soon as the second addend was greater than three. NG mainly used a *counting all* strategy in solving arithmetic problems, but was rapidly limited by his reduced capacity in verbal short-term memory. Using finger-counting led to calculation errors, and calculating with manipulatives was inaccurate as tokens dropped frequently.

[Table 1 and 2 near here]

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[1] Performance is considered as within the normal range as long as it does not deviate more than 1.6 standard deviation below the reference mean (i.e. Percentile 50).

[2] Performance within the normal range for this school grade.

### ***Intervention***

The two main priorities identified for this intervention were knowledge of Arabic number sense and arithmetical skills. As the main request of the parents, teachers and speech therapist was to focus on calculation abilities, the principal target of the present intervention was solve complex addition solving. The present rehabilitation was tailored to overcome NG's cognitive impairments in short-term memory and fine motor skills while taking advantage of acquired knowledge identified as strengths (knowledge of number word chain, counting and transcoding). Accordingly, specific equipment was used to provide NG with a concrete support for computation and limit the impact of working impairment on his performance.

#### *Materials*

*Preliminary step: finding a suitable tool.* Prior to starting the therapeutic intervention, a preliminary step was conducted to determine which type of computational equipment NG would be most comfortable with. With this aim in mind, he was asked to solve additions under four conditions with different types of external media: mental computation (no media), finger-counting, abacus or hundred square (i.e. a mat with a 10x10 matrix, each cell numbered from 1 to 100 with Arabic numbers, see below for a complete description). NG was presented with a set of 18 additions divided into three levels of syntactic complexity: (1) six Unit+Unit additions (U+U additions; e.g. 3+4); (2) six Ten Unit+Unit additions (TU+U additions; e.g. 14+3) and (3) six Ten Unit+Ten Unit additions (TU+TU additions; e.g. 25+12). At each level, half of the operations involved a carry. The task was stopped when all calculations of the same syntactic level were incorrect. An accuracy score and a proximity score (i.e. score of deviation from correct answer) were calculated for each type of support. Non-overlap of All Pairs scores (NAP-scores) were calculated to compare performance (Parker & Vannest, 2009).

The results (Table 3) show that NG answers were significantly more accurate when using the hundred square in comparison with the three other conditions, with a really marked effect. The incorrect answers fell closer to the target (large effect size) when calculating with the hundred square in comparison with the three other tools. NG's incorrect responses were significantly less precise when using finger-counting than when using mental strategies, suggesting that finger-counting was particularly non-functional for him. Based on these results the hundred square was adopted as the main tool during the intervention.

[Table 3 near here]

*Computational equipment.* The intervention relied on a three-fold tailor-made computational equipment composed of different tools specifically designed to support the assimilation of different knowledge entailed in arithmetical reasoning (Figure 1). The first tool was the *hundred square*, a mat (dimensions: 30.5 x 20 cm) presenting a square of 100 cells organized into 10 columns and 10 rows. Each cell was numbered from 1 to 100 with Arabic numbers. The rows were separated by a 2 cm-wide white band. The hundred square was fixed to a metal plate, and two magnetic pawns were provided to facilitate manipulation and so that NG could handle them without dropping them. The second tool, two sets of ten magnetic Cuisenaire rods of different colors (2 cm wide) and segmented into units (2 cm-long intervals) were provided to represent the numbers from 1 to 10. The third tool was a magnetic whiteboard used to write instructions and reasoning during the exercises in order to reduce the cognitive load in WM to the highest possible degree.

[Figure 1 near here]

### *Training procedure*

The present intervention was the result of an iterative process of co-construction involving the researchers and the speech therapist (hereafter referred to as *the professionals*) in addition to NG's mother. Each week, NG's mother participated in a 30-minute training session under the supervision of professionals in order to learn how to train NG to be successful at calculation exercises. Each session ended with a short mother-professionals debriefing (15 min) with the aim of defining how the exercises would be implemented ultimately at home. At home, NG participated in daily training sessions (10-15 min) guided by his mother with the purpose of assimilating the procedure and making it more precise and automatic with repeated practice. All sessions were recorded and shared online with the professionals. Online mother-professionals meetings were organized by request, with the purpose of debriefing about difficulties seen on the videos and in order to adjust the training procedures accordingly.

In accordance with the changing criterion design, the five stages of the intervention pursued specific sub-objectives of increasing difficulty. In stages 2 to 5, once the computation procedure had been completed, NG was encouraged to verbalize his reasoning, this was transcribed in real time by his mother onto the whiteboard. At each stage the final answer to each calculation had to be stated aloud by NG.

*Stage 1- Identifying a targeted Arabic number on the hundred square.* NG was given a two-digit Arabic number. He was trained to decompose the tens/units structure and to find the target number using a procedure relying on the hundred square organization (i.e. units presented horizontally, each row representing a ten, Figure 2a). After identifying the first digit (Tens), NG was invited to move his finger down the mat, from row to row, counting tens successively ("one ten, two tens…")

until the number of tens was reached. From this point, he was trained to move his finger, from cell to cell, to the right, counting forward from the ten (“twenty-one, twenty-two, twenty-three…”) until reaching and tagging the target Arabic number.

*Stage 2- Solving (T)U+U additions with no carry*. NG was given (T)U+U additions involving no carry and was invited to place the white pawn on the cell of the mat corresponding to the first operand of the addition, following the procedure of Stage 1. He was then taught to select the Cuisenaire rod corresponding to the second addend and to place this rod to the right of the pawn (Figure 2b). Finally, NG was trained to use a *counting-on* procedure to reach the correct answer.

*Stage 3- Solving (T)U+U additions with carry*. NG was given (T)U+U additions involving a carry and was trained to repeat the Stage 1 and 2 procedures until he noticed that the Cuisenaire rod came out of the mat, indicating that it was necessary to move the surplus on to the next ten. NG was then invited to map and replace this Cuisenaire rod (called the reference rod) by two shorter complementary rods representing the additive composition of the reference number (Figure 2c). To do so, NG was taught to determine the magnitude of the first rod by counting the number of units necessary to complete the ten (i.e. cells between the pawn and the end of the line). To determine the magnitude of the second complementary rod, NG was trained to place the first rod under the reference rod and to count the remaining units on the reference rod. Together, the cumulated magnitudes of both complementary rods had to be equivalent to the magnitude of the reference rod. Finally, NG had to place the first complementary rod to the right side of the white pawn, and to transfer the second to the beginning of the next row in order to reach the correct answer.

*Stage 4- Solving TU+TU additions with no carry*. NG was given a (T)U+TU additions with no carry and was asked to solve computations using Stage 1 and 2 procedures. He was trained to decompose the second addend in tens and units prior to the manipulations. Following the Stage 1 procedure, he placed the white pawn on the first addend on the hundred square. From the location of this white pawn, he was taught to add the tens of the second addend by moving a black pawn down, one row at a time, while counting the tens of the second addend ("one ten, two tens…"). From this new point, he was finally invited to select and place the Cuisenaire rod representing the unit of the second addend, following the Stage 2 procedure, to reach the correct answer (Figure 2d).

*Stage 5- Solving TU+TU additions with carry*. NG was given (T)U+TU additions involving a carry and was trained to combine the Stage 3 and Stage 4 procedures in order to move to the next ten using the additive composition. (Figure 2e).

[Figure 2 near here]

### ***Outcome measures***

In addition to the repeated assessments performed in the changing-criterion design, pre-, post- and follow-up intervention assessments were conducted following a multiple-baseline design. Outcomes measures were divided into *target measures* assessing the effectiveness of the intervention, *transfer measures* examining its specificity and *control measures* investigating the generalization effects.

#### *Target measures*

*Additions with tools.* NG was presented with a set of six additions to be solved using the procedures he had been taught to use during his intervention with the three-fold computational equipment. The difficulty level of the calculations varied according to (1) the Ten-Unit syntax of Arabic numerals (Level 1: six U + U additions; Level 2: six TU+U additions and Level 3: six TU + TU additions) and (2) the presence of a carry (half of the additions involved a carry at each level). Responses were assessed using the same scale as used by NG's mother during daily home training sessions. No time limitation was imposed during the task.

### *Transfer measures*

*Additions with no tools*. NG was presented with a set of six additions to be solved mentally without the computational equipment. He was simply asked to solve addition in his head and to say the result out loud. Additions were of the same complexity as in the task with equipment.

*Arabic number comparisons.* The processing of symbolic number magnitude was assessed using an Arabic number comparison task. NG was asked to read aloud two Arabic numbers (from 1 to 99) and to identify the larger one. He was presented with a set of 12 pairs of Arabic numbers with varying numerical distances: six close pairs (difference < 3) and six distant pairs (difference > 3). The syntactic structure of the two Arabic numbers to be compared was matched within each pair (same number of digits). Close pairs belonged to the same tens while distant two-digit number pairs belonged to different tens. Each correct answer was credited with one point.

### *Control measures*

*Subtraction fluency*. The ability to solve small subtractions was evaluated using an arithmetical fluency task based on the Tempo Test Rekenen (De Vos, 1992). A set of 40 calculations of increasing difficulty were presented to NG. The difficulty varied according to the Ten (T)- Unit (U) syntax of Arabic numerals, the magnitude of the difference and the presence of borrowing. NG was asked to solve as many subtractions as possible in one minute, and to state the responses orally. Each correct answer was credited with one point.

*Working memory*. Working memory abilities were assessed using the backward digit span task inspired by the Working memory subtest of the WISC-V (Fidelity coefficient= .86;Wechsler, 2014). The stimuli consisted of a set of 18-digit sequences of increasing length (i.e. two to eight digits). The participant had to repeat, in reverse order, a digit sequence read aloud by the experimenter. Two training trials were administrated before starting the task. Each correct answer was credited with one point. The task stopped after two successive errors on same-length sequences.

### ***Analyses***

Results were analyzed by combining qualitative and quantitative approaches. Repeated measures taken during daily home training sessions were analyzed by visual inspections of the figures, as recommended for N-of-1 trials (Kazdin, 2021). Visual inspections were conducted in terms of trend (i.e. increase or decrease of correct response rate over a stage of interventions), shift (i.e. discontinuity in the correct response rate), latency of change and overlap of performance.

Repeated measures were complemented by pre- and post- intervention measures analyzed in two steps. Firstly, visual inspections were conducted comparing pre- and post- baselines (pre-/post-baselines) and comparing post- and Follow-Up baselines (post-/FU baselines) to therefore describe the overlap between performance and the direction of change occurring during the intervention and the maintenance phases. To complete and confirm visual analyses, two different measures of progression between time points were calculated to assess the training effect (pre- vs post-baselines) and the maintenance effect (post- vs FU- baselines). These measures were adjusted to the initial level of performance (Vanclay, 1991), on the basis of the following formula:

$$\text{Progression score} = \frac{(\text{endpoint success rate} - \text{initial success rate})}{\text{maximum of success rate} - \text{endpoint success rate})} * 100.$$

Secondly, statistical analyses were conducted using a non-parametric approach consisting of calculating Non-overlap of All Pairs scores (NAP-scores, Parker & Vannest, 2009).  Ranging from 0 to 1, NAP-scores close to .93, .66 and ≤.65 indicated respectively as large, moderate and weak effect (Parker & Vannest, 2009).

## Results

### *Compliance with training*

A few guidelines were defined to optimize compliance. Five training sessions had to be administered over the week at times convenient to the child. NG was asked to solve a minimum of five calculations per session, which were to be interrupted whenever he appeared inattentive or uncomfortable with the task demands. Additional training sessions could be conducted on NG's request. Compliance with training was high, with an average of 5.7 sessions conducted per week. Only 10% of the sessions had to be shortened.

### *Effectiveness of the intervention.*

#### *Repeated measures.*

Visual inspections of repeated measures specific to each stage show strong upward trends followed by a stabilization phase across sessions for stages 1, 2, 3, and 4 (Figure 3). This pattern of results was less obvious at Stage 5 where scores seemed stable, with a weak upward trend observed from session 47. Quantitatively, comparing performance between the first and last session, the scores increased by 50%, 50%, 75% and 75% during stage 1,2,3 and 4 respectively. Concerning stage 5, scores were stable (Improvement rate = 0%). NAP-scores confirmed these trends with significant changes of moderate range during stages 1 (*NAP-score*=.82, *p*=.03) and stage 3 (*NAP-score*=.75, *p*=.02) and of a wide range during stages 2 (*NAP-score*=.93, *p*<01) and stage 4 (*NAP-score*=.93, *p*<.01). Changes during Stage 5 were not significant (*NAP-score*=.61, *p*=.45), probably due to the fact that NG's scores were already high at the beginning of this stage.

*Target measures.*

Concerning the pre-post assessment, visual inspection showed a positive change in additions with tools compared with pre/post baselines, as well as a maintenance of progress after a three-week timeframe. No overlap of performance was observed when comparing the pre/post baselines, whereas the post/FU baselines completely overlap (Figure 3). The results of the visual inspections were confirmed by a clear improvement of NG's performance when comparing pre/post baselines (Training effect = +100%) and a strict maintenance when comparing the post/FU baselines. The NAP-Score further confirmed these results (pre/post: *NAP-score*=1, *p*<.05; post/FU: *NAP-score*=0.5, *p*=1) with a significant change when comparing the pre/post-baselines (Table 4).

[Figure 3 near here]

### ***Specificity of the intervention***

Two methods were used to confirm that the changes observed in NG were attributable to the intervention, and not to aspecific factors. First, Figure 3 shows a close correspondence between the change in the criterion difficulty and NG's performance with respect to the specific objective of the stage (Kazdin, 2021). As depicted in Figure 3, NG's performance dropped sharply on three occasions just after an increase in the difficulty of the stage. Indeed, the performance dropped by

50% between stage 1 and 2, 75% between stage 2 and 3 and 75% between stage 3 and 4. No shift was observed between stages 4 and 5. In order to show the specific importance of stage 4 in achieving the pattern observed at stage 5, an intermediate assessment in solving TU+TU additions with carry (objective of stage 5) was conducted between session 26 and 29 (i.e. at the end of stage 3). Visual inspections reveal a positive change in scores between the intermediate baseline and stage 5, with no overlap of performance. Quantitative results show an important improvement of scores (Training effect = +87.2%) confirmed by a significant NAP-score with a significant change (*NAP-score* = 1, *p*<01). The procedures trained in stages 1 to 3 were not sufficient to reach the objective of the intervention (i.e. solve TU+TU additions with carry). Stage 4 was necessary in order give training in the missing procedure, to achieve the final objective and to generalize NG's knowledge of the procedure taught in stage 5.

A second way of examining the causal link between changes observed and the intervention was to demonstrate that these changes were not related to general cognitive development, nor to general numerical development. Regarding working memory measures, Figure 4a shows an overlap in performance between pre/post baselines and between post/FU baselines. Quantitative results reported in Table 4 demonstrate a slight decrease of working memory abilities between pre/post baselines (Training effect = -5.7%) and a maintenance of post-baseline performance after a three-week timeframe (Maintenance effect = +0%). However, the NAP-score indicated no significant changes in both situations (pre/post: *NAP-score*=.33, *p*=.51; post/FU: *NAP-score*=.50, *p*=1).

With regard to the subtraction fluency task, visual inspection of Figure 4a shows an overlap of performance when comparing pre/post baselines and comparing post/FU baselines. Quantitative results reported in Table 4 demonstrate a slight improvement of the score comparing pre/post-baselines (Training effect = +5.5%) and a small decrease when comparing post/FU baselines

(Maintenance effect = -2.9%). However, the NAP-scores were not significant in either of the situations (pre/post: *NAP-score*=.78, *p*=.28; post/FU: *NAP-score*=.33, *p*=.51).

### ***Generalization***

Only pre- post- measures were conducted to assess the generalization of the skills taught during the intervention to other numerical domains. Visual inspections of performance in addition with no tools (Figure 4b) shows the same pattern of results in both pre- and FU-baselines. Several overlaps may be observed between the three sessions. Qualitatively, results show that scores decreased moderately when comparing the pre/post baselines (Training effect = -12.5%) and increased moderately when comparing the post/FU baselines (Maintenance effect = +11.1%). However, statistical analyses demonstrate no significant changes when comparing pre-, post- and FU baselines (Pre/post: *NAP-score*=.33*, p=.51*; post/FU: *NAP-score*=.67*, p=.51).* No significant changes, when comparing the three sessions, suggests a lack of a generalization effect of the ability to perform additions without equipment.

Regarding Arabic number comparison, Figure 4b shows a negative change between pre/post baselines with no overlap of scores and a stabilization of performance during the maintenance phase with an overlap of baselines. Quantitative analyses of results reveals a moderate decrease of performance comparing pre/post baselines (Training effect = -25%) and a small decrease comparing the post/FU baseline (Maintenance effect = -8%). Statistical analyses show that the differences were not significant (Pre/post: *NAP-score*=.11, *p*=.13; post/FU: *NAP-score*=.33, *p*=.51*).* No significant changes when comparing the three sessions suggests the lack of a generalization effect in the processing of symbolic magnitude.

[Table 4 and Figure 4 near here]

### ***Social acceptability***

To assess the compliance with training, a three-part survey was distributed to NG's parents after the intervention. In the first part, they were asked to rate on a 10-points scale their level of satisfaction with the therapeutic setting, the support received in implementing home training sessions, the time spent on the intervention and the materials. Overall, parents reported an average satisfaction of 90%. In the second and third parts of the survey, they were asked to rate on a 7-points scale, NG's academic skills development and on a 4-points scale, his behavior when confronted with mathematics. Regarding academic skills, parents reported an improvement of 86% in calculating with the tool, 57% on the ability to perform additive decompositions with Cuisenaire rods and an average improvement of 22% in numerical skills that were not directly trained (i.e. mental computation and processing of the magnitude of Arabic numbers). No improvement was reported for reading and writing skills. Regarding emotional and behavioral aspects, parents reported a 50% decrease in mathematics task avoidance, fearful behavior and self-depreciation in the home context. NG's acceptability of the treatment was also assessed during an interview conducted by the speech therapist based on four open questions. Firstly, NG was asked for his opinion on the system and he reported that he appreciated working with his mother and the professionals. He also indicated that he liked working with his hundred square because it helped him to calculate. Secondly, NG was asked to judge his own progression. He confessed that before the intervention it *was difficult to calculate*, he felt that he was *not good at maths*, he was *angry* and *afraid* (making throat noise), whereas after training he felt *it was simple* to calculate, he felt that he was *good at maths*, and *was not afraid anymore* when calculating.

## Discussion

The present study aimed to assess the effectiveness of a training program designed to help a child with cumulative mathematical learning disabilities (MLD), impairment of fine motor skills and limited short-term memory resources, learning to solve complex additions using a computational tool composed of a hundred square and Cuisenaire rods. The specificity of the training program and the generalization to other untrained numerical domains were also questioned.

Data showed a large improvement in NG's ability to solve complex additions with the tailor-made equipment, followed by a maintenance up to three weeks after the rehabilitation had been stopped. The drop in NG's performance at each change of criterion, and the invariance of the control baselines (i.e. subtraction fluency and working memory) between the beginning and the end of the intervention, suggest that the improvements shown in the first four stages were due to a direct effect of the present intervention rather than a general developmental trend. The lack of any fall and the stabilization of performance observed in stage 5 appear to result from a generalization of the procedures trained during stage 1 through to 4, that specifically occurred at stage 4. Unfortunately, and contrary to what had been expected, no generalization was found in the ability to perform calculations without equipment, and additionally to the processing of the magnitude of Arabic numbers. NG's parents were satisfied with the intervention and reported a considerable improvement in their son's arithmetical skills in addition to a significant decrease in his anxiety and self-depreciation in a mathematical context.

Several factors related to the interventional design and therapeutic setting, implemented in accordance with EBP in psychology (McCurtin & Clifford, 2015), could have contributed to the success of the present intervention. Notably, the present rehabilitation was conducted using systematic and explicit instruction. This approach, based on Vygotsky’s concept of the zone of proximal development (Vygotsky, 1978), is commonly recommended in special education for the teaching of mathematics to children with cognitive disabilities (Browder et al., 2008). It allows students to increase their learning in small steps, and to be guided during practice with the goal of achieving a high level of success. In the present case the target skill was divided into five sub-skills and the complexity of the exercises was gradually increased. Forward chaining procedures (i.e. procedures of increasing complexity built on to one another) were progressively integrated into the training schedule along with procedural verbal routines that supported mathematical thinking. Each time a new procedure was introduced the therapist accompanied the demonstration with clear instructions, so that NG could make connections between the different stages of reasoning. These elements, when combined, could have been particularly effective for NG as they promoted the transition at each stage between what he could do with assistance at the beginning to what he could ultimately do independently. As a result, NG was placed in a position that led to success at every stage of the intervention, which was highly beneficial towards fostering of his motivation, restoring his self-esteem and contributing to a sense of competence. Overall, this particular approach had a very positive influence on his mathematical anxiety and his general attitude towards the subject. Similarly, the lack of clear procedures and instructions making the explicit relationship between the ordinal position on the mat and numerical magnitude of numbers could explain why NG’s knowledge did not generalize to the processing of the magnitude of Arabic numbers.

The triadic parent-child-professionals partnership was another active component of this training program. Unlike traditional interventions in which a therapist works alone with the patient, triadic interventions focus primarily on the parent, so that they can develop the skills necessary to support their child on a daily basis (Peterson et al., 2007). In this case NG’s mother was present at every therapy session, to observe how the training was conducted with the therapist but also to suggest possible adjustments based on her own knowledge of the way her child works. Our results are consistent with previous studies showing the effectiveness of triadic intervention models (Salisbury & Cushing, 2013) assigned to how the professional accompanies the parent, but also how the parent interacts with the child at home (Barton & Fettig, 2013). In line with recommendations (McDuffie et al., 2013), child-mother interactions that took place at home were filmed and used during video-feedback sessions conducted at the behest of the mother, so that she could adjust her behavior according to her son's needs. In addition, the therapist-researchers collaboration has strengthened the therapeutic setting, deeply grounding the practices in both the scientific evidence and in the child's cognitive profile, by taking advantage of NG's strengths and reducing the effect of his impairment on his development. This therapeutic setting was highly beneficial to all parties: NG who emerged from the process with increased skills and confidence in maths, parents who have become more confident at coping with their child's difficulties and the therapist who has enriched their therapeutic toolbox with a higher level of evidence-based practice. This type of therapeutic framework, based on a close partnership between parents/patient and professionals, brings into question the current practice focused mainly on the patient, and should be promoted as a model for future mathematical interventions conducted with children identified as having MLD and, more widely, for neuropsychological interventions.

### *Limits and Perspectives*

The current intervention was the first to show the effectiveness and the specificity of an arithmetical training program on a child with comorbid CP and MLD. By the end of the training NG had flawlessly mastered the procedures necessary to the resolution of complex additions with the tailor-made computational tools.

Similar to the others neuropsychological intervention studies, this research has some limitations. First, no explicit instructions other than those necessary to perform the trained procedures were given to the child. Therefore, NG was unable to generalize the tool usage to other numerical tasks, such as processing numerical magnitude. Moreover, at the end of training, NG was still dependent on the tool to calculate complex additions. Secondly, despite requests, there were few opportunities for interactions with educators from the special school in which NG is enrolled, thus limiting the partnership with the school.

Future avenues of specific work to lead NG to internalize the acquired procedure, and thus gradually discard the tool, should be initiated. This work should be supplemented with training focused on the memorization of arithmetic facts, as recommended in children with MLD in order to encourage abstract reasoning (Fuchs et al., 2008).

The objective of future training programs should also target NG’s number sense by using the successor function. Due to his knowledge of the verbal number sequence, NG has learned to use equipment in a way that could be exploited with the goal of supporting his understanding of symbolic number magnitude, instead of his constant reliance on cardinal information, which has so far been unsuccessfully favored by teachers and therapist. Based on explicit instructions, NG could be trained to associate the position of Arabic numbers on the mat with their magnitudes, and thus compare the properties of ordinal numbers (i.e. units and tens represented in ascending order, from left to right and from top to bottom, respectively) instead of their cardinal values.

Finally, the parent-professionals therapeutic setting and partnership should be opened up even further to include educational establishment. Future research should encourage more collaboration between the educational teams that work with NG within the setting of his special school. This study found, similarly to previous studies conducted in children with developmental language disorder (Archibald, 2017), that promoting collaboration between therapists and educators is essential for therapeutic continuity; it enables the transfer of training on tools and procedures used in therapy, and at home, to within the classroom setting.

## Declaration of interest statement

All authors contributed to the study conception. All authors read and approved the final manuscript. The authors declare no conflict of interest. Funding was received from the National Fund for Scientific Research (F.R.S-FNRS).

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**Table 1**: Fine motor skills, motor latencies and general cognitive assessment (9 years and 4 months)

| Functions and test | Raw score | Standard score |
|---|---|---|
| *Global functioning (WISC V)* | | |
| Verbal comprehension | 81 | |
| Similitaries | 18/46 | ss 8 |
| Vocabulary | 13/54 | ss 5 |
| Visuo-spatial index | **69** | |
| Block design | 10/58 | **ss 4** |
| Visual puzzles | 7/29 | ss 5 |
| Fluid Reasoning | 74 | |
| Matrix Reasoning | 5/32 | **ss 2** |
| Figure Weights | 17/34 | ss 9 |
| *Memory* | | |
| Questionnaire of memory (Q-MEM) | | |
| Effortful intentional learning | 27 | z = 1.41[a] |
| Prospective memory/ organization | 11 | z = 0.12[a] |
| Working memory | 25 | **z = 4.59[a]** |
| Working memory | | |
| Forward digit span (WISC-V) | 4 - span 3 | **ss 4** |
| Backward digit span (WISC-V) | 7 - span 3 | ss 9 |
| Picture span (WISC-V) | 11 - span 3 | **ss 4** |
| Long term memory | | |
| Story subtest (CMS) | | |
| Total Free Recall | 19/82 | **ss 2** |
| Total Free Recall after delay | 19/82 | **ss 4** |
| Recognition | 24/30 | ss 8 |
| *Attentional functioning* | | |
| Alertness (TAP) | | |
| RT without warning | 407 ms | **P4** |
| RT with warning | 315 ms | P14 |
| Phasic alertness index | 0.277 | P95 |
| Auditory selective attention | | |
| Simple auditory task (TAP) | | |
| RT | 617 ms | P38 |
| Omitted answers | 0 | >P38 |
| Incorrect answers | 1 | P54 |
| Visual selective attention | | |
| Cancellation (WISC-V) | | |
| Randomized order | 19 | ss 6 |
| Structured order | 18 | **ss 4** |
| Error | 0 | |
| Total | 37 | ss 5 |
| *Fine motor skills (MABC-2)* | | |
| Checklist | 54 | **<P5** |
| Manual dexterity subtests for children from 3 to 6 years old | | |
| Posting coins | | Scale 3-3years and 5 months |
| Best hand (Left) | 17s | ss 6 |
| Other Hand | 20s | ss 7 |
| Threading Beards | **Impossible** | |
| Tracing trail | **Impossible** | |

*Note.* z = z-score; ss = standard score; P = percentile; [a] reversed scale, performance interpreted as impaired when z-score ≥ + 1,66.

**Table 2**: Developmental profile in numerical and arithmetical tasks of the TEDI-MATH PETIT battery.

| | | **Kindergarten** | | **1st grade** | | **2nd grade** | | **3rd grade** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Scores** | **1st period** | **2nd period** | **1st period** | **2nd period** | **1st period** | **2nd period** | **1st period** | **2nd period** | **Maximum** |
| Number sequence | 12/12 | | | | | | | | | **x** |
| Counting | 13/13 | | | | | | | | | **x** |
| Knowledge of Arabic numeral system | 17/20 | | | 100 | 19 | <all | | | | |
| Written numerical decision | 8/8 | | | | | | | | | **x** |
| Comparison of Arabic numbers | 9/12 | | | 100 | 15 | <all | | | | |
| Knowledge of oral numerical system | 27/39 | | | 100 | 79 | 57 | <all | | | |
| Oral numerical decision | 12/12 | | | | | | | | | **x** |
| Judgement of grammaticality | 10/12 | | | | 100 | 29 | 3 | 4 | <all | |
| Comparison of oral numbers | 5/15 | | | < all | | | | | | |
| Base-10 | 5/27 | | | | | < all | | | | |
| Transcoding | 31/40 | | | | 100 | 23 | <all | | | |
| Writing Arabic numbers | 15/20 | | | | 100 | 23 | <all | | | |
| Reading Arabic numbers | 16/20 | | | | 100 | 27 | <all | | | |
| Additive decomposition of numbers | 0/6 | | 100 | 8 | <all | | | | | |
| Arithmetical operations | | | | | | | | | | |
| With pictorial aids | 4/6 | 42 | 18 | 7 | <all | | | | | |
| Verbal problem solving | 3/8 | 100 | 57 | 28 | 11 | 3 | <all | | | |
| With Arabic numbers | 10/40 | | 100 | 47 | 5 | <all | | | | |
| Simple additions | 5/12 | | 100 | 46 | 12 | <all | | | | |
| Incomplete additions | 0/8 | | 100 | 28 | 4 | 4 | | | | |
| Simple subtractions | 5/10 | | 100 | 96 | 77 | 19 | 9 | 7 | <all | |
| Incomplete subtractions | 0/4 | | 100 | 54 | 24 | 11 | 7 | 5 | <all | |

*Note*. This table provides normative scores corresponding to NG's performance (9 years and 4 months) in the numerical and arithmetical tasks from the TEDI-MATH standardized battery as a function of school grade and period of year. Data are expressed in cumulated percentages. <all = all children of the reference population scored higher than NG.

**Table 3**: Results for addition problems solved in order to find the most suitable tool for NG.

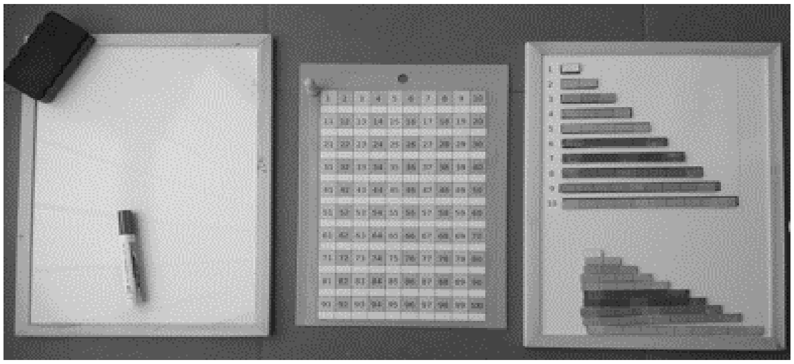
| **Conditions** | **Accuracy score (NAP)** | | | | **Proximity score (1-NAP)** | | | |
|---|---|---|---|---|---|---|---|---|
| | Raw score (/16) | Fingers | Abacus | Hundred square | Raw score [b] (%) | Fingers | Abacus | Hundred square |
| Mental computation | 2 | .67 | .67 | 1*[a] | 53.32 | 0* | .11 | 1*[a] |
| Fingers | 3 | | .50 | 1*[a] | 78.22 | | .89 | 1*[a] |
| Abacus | 3 | | | 1*[a] | 60.56 | | | 1*[a] |
| Hundred square | 11 | | | | 16.13 | | | |

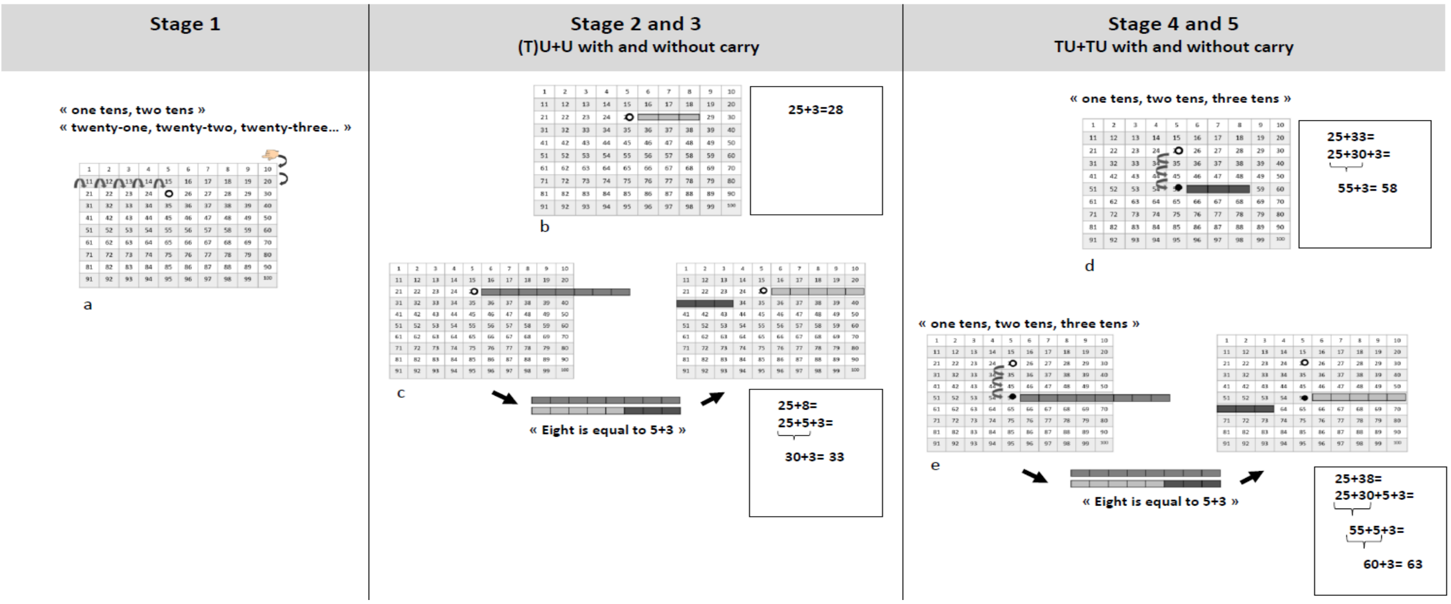
*Note.* NAP = Non-overlap of All Pairs index (NAP); **p<.05*; [a] large effect size; [b] reversed scale, the best scores were reported by the smallest values.

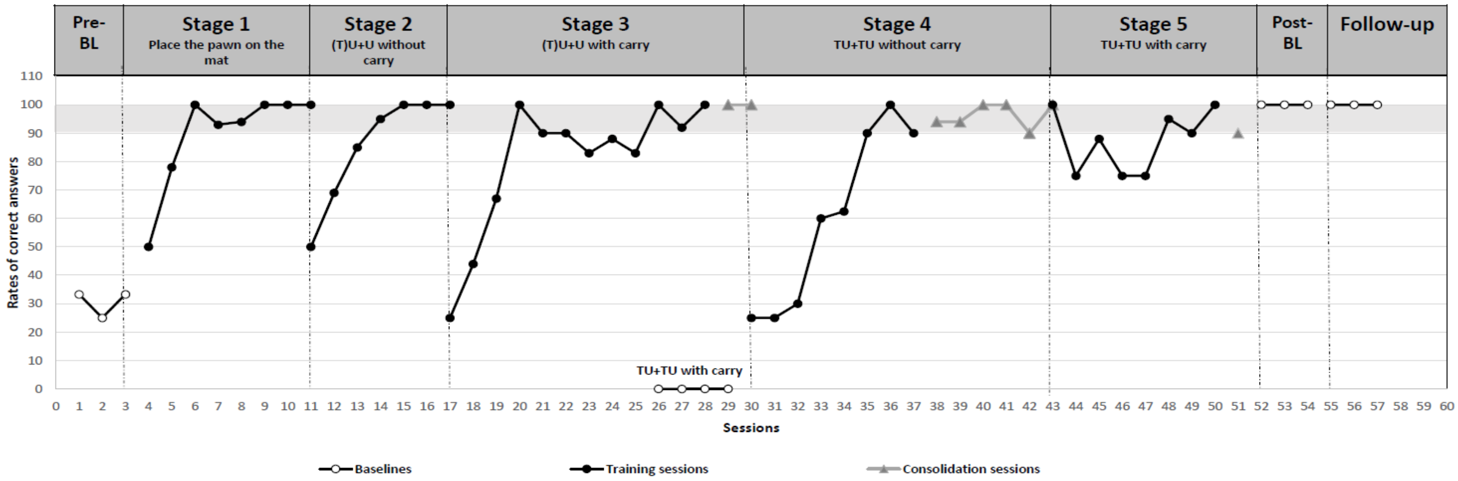
**Table 4**: Summary of NG’s results across phases**.**

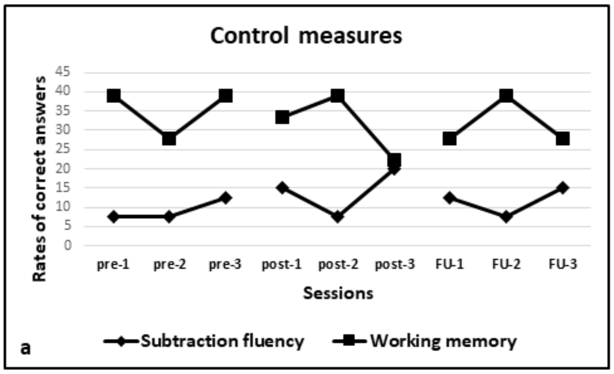
| Measures | Pre M (sd) | Post M (sd) | FU M (sd) | Pre/post | | Post/FU | |
|---|---|---|---|---|---|---|---|
| | | | | Training effect (%) | NAP | Maintenance effect (%) | NAP |
| Target measures | | | | | | | |
| Addition with tools | 30.55 (4.81) | 100 (0) | 100 (0) | 100 | 1*[b] | - | .50 |
| Transfer measures | | | | | | | |
| Addition with no tools | 11.11 (19.24) | 0 (0) | 11.11 (19.24) | -12.50 | .33 | 11.11 | .67[a] |
| Arabic number comparisons | 44.47 (4.79) | 30.57 (9.64) | 25 (0) | -25.03 | .11 | -8.02 | .33 |
| Control measures | | | | | | | |
| Subtraction fluency | 9.17 (2.89) | 14.17 (6.29) | 11.67 (3.82) | 5.50 | .78[a] | -2.91 | .33 |
| Working memory | 35.19 (6.41) | 31.48 (8.49) | 31.48 (6.41) | -3.72 | .33 | 0 | .50 |

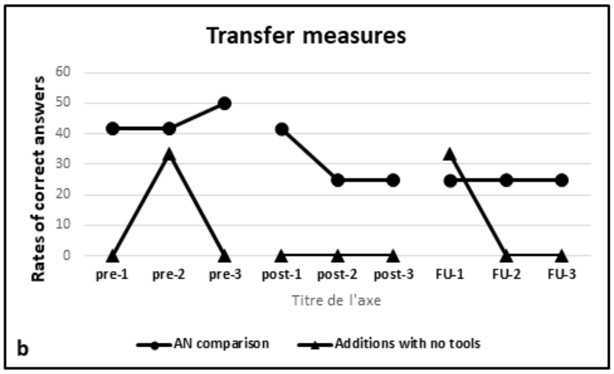
*Note.* Scores in success rate, FU= Follow-Up, NAP = Non overlap of All Pairs index, *$p<.05$, [a] Moderate effect size, [b] Large effect size




Stage 1
Stage 2 and 3
(T)U+U with and without carry
Stage 4 and 5
TU+TU with and without carry
« one tens, two tens »
« twenty-one, twenty-two, twenty-three… »
a
25+3=28
b
c
« Eight is equal to 5+3 »
25+8=
25+5+3=
30+3= 33
« one tens, two tens, three tens »
25+33=
25+30+3=
55+3= 58
d
« one tens, two tens, three tens »
e
« Eight is equal to 5+3 »
25+38=
25+30+5+3=
55+5+3=
60+3= 63


Pre-BL
Stage 1
Place the pawn on the mat
Stage 2
(T)U+U without carry
Stage 3
(T)U+U with carry
Stage 4
TU+TU without carry
Stage 5
TU+TU with carry
Post-BL
Follow-up
Rates of correct answers
0
10
20
30
40
50
60
70
80
90
100
110
TU+TU with carry
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
Sessions
Baselines
Training sessions
Consolidation sessions


Control measures
Rates of correct answers
45
40
35
30
25
20
15
10
5
0
pre-1
pre-2
pre-3
post-1
post-2
post-3
FU-1
FU-2
FU-3
Sessions
a
Subtraction fluency
Working memory


Transfer measures
Rates of correct answers
60
50
40
30
20
10
0
pre-1
pre-2
pre-3
post-1
post-2
post-3
FU-1
FU-2
FU-3
Titre de l'axe
b
AN comparison
Additions with no tools

## Figure captions

**Figure 1:** Computational equipment used during the intervention

**Figure 2:** Illustration of the five stages of the intervention

**Figure 3:** Rates of correct responses over the baselines, the five stages of the intervention and the maintenance. *Note*. BL= baselines.

**Figure 4:** Evolution of transfer and control measures. *Note.* AN=Arabic Number