A teacher-implemented intervention program to promote finger use in numerical tasks

Fanny Ollivier, Yvonnick Noël, Aline Legrand, Nathalie Bonneton-Botté

A Teacher-Implemented Intervention Program to Promote Finger Use in Numerical Tasks

Fanny Ollivier (1), Yvonnick Noël (1), Aline Legrand (2), Nathalie Bonneton-Botté*(1)

(1) Psychology of Cognition, Behavior and Communication Laboratory (LP3C), University of Rennes, Rennes, France

(2) National Ministry of Education

Author accepted manuscript

Published in European Journal of Psychology of Education:

Ollivier, F., Noël, Y., Legrand, A., & Bonneton-Botté, N. (2020). A teacher-implemented intervention program to promote finger use in numerical tasks. *European Journal of Psychology of Education*, *35*, 589–606. https://doi.org/10.1007/s10212-019-00441-9

Abstract

What constitutes effective teaching of arithmetical skills in early school years is still uncertain. Finger use could play a crucial role in this acquisition but some children do not use them spontaneously and studies would be necessary to know if it is possible to teach them. This research assesses the impact of a teacher-implemented intervention program to teach 5 to 6 year-old children to use their fingers in numerical tasks. Participants were 36 kindergarten pupils (16 girls, 20 boys; mean age 5 years, 5 months) from two classrooms. The research compares a program in which motor training and explicit teaching of finger use are promoted to represent numbers and to act on them, with a "business as usual" contrast group. Children were tested before and after the intervention with problem solving. After the experimental training program, finger counting appears to be a good strategy because its frequency is positively linked to the scores in the problem solving tasks. We showed a greater improvement in problem solving following the finger use intervention, compared to the contrast group. Our results support the explicit teaching of finger use to build numerical representation and enhance the calculation skills of kindergarten students (age 5) in French schools.

Keywords: problem solving; mathematics; finger use; finger counting; teacher intervention; kindergarten

Introduction

Many countries observe that academic achievement is linked to children's skills in mathematics (Duncan, et al., 2007; Ritchie & Bates, 2013). Unfortunately, international assessment studies (PISA, 2012, 2015) reveal a decline in mathematics proficiency for French pupils as well as an increase in the gap between the weakest and the best pupils. Mathematical vulnerabilities have been identified before the first grade (Feigenson, Dehaene, & Spelke, 2004; Gray & Reeve, 2014; Hornung, Schiltz, Brunner, & Martin, 2014; Fayol, Barrouillet, & Marinthe, 1998; Penner-Wilger, n.d). This emphasizes that it is crucial that some experiences take place during the first years of life in the family or in nursery school (Dyson, Jordan, & Glutting, 2014). In this instance, one of the recent recommendations of the French National Council is to change teaching practices in the field of mathematics beginning in kindergarten. The issue of early teaching practices and of their impact on emergent numeracy should be the focus of future research. Some research pointed out that most pupils from low income populations are lacking in fundamental skills such as as counting, number knowledge or number operation. Among these crucial skills, the use of fingers for numerical activities is currently debated both from the theoretical and the practitioner's point of view (Moeller, Martignon, Wessolowski, Engel, & Nuerk, 2011). The purpose of this study is to demonstrate the influential and beneficial role of fingers in developing numerical skills in school settings for kindergarten students.

The Role of Fingers for Numerical Development

1.1. Emerging Numeracy

From a neuroscientific approach, quantity recognition is already in process, at the beginning of life in an intuitive form due to an innate Approximate Number System (ANS) shared by different species (Agrillo, Piffer, Bisazza, & Butterworth, 2012; Dehaene, Piazza, Pinel, & Cohen, 2003; Piazza, 2011). In humans, the triple code model states that numerosity, initially apprehended in an analogic form (*i.e.*, subitizing, magnitude estimation) must gradually be "recoded" in a so-called symbolic (verbal and Indo-Arabic) format (Dehaene, et al., 2003). Gradually, the child will be able to consider all the decompositions of a number that is presented to him/her in analogic or symbolic form and to easily switch in both ways from one form to another (*i.e.*, a bidirectional mapping; Libertus, Odic, Feigenson, & Halberda, 2016). The frequently raised issue is how to establish the relationship between analogic number coding and its Arabic verbal and symbolic forms. The role of fingers to read, express, or transform quantities could prove to be a good candidate for the transition from the most primitive, analogical form to the most elaborate, symbolic ones. That is why Butterworth (1999) and Andres, Di Luca and Pesenti (2008), from an embodied cognition perspective, consider the finger mental representation as the probable missing tool to link primary and secondary formats of number. Embodied cognition refers to the idea that features of human cognition are formed not only brain but also by body (Wilson, 2002). From their point of view, concept of number could emerge from sensorimotor experience through a bottom-up process. This way, finger gnosia (*i.e*., the ability to mentally represent one's fingers) and finger use (*i.e.* using one's finger to represent or to handle numbers) could be milestones in number concept construction. Recent results, to be reported in the two next sections, support this hypothesis.

1.2. Neuropsychological studies

A topographical proximity between the areas hosting the representations of fingers and hands and those contributing to the processing of numbers is now attested (Gertsmann, 1940; Dehaene, et al., 2003). This proximity would explain why both adults and children (Gertsmann, 1940; Kinsbourne & Warrington, 1963; Rourke, 1993) can simultaneously present disorders of digital perception and processing of numbers. Transcranial magnetic stimulation studies showed that stimulation of angular gyrus, situated in the parietal area, interrupts both number processing and finger sense (Roux, et al., 2003; Rusconi, Walsh, &

Butterworth, 2005). In adults, the results obtained by Andres, Michaux and Pesenti (2012) show an activation of the same brain regions when the subject simultaneously performs finger discrimination tasks and addition tasks. If this anatomical proximity reflects a functional relationship between the two abilities, then this relationship should be observable during the development and the learning process of numerical skills.

1.3. Cognitive and developmental studies

Preschool children, school-aged children and even adults frequently use their fingers to support their numerical and mathematical activities (Butterworth, 1999, 2005; Fuson, 1998; Geary, 2004, 2007, 2013; Gelman & Gallistel, 1992; Lucidi & Thevenot, 2014; Newman, 2016; Sato & Lalain, 2008). Therefore, and considering the neuroscientific arguments described above, there is currently a strong hypothesis of functional and developmental relationships between finger use and numerical skills. In this perspective, finger use would allow the young child to represent quantities in an analogic mode before the symbolic representations are available, and to perform calculations on these representations (Siegler & Shrager, 1984). Di Luca and Pesenti (2011) pointed out that the use of an orderly and stable sequence of movements during counting allows the child to memorize the already counted elements by relying on the forward correspondence between raised fingers and counted objects. They also assume that this strategy facilitates the understanding and development of the concept of number, including its cardinal and ordinal properties. Some empirical evidence supports this functional hypothesis. Children who most often use fingers to calculate in pre-school classes perform best in arithmetic tasks (Jordan, Kaplan, Ramineni, & Locuniak, 2008). Over time, the use of fingers, however, does not seem to be equally relevant for all children. Jordan, et al. (2008) studied children's trajectories in frequency of finger counting during number combination tasks from kindergarten to the end of the second grade. Their result shows that kindergarteners with the worst performance on number combinations, who also tended to be from low-income backgrounds, almost never used their fingers spontaneously. Furthermore, low-income children showed linear growth in frequency of finger counting while middle-income children slowed down by second grade, and even started to decline. Middle-income children's trajectory (*i.e.*, they use their fingers less often in first grade than they did in kindergarten) suggests to the authors that early use of fingers helped children shift more quickly to accurate mental calculation or retrieval. More recently, Dupont-Boime and Thevenot (2018) reached the same conclusions as Jordan et al. (2008) and showed that Swiss French-speaking children aged between 5 and 6 years who count on their fingers perform better in an addition task than children who do not. Moreover, they showed that children who count on their fingers correspond to children with the best working memory capacities, showing that, in addition to the factors evoked by Jordan et al. (*i.e.*, culture, and family environment), cognitive efficiency modulates the frequencies of finger counting. Consequently, the authors of these two studies reach the same conclusions by recommending explicitly teaching the use of fingers to kindergarten students and encouraging them to use their fingers when performing tasks.

Beyond the use of fingers, the hypothesis of a functional relationship between fingers gnosia (*i.e.*, the ability to mentally represent one's fingers) and arithmetic skills has also been supported by longitudinal studies. The perceptual tactile abilities of 300 children of 5-6 years of age better predict their performance on computation task than their level of intellectual development (Fayol, et al., 1998). In a three-year follow-up study, the authors also found that this relationship is maintained over time for the same children.

As Fayol (2012) suggests, studies showing the beneficial effect of finger gnosis training are still needed to support these hypotheses. Gracia-Bafalluy and Noël (2008) proposed a manual motor training to 33 first-year primary students with low performance in digital gnosis and 14 students with good performance. They hypothesized that improving recognition and digital discrimination should have a positive impact on numerical skills. After an 8-week training program, the experimental group obtained the best performances in finger gnosia and math tests which had not been explicitly trained. However, Fischer (2010) posits that the results of this study could be explained by the regression toward the mean; this weakens Gracia-Bafalluy and Noël's (2005) conclusions, thus further training studies would be needed.

Although there are studies aiming at highlighting the relationship between finger gnosia and arithmetic skills, the relationship between finger gnosia and finger counting remains relatively under-researched. For the first time, in 2011, Reeve and Humberstone bring some evidence about this link. As a matter of fact, their results point out that low finger gnosia and low finger use are associated, and conversely for high finger gnosia and high finger use in counting tasks. Moreover, "finger gnosia representations change between 5- and 7- years, and these changes are related to finger-use in computation" (p.7).

In addition to investigations conducted on finger gnosia or on finger use, some research has specifically considered the functional dimension of the body schema of the hand, the ability to produce fine movements of the fingers generally requiring a good coordination of the eye and the hand. The results corroborate the role of fine motor skills or dexterity for numerical skills (Asakawa & Sugimura, 2009, 2011, 2014; Luo, Jose, Huntsinger, & Pigott, 2007; Suggate, Stoeger, & Fischer, 2017).

However, it must be mentioned that some behavioral studies do not find a significant relationship between finger gnosia measurement and arithmetical abilities (Long et al., 2016) or find a weak relationship (Wasner, et al, 2016). Regarding the use of fingers, it correlates with enumeration task performance for some children, but some who never use their fingers perform optimally (Lafay, Thevenot, Castel, & Fayol, 2013). Moreover, children with motor disorders that affect the representations of the fingers do not always have arithmetic delays

(Thevenot, et al., 2014). At least three non-exclusive causes could be considered to understand these divergences. First, as suggested by Lafay et al. (2013), one can assume that fingers are a useful but not a necessary tool during numeracy emergence. Second, studies are rarely culturally situated. Populations studied, generally in pre-school or grade 1, could have received differing amounts of exposure to the use of fingers in a mathematical context depending on the school systems to which they belong. These differences in educational practices may reflect the intercultural and intra-cultural differences that have been observed in the use of fingers in a mathematical context (Beller & Bender, 2008; Bender & Beller, 2012; Fischer, 2008). Third, cognitive efficiency, especially working memory, could modulate the frequency and the way children use their fingers to count. Moreover, Dupont-Boime and Thevenot (2018) observed both more finger counting and more efficient finger-counting strategies for children with high working memory spans.

Beyond theoretical debates, finger use is now seen as a useful tool for the development of symbolic numerical abilities. Finger use habits in mathematics differ from one culture to another (Beller & Bender, 2008; Bender & Beller, 2012; Fischer, 2008; Fischer & Shaki, 2014) and it could be assumed that opportunities for the children to use their fingers in a mathematical context differ quantitatively and qualitatively from one school system to another. The ability to mentally visualize one's hands and to discriminate one's fingers has been studied and found to be frequently decisive in the construction of number and early computational skills (Authors, 2015; Lafay, et al., 2013). However, finger gnosis is not the only component of embodied knowledge of numbers. The role of the functional motor component of finger use is also mentioned by some researchers (Asakawa & Sugimura, 2014; Butterworth 1999, 2005; Suggate, et al., 2017). Children must be able to raise and lower their fingers easily without using their second hand. They must also be able to imitate motor pattern with one or two hands by reproducing a model or by proposing a different decomposition of the number than the one proposed by the teacher. Thus, pre-school activities of counting and calculating assisted by fingers therefore require complex fine manual motor skills defined by Suggate et al. (2017) as “small muscle movements requiring close eye-hand coordination” (p.1087). Paradoxically, if fine motor skills are trained, the French school curriculum does not recommend a motor manual training explicitly linked to numerical skills. Otherwise, to our knowledge, there are no studies assessing the impact of an explicit teaching of finger use in mathematics, at least in a French school context. Furthermore, a reading of the French official instructions that were in place last century shows that finger counting has been proscribed or reduced to its function as a tool to represent numerosity (Brissiaud, 2013). If manual motor training is not recommended in the French curriculum, the explicit teaching of finger counting in mathematics does not appear either. Explicit instructions could be defined as a systematic instructional approach that facilitates frequent and meaningful instructional interactions between teachers and students around critical academic content. Explicit instructions dedicated to formal knowledge have proved their efficiency for mathematic achievement (Doabler, et al., 2015) and for writing achievement (Fayol, Grimaud, & Jacquier, 2013).

The Current Study

The main purpose of our research is to evaluate the impact of an explicit teaching program in kindergarten that combines both fine motor skills (Gracia-Bafalluy & Noël, 2008; Suggate, et al., 2017) and explicit knowledge on the finger use to compose numbers as recommended by some researchers (Jordan & Levine, 2009; Lafay, et al., 2013). First, we wish to replicate the results obtained by Jordan et al. (2008) in a French schooling context. With regard to these studies, we predict that students who spontaneously use their fingers during the problem solving tasks proposed at the beginning of the study to measure children's initial skills are also those who will perform best in problem solving. Second, in accordance with some recommendations, (Dupont-Boime & Thevenot, 2018; Lafay, et al., 2013; Reeves and Humberstone, 2011; Wasner, et al., 2016), we hypothesize that a training program aiming at developing fine motor skills and explicit knowledge of finger use to represent and decompose numbers will lead pupils to finger counting and to better perform in calculation tasks (*i.e.*, solving problems). As suggested by Lafay et al.: *"it could be fruitful to more explicitly encourage children in using their fingers and establishing the link between fingers and numerosities"* (Lafay, et al., 2013; p. 6).

Method

Participants

Participants were 36 pupils (16 girls, 20 boys; mean age 5 years, 5 months). All participants were in their final year of kindergarten in France (where kindergarten lasts three years). All were typically developing children, recruited from two classes each belonging to two different schools in a middle sized city. The children did not have cognitive, motor or visual impairments. The study was conducted in accordance with the authors' University's Human Ethics Committee requirements. We obtained written informed parental consent for each child. Both schools were attended by children from a middle class background.

School Context

The finger use teaching program was implemented by the children's regular teacher. Teachers were school employees; none were affiliated with this university research project prior to the study and both have prior experience of 10 and 12 years. In this study, prior to introducing the intervention program, the teacher who was randomly assigned to the finger training session participated in three 1-hour theoretical and methodological workshops (one theoretical hour before the experimental device and two hours of exchange during it) from which she received information about motor and numerical skills, experimental methodology, and how to follow the experimental protocol.

The two classes assigned to the control and experimental groups were selected such that initial teaching practices regarding numerical skills be fairly similar across teachers, both quantitatively and qualitatively, on the following important criteria (Baroody, Lai & Mix, 2005): During the year, both teachers plan daily work to develop the various numerical skills with a significant amount of time dedicated to composing and decomposing numerosities (about 30 minutes a day) either as a collective ritual (*i.e.*, decompositions of the number of absentees), or by games offered in the form of stations of 2 to 4 players.

Teaching practice similarity was assessed based on a preliminary interview of the two teachers, conducted by an educational consultant at the beginning of the academic year as part of their professional follow-up. Furthermore, during this preliminary interview, it was made clear from both teachers that while they did authorize the use of the fingers or specific material for numerical activities, they did not engage in a systematic and explicit teaching of the finger counting. In accordance with the curriculum for kindergarten, the two teachers stated that they granted a daily time to the development of fine and gross motor skills (about 1 hour per day, such as cutting, graphics, modeling clay, pearl threading activities). Pretests were conducted in December in both classes. From March to June, 10 weeks were allocated to the intervention and the posttests were carried out at the end of June.

Pre- and Posttests

A researcher tested all students individually on 10 problem solving tasks in a quiet room of the school with an unlimited time given to pupils. All items, proposed by oral instruction, came from the TEst for the DIagnosis of Mathematical Competences (TEDI-MATH; Grégoire, Noel, & Van Nieuwenhoven, 2004). The interest of this Belgian test is that its norms are also established for French pupils. The same items were offered to children for pre and posttest. Five items are arithmetical problems (*i.e.*, AP; five single digit additive operation as 6+3=) and five are word problems (*i.e.*, WP; two single digit additive operation and three single digit subtraction as “Sophie has 5 marbles. She loses 3 marbles. How many marbles does she have left?”). From this problem solving task, a global score (between 0 and 10) is assigned to each child. During the test, the researcher ensures that children keep their hands on the table so that she can observe their procedures. The researcher observes if each child spontaneously uses his/her fingers at least once for each type of problem (*i.e.*, AP and WP). Children who use their fingers at least once are assigned a score of 1, while children who do not use their fingers have a score of 0. A finger use is considered by the researcher if the child has clearly tried to solve the problem using his/her fingers and whether he/she is successful or not. It can be finger counting or finger montring, which allows the child to rely on a numerical representation on his/her fingers to solve the problem. The pre and posttests were administered individually by an experimenter in a quiet room at the child’s school two weeks before and two weeks after the interventions. The time allowed for the test was unlimited with the task taking around 10 minutes each per child.

Intervention for Finger Use Group

The teacher worked along two main components with the whole class group: perceptual and motor representations of hands and fingers (*i.e.*, sensitivity and motility) and the composition and decomposition of numbers using the fingers which involves finger montring and finger counting.

Perceptual and motor training of hands and fingers

The training aimed at helping children differentiate their fingers, in terms of both sensitivity and motility. Children performed daily 15-minute exercises of finger untying and gymnastics. The aim was to teach children to use their fingers independently of each other and in succession for each hand. The 8 exercises proposed to the teacher are extracted from a series of videos available on a graphomotricity remediation website (http://www.reeducationecriture.fr). During this time, the children could also play with an elastic band while passing it from fingers to fingers or by performing figures. The purpose of the session was presented daily to students: Manual motor training was systematically explicitly linked by the teacher to the fact that the hands and the fingers must be easy to use in mathematical situations but the time of these stations is counted on the teaching time of the motricity with regard to the school curriculum.

Composition and decomposition of numbers

The announcement game

A daily 15 minute game was organized in the classroom, in the form of a 3 to 4 children workgroup. The announcement game is a didactic game (Sensevy, 2015), used usually in first grade, to help children link analogic and verbal representations of numbers. The script could be summed up by the following sequence: 1/ children announce a number by representing it verbally and digitally with one or two hands, 2/ two dice are thrown by a player, 3/ the number made by the dice is compared to the players' announcements. Players with correct announcements, whatever the composition, get a point. At each new game and during the activity, the teacher presents the objective (knowing how to represent with fingers all decompositions of numbers lower than 12 with one, two or three players' hands).

Finding the tactile number

This activity aims at simultaneously developing digital sensitivity and quantity decomposition. During daily 15-minute sessions, children have to work on number decomposition (from 3 to 8) the tactile way, by blindly touching pads of felt glued upon two cardboard sheets (*e.g.*, 3 and 5 pads), enclosed in a box, and verbally returning the total quantity. In the first step of the game, children have to associate the pattern explored with a visual pattern to choose from two suggestions (analog match). When successful, they have to verbally identify and name the total number (in our example children should say 8).

Contrast Group

The contrast group was "business as usual" so no specific instructions were given by the researcher. The teacher was simply informed that children's progress would be measured in December and April for research purposes, without giving more details on the skills assessed. We suggested that she continued her usual class progression (for more details see school context section). The time allocated to composing and decomposing numerosities is about 30 minutes a day either as a collective ritual (*i.e*, decompositions of the number of absentees) or by games offered in the form of stations of 2 to 4 players during which students learn to decompose from materials such as cubes or tokens. A post-search interview verified that for the contrast group, students were not subjected to a perceptual and motor training of fingers, to the "announcement game" or to the activity named "finding the tactile number".

Results

Data Analysis

Although all tasks were presented in a verbal and an arithmetic form, treating this distinction as a factor in the analyses, to be crossed with the (invoked, unbalanced) finger use factor would have led to a heavily unbalanced design with empty cells. Moreover, correct responses counts on a limited 5-item scale are unlikely to be correctly modeled as a Gaussian distribution with within-groups equal variances. For these reasons, a pooled performance score, calculated across all verbal and arithmetic items, was used in the analyses below.

Because data consisted of repeated measurements, mixed-effect models, treating the subject factor as random, were used throughout the analyses, using the lme4 (Bates et al., 2015) and R2STATS R packages (XX, 2014), in a model comparison approach. A more traditional approach (e.g. ANOVA and post-hoc tests) was not feasible here because of an unbalanced design (a commonly encountered situation in clinical studies with invoked independent variables).

This is one of the reasons why the mixed approach has gained popularity in the last decade (Magezi, 2015) for the analysis of repeated measurements. While ANOVA inference, based on *F* tests, requires balanced designs, linear mixed effects, in a model comparison approach based on Residual Maximum Likelihood (REML), can manage more complex (unbalanced, nested, with missing values) designs in a flexible way (Baayen, Davidson & Bates, 2008).

A second advantage of this method is that specific structural hypotheses on cell means may be straightforwardly tested through the comparison of a sequence of nested models. In the present context, because a different evolution of performance is expected in both groups (*i.e.*, a significant interaction term), an analysis (and a model) of this interaction is anticipated. As is well known, main effects are meaningless in linear models, as soon as an interaction term is present, and should not be interpreted (a principle sometimes referred to as the "marginality principle", Nelder, 1977). Specifically, it is expected in this study that: i) There should be no between-group difference at pre-test, ii) progress will occur only in the experimental group. Both hypotheses, as a whole, can be formulated as a specific mean model, to be tested against alternative models.

This approach, by comparing nested models, has the additional benefit of circumventing the problem of correcting the decision level for multiple post-hoc tests and the associated inflation of type I error (Cribbie & Keselman, 2003).

Finally, the Bayesian Information Criterion (BIC) was used as the main decision statistic for comparing models (Schwarz, 1977). This is also a nice side effect of a model comparison approach that, using Bayesian inference, expected null hypotheses can be positively asserted in the final conclusions (Raftery, 1995), which is of course not possible in the standard *p*-value approach (Wagenmaker, 2007).

Model Comparisons

Although finger use is an invoked rather than provoked variable in the current design, we wanted to check that the previous result of a positive link between finger use and arithmetic performance was replicated by our data. A preliminary one-sided *t*-test comparing performances across both groups of finger users and non-users was performed.

Because we were interested in measuring the impact of the training session on both finger use frequency and arithmetic performance, the following sequence of four nested models, defining a decreasing sequence of constraints over the GROUP variable (Contrast vs. Trained) and the PHASE (Pre-training vs. Post-training) variables, was fitted to both dependent variables:

1. A null model (M0) of no effect at all. This trivial model was used as a reference point for all comparisons,
2. A model (M1) assuming a post-test difference between both groups, but constraining pre-test means to equality (hypothesizing the equivalence between both groups before the session), but also ii) equal pre and post-test means among the control subjects (no-change expected within the control group),
3. A model (M2) analogous to the previous one, but relaxing the constraint of no change within the contrast group.
4. A model (M3) assuming all effects (*i.e.*, relaxing the last constraint of equality of pre-test means).

A preliminary *t*-test comparing both groups of finger spontaneous users (n=12) vs. non-users (n=24) provided evidence of better performance in the arithmetic task for finger users (N=36, t(34)=5.378, p<0.001). Homogeneity of variance and normality were acceptable on these data (Levene F(23,11)=0.8086, p<0,64 ; Shapiro-Wilk's W=0.968, p<0.37).

Summary statistics of arithmetic performance and finger use, for both experimental groups and phases are reported in Table 1. Additionally, although these factors were not included in the final analysis for reasons explained above, we noted that during the posttest 85% of students for the training group used their fingers for arithmetic and verbal items and the remaining 15% used their fingers once either for the arithmetic items, or for verbal items. For the control group, it is observed during the posttest that 25% used the fingers for both types of tasks, 19% of them used their fingers in only one of the two tasks and 56% never used them.

Comparisons of all four target models on finger use (using binomial mixed-effect models) and on arithmetic scores (using Gaussian mixed-effect models) are summarized in Table 2 and 3.

[insert table 1]

[insert table 2]

[insert table 3]

Based on the *BIC* statistic, the most constrained model (*MI*) is retained as the best model, on both dependent variables (Figure 1), i.e. a model assuming i) no change within the contrast group, and ii) a joint increase in performance and finger use within the trained group. Interestingly, we note that a decision based on the more traditional likelihood ratio statistic would have led to the very same conclusion: a model assuming no change within the contrast group, and a joint increase in performance and finger use within the trained group is retained as the best model. Because the only difference between both groups is a specific training promoting finger use, this analysis bears some evidence that finger use leads to better results in arithmetic proficiency.

In the Gaussian case (arithmetic scores), homogeneity of variance and normality hypotheses are both acceptable within the best model (Levene $F(1,70)=0.1797$, $p<0.59$; Shapiro-Wilk's $W=0.974$, $p<0.134$).

Discussion

The purpose of this study was to better understand how to promote numeracy and to demonstrate the influential and beneficial role of fingers in developing numerical skills in school settings for children aged 5 to 6 years. Our main objective was to evaluate the effectiveness of a 10-week instruction program in last year of kindergarten in France that combines sensitivity and motility training of fingers and explicit instruction during pedagogical workshop to use fingers to represent and explore numerical representations (Dupont-Boime & Thevenot, 2018; Gracia-Bafalluy & Noël, 2008; Jordan & Levine, 2009; Lafay, et al., 2013). Implementing the instructional programs in the children's normal learning setting was intentional and thought to strengthen the link between innovative research and typical teaching activities. It is rare for teachers to implement intervention research directly, even though two meta-analyses (Ehri, et al., 2001; Piasta & Wagner, 2010) have shown that, in the literacy domain, teachers are as effective as researchers. Additionally, when researchers do the teaching, their involvement is typically limited to the duration of the research, whereas when teachers introduce new interventions, they are apt to internalize the educational goals within the research and continue using the program to benefit future pupils. Finally, concerning the field of numeracy, it has been found that supplemental interventions are more effective when they are aligned with what takes place in the classroom (Craddock, Hollenback Hamlett, & Schatschneider, 2008).

As we supposed in our first hypothesis, French students who spontaneously use their fingers during the problem solving tasks proposed at the beginning of the study to measure children's initial skills are also those who will perform the best in problem solving. This result confirms those obtained in Switzerland and the United States (Dupont-Boime & Thevenot, 2018; Jordan et al., 2008). Studies previously established a relationship between finger gnosis and arithmetic performance (Marinthe, et al., 2001; Reeve & Humberstone, 2011) and between finger gnosis and enumeration skills (Gracia-Bafalluy & Noël, 2008; Lafay, et al., 2013). Although finger gnosis is a reliable predictor of certain numerical performances, it cannot be used by teachers in observation, evaluation or remediation situations. It therefore seemed necessary and relevant to study the predictive value of a behavioral indicator (*i.e.*, the use of a finger during a problem-solving task). The positive relation observed between spontaneous finger use and arithmetical performance for pre-schoolers can be interpreted in light of the embodied hypothesis highlighting a strong relationship between the mental representations of fingers and the numerical skills. However, as already pointed out by Reeves and Humberstone (2011) who show a significant relationship between finger gnosia and single-digit addition problem solving abilities, this relationship is also characterized by significant individual differences at the same age. In our study, during the pretest and before the teaching session, only a third of the subjects used their fingers to solve problems. These individual differences could be explained by the amount of experiences that have benefited children in the school and family context (Bender & Beller, 2011, 2012; Jordan & Levine, 2009) but also by differentiated working memory capacities (Dupont-Boime & Thevenot, 2018). Finally, the functional motor component of finger counting mentioned as decisive by some researchers could also explain these differences between children if we consider the diversity in motor development (Asakawa & Sugimura, 2014; Butterworth, 1999, 2005; Penner-Wilger, n.d; Suggate, et al., 2017).

In a second hypothesis, we assumed that an explicit teaching program aiming at developing sensitivity and motility of fingers and explicit instruction to use fingers to construct numerical representations would help pupils to spontaneously use their fingers and to perform optimally in mathematical problem requiring calculation. The motor training and the explicit instruction of finger use both resulted in improved mathematical performance and enhanced finger counting during post-test comparing to a “business as usual” control group for which learning has been mainly designed from the manipulation of objects. This is an interesting result as, to our knowledge; no such teaching program has been studied previously, in particular in an ecological school context. Results obtained by Gracia-Bafually and Noël (2008) after a session of motor manual training was close but the impact was measured on enumeration and this study presents some statistical weaknesses (Fischer, 2010). Our results also question the difference between body movements and object manipulation to support arithmetical skills. In a meta-analysis dedicated to the efficacy of teaching with concrete manipulatives, Carbonneau, Marley, and Selig (2013) report that children under 7 years old found little benefits from using manipulatives. Authors explain that, from a developmental approach, "*younger children may struggle with the concept that an object can stand for the item while simultaneously representing a larger mathematical concept*" (Carbonneau, et al., 2013; p.394). Fingers are not objects like others, on the one hand, because their mobilization contributes to an embodied cognition of numbers and of transformations on them even in adulthood (Andres, et al., 2012) and, on the other hand, because their matching with a wide variety of everyday objects of the child facilitates the abstraction of the notion of number, that is to say the transition from "number of" to "number".

If the statistical analysis carried out allows affirming that globally, the teaching of the finger use (fine manual motor skills, finger montring and finger counting) is beneficial for the arithmetic performances, the question of the individual differences with this type of training can arise. Did all the students in the finger training group benefit from the experiment? While 85% of trained students were counted in the statistical study as having used the fingers at least once in each type of item (*i.e.*, word or arithmetical problem), a qualitative analysis of the data shows that the remaining 15% used their fingers once either for the arithmetic items, or for verbal items. This result shows that the training was successful in using fingers for all students in the experimental group. Comparatively, for students in the contrast group, 56% of students never use their fingers during the posttest, whether items are presented in arithmetic or verbal form.

It is worth noting that, for the finger training group, the finger use frequencies dramatically increase (from .30 to .85) during an arithmetical tasks while our training program was not a finger counting training per se. This result highlights the decisive role of a functional motor component of finger use mentioned by some researchers (Asakawa & Sugimura, 2014; Butterworth, 1999, 2005; Penner-Wilger, n.d; Suggate, et al., 2017). Provided that the child does not have a motor disorder, our study suggests that manual motor skills are sensitive to learning in school context and is not determined simply by maturation as thought Gesell in 1947. Some studies have shown that environment and cultural attitudes, by orienting the opportunities for actions offered to the child to exercise, impact motor development (Bril, 1986; Suggate, Stoeger, & Pufke, 2016; Harkness, 1986). Thus, considering school as "a field of promoted action" (Reed & Bril, 1996) to develop manual motor skills could create a virtuous circle because children with better fine motor skills might better interact with their environment, which in turn bolsters their fine-motor skills (Iverson, 2010; Suggate, et al., 2017). It seems to us that the curriculum and educational practitioners could give a greater share to manual motor skills, especially in the pre-school period by integrating this component into the assessment and remediation of students with difficulties in mathematics. Finally, our results suggest that embodied cognition could support learning in mathematics provided that the learning context allows it, that is to say that opportunities for action are offered to young children to explore the use of fingers in mathematical situations and exercise their fine motor skills to make their hands functional tools to represent reality.

Limitations

If in the short term, an explicit instruction on finger use proved beneficial, a longitudinal study would have made it possible to verify that it is not in the long term an obstacle towards access to the most economical and optimal strategies. Furthermore, the proposed training involved heterogeneous skills (*i.e.*, perceptual and motor representations of hands and fingers and the composition and decomposition of numbers using the fingers) which does not make it possible to precisely identify the factors which explain its efficiency. Additional training studies will be needed to clarify the involvement of each skill being trained.

Given the likely impact of motor skills and the diversity of motor development rhythms, an initial control of manual motor skills, dexterity and motor coordination would have provided valuable insight to understand the inter-individual differences before and after the learning session, a study in progress investigates the relationship between the quality of the initial motor skills and the benefit of a training program.

Finally, while we chose to implement the finger training program by the teacher rather than the researcher, we recognize that measuring the fidelity of the teacher's implementation is difficult. Filmed sessions would probably have measured this fidelity; however, we did not make this choice considering that filming sessions could have disrupted the ecology of teaching and learning.

Conclusions

The present study has shown that the use of fingers to build numerical representations can be taught effectively and that this teaching translates into a meaningful improved ability to solve verbal and arithmetic problems in children aged 5 to 6 years. Training fine motor skills and an explicit teaching of finger use to compose and decompose numbers constituted this 10 week teacher-implemented intervention. This intervention which provides students benefits in a relatively short time period should be extended to larger samples and with particular attention to learning outcomes obtained from at-risk students.

References

Agrillo, C., Piffer, L., Bisazza, A., & Butterworth, B. (2012). Evidence for Two Numerical Systems That Are Similar in Humans and Guppies. PLoS ONE, 7(2), e31923. doi:10.1371/journal.pone.0031923

Andres, M., Michaux, N., & Pesenti, M. (2012). Common substrate for mental arithmetic and finger representation in the parietal cortex. *NeuroImage*, 62, 1520-1528. doi:10.1016/j.neuroimage.2012.05.047

Asakawa, A.,& Sugimura, S. (2009). The relationship between finger dexterity and numerical abilities of young children. *Japanese Journal of Developmental Psychology*, *20*, 243–250. (In Japanese with English abstract.)

Asakawa, A.,& Sugimura, S. (2011).The specific relationship between numerical abilities and finger dexterity in early childhood. *Japanese Journal of Developmental Psychology*, *22*, 130–139. (In Japanese with English abstract.)

Asakawa, A., & Sugimura, S. (2014). Developmental trajectory in the relationship between calculation skill and finger dexterity: A longitudinal study. *Japanese Psychological Research*, *56*(2), 189-200. doi:10.1111/jpr.12041

Baroody, A. J., Lai, M. L., & Mix, K. S. (2005). Changing views of young children's numerical and arithmetic competencies. In *annual conference of the National Association for the Education of Young Children, Washington, DC*.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48. doi:10.18637/jss.v067.i01.

Beller, S., & Bender, A. (2008). The limits of counting: Numerical cognition between evolution and culture. *Science*, *319*(5860), 213-215. doi:10.1126/science.1148345

Bender, A., & Beller, S. (2012). Nature and culture of finger counting: Diversity and representational effects of an embodied cognitive tool. *Cognition*, *124*(2), 156-182. doi:10.1016/j.cognition.2012.05.005

Authors (2015).

Bril, B. (1986). Motor Development and Cultural Attitudes*. Themes in Motor Development, 297–313. doi:10.1007/978-94-009-4462-6_17

Brissiaud, R. (2013). *Apprendre à calculer à l'école: les pièges à éviter en contexte francophone*. Retz. doi: 10.14375/np.9782725631639

Butterworth, B. (1999). *The mathematical brain*. London : Mac Millan.

Butterworth, B. (2005). The development of arithmetical abilities. Journal of Child Psychology and Psychiatry, 46(1), 3–18. doi:10.1111/j.1469-7610.2004.00374.x

Carbonneau, K. J., Marley, S. C., & Selig, J. P. (2013). A meta-analysis of the efficacy of teaching mathematics with concrete manipulatives. Journal of Educational Psychology, 105(2), 380–400. doi:10.1037/a0031084

Carpenter, T. P., Moser, J. M., & Romberg, T. A. (Eds.). (1982). *Addition and subtraction: A cognitive perspective*. Lawrence Erlbaum Associates.

Carpenter, T. P., & Moser, J. M. (1984). The acquisition of addition and subtraction concepts in grades one through three. *Journal for research in Mathematics Education*, 179-202. doi:10.2307/748348

Cribbie, R.A., Keselman, H.J. (2003). Pairwise Multiple Comparisons: A Model Comparison Approach Versus Stepwise Procedures. *British Journal of Mathematical and Statistical Psychology*, 56, 167-182.

Dehaene S., Piazza M., Pinel P., & Cohen L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology,* 20, 487-506. doi:10.1080/02643290244000239

Di Luca, S., & Pesenti, M. (2011). Finger numeral representations: more than just another symbolic code. *Frontiers in Psychology*, 2:272. doi: 10.3389/fpsyg.2011.00272

Doabler, C. T., Baker, S. K., Kosty, D. B., Smolkowski, K., Clarke, B., Miller, S. J., & Fien, H. (2015). Examining the association between explicit mathematics instruction and student mathematics achievement. *The Elementary School Journal*, *115*(3), 303-333. doi:10.1086/679969

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., & Sexton, H. (2007). School readiness and later achievement. *Developmental psychology*, *43*(6), 1428. doi:10.1037/0012-1649.43.6.1428

Dupont-Boime, J., & Thevenot, C. (2018). High working memory capacity favours the use of finger counting in six-year-old children. Journal of Cognitive Psychology, 30(1), 35–42. doi:10.1080/20445911.2017.1396990

Dyson, N. I., Jordan, N. C., & Glutting, J. (2013). A number sense intervention for low-income kindergartners at risk for mathematics difficulties. *Journal of learning disabilities*, *46*(2), 166-181. doi:10.1177/0022219411410233

Ehri, L. C., Nunes, S. R., Willows, D. M., Schuster, D. M., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly*, *36,* 250-287. doi : 10.1598/rrq.36.3.2

Fayol, M., Barrouillet, P., & Marinthe, C. (1998). Predicting arithmetical achievement from neuro-psychological performance: A longitudinal study. *Cognition*, *68*(2), B63-B70.

doi:10.1016/s0010-0277(98)00046-8

Fayol, M. (2012). *L'acquisition du nombre.* Paris : PUF.

Fayol, M., Grimaud, F., & Jacquier, M. (2013). Une expérience d'enseignement explicite de l'orthographe lexicale. *Approche Neuropsychologique des Apprentissages chez l'Enfant*, *31*, 22-29.

Feigenson, L., Dehaene, S., & Spelke, E. (2004). Core systems of number. Trends in Cognitive Sciences, 8(7), 307–314. doi:10.1016/j.tics.2004.05.002

Fischer, J. P. (2010). Numerical performance increased by finger training: A fallacy due to regression toward the mean?. *Cortex*, *46*(2), 272-273. doi:10.1016/j.cortex.2008.06.010

Fischer, M. H. (2008). Finger counting habits modulate spatial-numerical associations. *cortex*, *44*(4), 386-392. doi:10.1016/j.cortex.2007.08.004

Fischer, M. H., & Shaki, S. (2014). Spatial associations in numerical cognition—From single digits to arithmetic. *The Quarterly Journal of Experimental Psychology*, *67*(8), 1461-1483. doi:10.1080/17470218.2014.927515

Fuson, K. C. (1998). Pedagogical, mathematical, and real-world conceptual-support nets: A model for building children's multidigit domain knowledge. *Mathematical Cognition*, *4*(2), 147-186. doi: 10.1080/135467998387370

Gallistel, C. R., & Gelman, R. (1992). Preverbal and verbal counting and computation. Cognition, 44(1-2), 43–74. doi:10.1016/0010-0277(92)90050-r

Geary, D. C. (2004). Mathematics and Learning Disabilities. Journal of Learning Disabilities, 37(1), 4–15. doi:10.1177/00222194040370010201

Geary, D. C. (2007). An Evolutionary Perspective on Learning Disability in Mathematics. Developmental Neuropsychology, 32(1), 471–519. doi:10.1080/87565640701360924

Geary, D. C. (2013). Early foundations for mathematics learning and their relations to learning disabilities. *Current directions in psychological science*, *22*(1), 23-27. doi:10.1177/0963721412469398

Gertsmann, J. (1940). Syndrome of finger agnosia, disorientation for right and left, agraphia and acalculia. *Archives of Neurology and Psychiatry*, 44, 398-408. doi:10.1001/archneurpsyc.1940.02280080158009

Gracia-Bafalluy, M., & Noël, M.P. (2008). Does finger training increase young children's numerical performance? *Cortex*, 44, 4, p. 368-75. Doi: 10.1016/j.cortex.2007.08.020

Gray, S. A., & Reeve, R. A. (2014). Preschoolers' dot enumeration abilities are markers of their arithmetic competence. *PloS one*, *9*(4), e94428. Doi : 10.1371/journal.pone.0094428

Grégoire, J., Noël, M.-P., & Van Nieuwenhoven, C. (2004). Test for the Diagnosis of Mathematical Competences. PsycTESTS Dataset. doi:10.1037/t23343-000

Hornung, C., Schiltz, C., Brunner, M., & Martin, R. (2014). Predicting first-grade mathematics achievement: the contributions of domain-general cognitive abilities, nonverbal number sense, and early number competence. *Frontiers in Psychology*, *5*, 272. doi:10.3389/fpsyg.2014.00272

Jordan, N. C., Glutting, J., & Ramineni, C. (2010). The importance of number sense to mathematics achievement in first and third grades. *Learning and individual differences*, *20*(2), 82-88. doi:10.1016/j.lindif.2009.07.004

Jordan, N.C., Kaplan, D., Ramineni, C., & Locuniak, M.N. (2008). Development of number combination skill in the early school years: When do fingers help? *Developmental Science, 11*(5), 662-668. doi:10.1111/j.1467-7687.2008.00715.x

Jordan, N.C., & Levine, S.C. (2009). Socioeconomic variation, number competence, and mathematics learning difficulties in young children. *Developmental Disabilities Research Reviews* 15, 60-68. doi:10.1002/ddrr.46

Kinsbourne M., & Warrington, E. (1963). The developmental Gerstmann syndrome. *Archives of neurology,* 8, 490.

Lafay, A., Thevenot, C., Castel, C., & Fayol, M. (2013). The role of fingers in number processing in young children. *Frontiers in psychology*, *4*, 488. doi:10.3389/fpsyg.2013.00488

Libertus, M. E., Odic, D., Feigenson, L., & Halberda, J. (2016). The precision of mapping between number words and the approximate number system predicts children's formal math abilities. Journal of Experimental Child Psychology, 150, 207–226. doi:10.1016/j.jecp.2016.06.003

Long, I., Malone, S. A., Tolan, A., Burgoyne, K., Heron-Delaney, M., Witteveen, K., et al. (2016). The cognitive foundations of early arithmetic skills: it is counting and number judgment, but not finger gnosis, that count. Journal of Experimental Child Psychology, 152, 327–334. doi:10.1016/j.jecp.2016.08.005

Lucidi, A., & Thevenot, C. (2014). Do not count on me to imagine how I act: behavior contradicts questionnaire responses in the assessment of finger counting habits. Behavior Research Methods, 46(4), 1079–1087. doi:10.3758/s13428-014-0447-1

Luo, Z., Jose, P. E., Huntsinger, C. S., & Pigott, T. D. (2007). Fine motor skills and mathematics achievement in East Asian American and European American kindergartners and first graders.British Journal of Developmental Psychology, 25, 595–614. doi:10.1348/026151007X185329

Marinthe, C., Fayol M., & Barrouillet, P. (2001). Gnosies digitales et développement des performances arithmétiques. In A. Van Hout, C. Meljac et JP. Fischer (eds), *Troubles du calcul et dyscalculies chez l'enfant.* Paris : Masson (pp. 239-254).

Moeller, K., Martignon, L., Wessolowski, S., Engel, J., & Nuerk, H.-C. (2011). Effects of Finger Counting on Numerical Development ? The Opposing Views of Neurocognition and Mathematics Education. Frontiers in Psychology, 2. doi:10.3389/fpsyg.2011.00328

Moyer, R. S., & Landauer, T. K. (1967). Time required for Judgements of Numerical Inequality. Nature, 215(5109), 1519–1520. doi:10.1038/2151519a0.

Newman, S. D. (2016). Does finger sense predict addition performance? Cognitive Processing, 17(2), 139–146. doi:10.1007/s10339-016-0756-7

XX (2014).

Penner-Wilger, M. (n.d.). Subitizing, finger gnosis, and finger agility as precursors to the representation of number. doi:10.22215/etd/2009-06553

Piasta, S. B., & Wagner, R. K. (2010). Developing early literacy skills: A meta-analysis of alphabet learning and instruction. *Reading Research Quarterly*, *45*(1), 8-38. doi:10.1598/rrq.45.1.2

Piazza, M. (2011). Neurocognitive start-up tools for symbolic number representations. In *Space, Time and Number in the Brain* (pp. 267-285). doi:10.1016/b978-0-12-385948-8.00017-7

PISA, (2012). Results in focus. *2014-02-17]. http://www, oecd. org/pisa/keyfindings/pisa-2012-results-o-verview, pdf*.

PISA, (2015). Draft Science Framework. *2014-07-17]. http://www. oecd. org/pisa/pisaproducts/Draft PISA 2015 Science Framework. pdf*.

Raftery, A.E. (1995). Bayesian model selection in social research (with Discussion). *Sociological Methodology*, 25, 111-196.

Reed, E. S., & Bril, B. (1996). The primacy of action in development. *Dexterity and its development*, 431-451.

Reeve, R., & Humberstone, J. (2011). Five-to 7-year-olds' finger gnosia and calculation abilities. *Frontiers in Psychology*, *2*, 359. doi:10.3389/fpsyg.2011.00359

Ritchie, S. J., & Bates, T. C. (2013). Enduring links from childhood mathematics and reading achievement to adult socioeconomic status. *Psychological science*, *24*(7), 1301-1308. doi:10.1177/0956797612466268

Rourke, B. (1993). Arithmetic disabilities, specific and otherwise: a neuropsychological perspective. *Journal of learning disabilities*, 26, 214-226. doi:10.1177/002221949302600402

Roux, F.-E., Boetto, S., Sacko, O., Chollet, F., & Trémoulet, M. (2003). Writing, calculating, and finger recognition in the region of the angular gyrus: a cortical stimulation study of Gerstmann syndrome. Journal of Neurosurgery, 99(4), 716–727. doi:10.3171/jns.2003.99.4.0716.

Rusconi, E., Walsh, V., & Butterworth, B. (2005). Dexterity with numbers: rTMS over left angular gyrus disrupts finger gnosis and number processing. Neuropsychologia, 43(11), 1609–1624. doi:10.1016/j.neuropsychologia.2005.01.009

Sato, M. & Lalain, M. (2008). On the relationship between handedness and hand-digit mapping in finger counting. *Cortex, 44,* 393-399. doi:10.1016/j.cortex.2007.08.005

Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics, 6,* 461-464.

Siegler, R. S., & Shrager, J. (1984). Strategies choices in addition and subtraction: How do children know what to do? In C. Sophian (eds), *Origins in cognitive skills* (pp. 229-293). Hillsdale N.J.: Lawrence Erlbaum Associates.

Sensevy, G. (2015). Serait-il pertinent d'identifier certaines ressources pour les enseignants et les élèves? L'exemple d'ACE. Communication présentée à la conférence de consensus sur les nombres et opérations, premiers apprentissages, Lycée Buffon, Paris XV. Consulté à l'adresse: http://www. cnesco. fr/wp-content/uploads/2015/11/26-Gerard-Sensevy. pdf

Soylu, F., & Newman, S. D. (2015). Anatomically ordered tapping interferes more with one-digit addition than two-digit addition: a dual-task fMRI study. Cognitive Processing, 17(1), 67–77. doi:10.1007/s10339-015-0737-2

Suggate, S., Stoeger, H., & Fischer, U. (2017). Finger-Based Numerical Skills Link Fine Motor Skills to Numerical Development in Preschoolers. *Perceptual and motor skills, 124*(6), 1085-1106. doi:10.1177/0031512517727405

Suggate, S., Stoeger, H., & Pufke, E. (2016). Relations between playing activities and fine motor development. Early Child Development and Care, 187(8), 1297–1310. doi:10.1080/03004430.2016.1167047

Thevenot, C., Castel, C., Danjon, J., Renaud, O., Ballaz, C., Baggioni, L., et al. (2014). Numerical abilities in children with congenital hemiplegia: an investigation of the role of finger use in number processing. Developmental Neuropsychology, 39, 88–100. doi:10.1080/87565641.2013.860979

Wasner, M., Nuerk, H. C., Martignon, L., Roesch, S., & Moeller, K. (2016). Finger gnosis predicts a unique but small part of variance in initial arithmetic performance. *Journal of experimental child psychology*, *146*, 1-16. doi:10.1016/j.jecp.2016.01.006

Wilson, M. (2002). Six views of embodied cognition. Psychonomic Bulletin & Review, 9(4), 625–636. doi:10.3758/bf03196322

Table 1

Scores (means and standard deviations) and finger use (frequencies) in pre and post tests

		Pre-test		Post-test	
Teaching condition	Counts	Arithmetic scores	Finger Use	Arithmetic scores	Finger Use
Finger training group	*N=20*	4.1500 (2.56)	0.300	8.6500 (1.93)	0.85
Traditional instruction group	*N=16*	4.3125 (2.89)	0.375	5.3125 (2.87)	0.25

Table 2

Model comparisons for the finger use variable

Model	Df	*AIC*	*BIC*	Log-likelihood	Deviance	Chi-square	Df.	*p*
M0	3	373.39	380.22	-183.70	367.39			
M1	4	332.27	341.38	-162.14	324.27	43.1171	1	0.0000
M2	5	330.65	342.04	-160.33	320.65	3.6220	1	0.0570
M3	6	332.61	346.27	-160.31	320.61	0.0381	1	0.8453

Table 3

Model comparisons for the arithmetic score variable

Model	Df	*AIC*	*BIC*	Log-likelihood	Deviance	Chi-square	Df.	*p*
M0	2	103.268	107.822	-49.634	99.268			
M1	3	86.110	92.940	-40.055	80.110	19.1582	1	0.0000
M2	4	87.601	96.708	-39.801	79.601	0.5090	1	0.4756
M3	5	89.370	100.753	-39.685	79.370	0.2313	1	0.6306

Figure 1

Evolution of finger use and arithmetic performance