An intervention programme using fingers and games in primary classrooms to improve mathematical achievement

Julie Betenson

University of Bristol

In recent years studies have demonstrated the positive association between mathematics achievement and finger-based numerical representations of number where training in finger gnosis has led to gains in mathematical skills. An association between mathematics achievement and numerical magnitude processing has also been established and playing mathematical games has proved beneficial. The aim of the current study was to evaluate the effectiveness of an intervention combining finger gnosis training with games to see if it is more effective than either part alone. 133 children aged 6 - 7 years from five classes took part in the pre-test, intervention, post-test study. The classes were randomly assigned to different conditions: finger gnosis only, games only, full intervention and no intervention control. Results demonstrated that the pupils in the two full intervention groups made significantly more increases in mathematics achievement tests than those in the other groups. This suggests that the combined intervention using the visual representation of fingers and dot patterns acting as mediators could help children of this age to make connections between symbolic and non-symbolic representations of number and raise mathematical achievements.

Keywords: finger gnosis; mathematical games; symbolic and non-symbolic representations of number; mathematical achievement

Introduction

In order for children to manipulate numbers successfully, they first need to develop a precise representation of numerical magnitude. It has been demonstrated that a child's ability to successfully compare both symbolic and non-symbolic magnitudes is related to their mathematics achievement (Geary, 2011). However the role they play in developing a precise representation for number is still unclear and may differ according to the age of the learner. Bonny & Lourenco (2013) suggest that the relationship between non-symbolic magnitude comparison and mathematics achievement is only present in early mathematics development. However, Dehaene, Piazza, Pinel & Cohen (2003) argue that the non-symbolic representation of magnitude is still active in adults during mathematical tasks.

Other arguments centre on the importance of each representation for mathematical development. Fazio, Bailey, Thompson & Siegler (2014) believe that symbolic magnitude knowledge is related to mathematical achievement to a greater extent than non-symbolic. They conclude therefore that interventions which target symbolic magnitude understanding would be more effective than those targeting non-symbolic representations of number. However Holloway & Ansari (2009) suggested that children who were less able to discriminate between relative non-symbolic magnitudes would have more difficulty in accessing an exact representation of a symbolic magnitude whilst processing a numerical calculation. This suggests that

time taken to help students discriminate non-symbolic number magnitudes more effectively may contribute to mathematics achievements. Mundy & Gilmore (2009) put forward the suggestion that successful mathematics development is dependent on pupils being able to map the symbolic representation of a number onto its pre-existing non-symbolic depiction, indicating that an intervention combining non-symbolic and symbolic representations of mathematics may help to make those connections.

It has been proposed that representing numerosities with fingers allows children to internalise number meaning through motor-sensory channels. Di Luca & Pesenti (2011) propose that the visual representation of the fingers preserve the cardinal aspect of number and using the sequence of fingers whilst counting helps understanding of the ordinality of number. They put forward the idea that the fingers allow a student to physically experience mathematical principles which may contribute to a faster, deeper understanding of number concepts. In terms of interventions evidence has been put forward that training in finger gnosis can lead to improvements in subitising, counting raised fingers and ordinality judgement (Gracia-Bafalluy & Noel, 2008).

Equally with regard to using mathematical games, Ramani & Siegler (2008) demonstrated that playing number board games correlated positively with a child's numerical knowledge. A recent study (Skwarchuk, Sowinski, & LeFevre, 2014) indicated that the amount of counting and practicing of sums at pre-school level predicted the child's symbolic knowledge, whereas the mathematical games played predicted their non-symbolic arithmetic ability.

I am unaware of any studies which have compared the effects of combining finger gnosis training with mathematical games-based interventions to see if these can act as mediators between the non-symbolic and symbolic representations of number and help students to develop their own unique understanding more successfully to produce accelerated learning.

The current study

The goal of the present research was to design, implement and evaluate an intervention programme. The hypothesis was that by using fingers as canonical representations for counting whilst performing activities based on estimation and the count sequence, including games, the children would be able to make or strengthen connections between their symbolic and non-symbolic representations of number.

The study was based in three primary schools and involved the testing of 133 pupils in Year 2 (age 6-7 years). The five classes were allocated different elements of the intervention programme. A control group with no intervention was set up to analyse any increases in scores due to the natural maturing process over the time of the intervention or familiarity with the tests. Two further groups were allocated as 'finger gnosis only' or 'games only' in order to analyse any differences between these parts of the intervention. The final two classes were allocated the full intervention which included both parts, one introduced by a teacher and one by the researcher to be able to analyse for any possible teacher effects.

Testing

All pupils completed the group-administered tests of numeration, calculation, and magnitude comparison tests. These were delivered in their usual classroom with their teacher present. The finger gnosis testing was administered individually in a quiet

space outside the children's classroom. All tests were performed before and repeated after the intervention sessions had been completed.

Number system knowledge was tested using an achievement test for counting based on Gelman and Gallistel's (1978) five implicit principles of counting. The tests used both symbolic and non-symbolic format and were arranged on five different pages with one minute allowed for completion of each page. Addition and subtraction skills were assessed using the One Minute Basic Number Facts Tests (Westwood, 2000). These tests consist of 33 items each and the pupils were given one minute per sheet to complete as many addition and then subtraction problems as possible. The test used a purely symbolic format. It was expected that the results of these tests would correlate with the numeration tests and would be combined to give an overall mathematics achievement score for ease of analysis.

The finger gnosis test was managed using the task largely as described by Gracia-Bafalluy & Noel (2008). Each pupil was asked to put their hand flat on the table inside a box so that the fingers were not visible to the pupil and the instructor then pressed the pupil's fingers in a random order whilst the pupil said the number corresponding to the finger or consecutive fingers which had been touched. A correct answer was scored as 1 and therefore a maximum total of 30 could be achieved.

One-minute paper and pencil tests of magnitude comparison were devised using a similar format to Nosworthy, Bugden, Archibald, Evans & Ansari (2013). Pupils were given one minute to compare firstly twenty pairs of dot arrays in order to tick the larger amount in each pair and secondly to compare dot arrays with Arabic digits. The tests were designed as simple accuracy measures giving a maximum total of 20 marks each.

The intervention programme

The half-hourly intervention sessions took place twice a week for a period of four weeks and consisted of two different elements. The first based on finger gnosis activities was designed to reinforce the connections between the verbal count sequence and the canonical representation of that number on the fingers. Various activities were undertaken to strengthen the understanding of both cardinal and ordinal properties of number using fingers to represent those numbers. The second element involved the use of dice, dominoes and playing cards in different games. These were designed to improve the connections between the number name and the regular dot pattern associated with it as well as encouraging the composition and decomposition of numbers. The control group received no intervention; the fingers only group received half-hour sessions on finger training only, the games only group received half an hour of games only and the full intervention groups took part in half an hour shared between the two elements of the intervention.

Results

A factor analysis was conducted on the numeration and calculation tests results which indicated that all factors correlated significantly between $r\ (133) = 0.56 – 0.78$, $p < 0.01$ and therefore combining them as a single measure of mathematical achievement was appropriate. This combined score (max. 106) was then tested for correlation with the finger gnosis and magnitude comparison tests. The results showed significant

correlation ($p < 0.01$) between the combined mathematics achievement score, the finger gnosis test and both magnitude comparison tests.

The pre- and post-intervention scores for maths achievement, magnitude comparisons and finger gnosis were then tested to see if there were significant differences between the five groups of students in the study. The results demonstrated in Figure 1 show significant differences between the groups on the pre-intervention scores for mathematics achievement, for non-symbolic magnitude comparison and for the non-symbolic/symbolic magnitude comparison test ($p < 0.01$). The finger gnosis score was not significantly different between the groups.

Pre intervention	Class 1 Teacher both	Class 2 Control	Class 3 Finger gnosis	Class 4 Games	Class 5 Researcher both
Maths Achievement Score	50.61 (24.3)	52.61 (17.1)	59.81 (19.3)	71.21 (18.2)	58.29 (23.5)
Non-symbolic magnitude	8.39 (4.02)	10.96 (5.35)	13.11 (4.93)	14.29 (3.6)	12.30 (4.9)
Symbolic/Non-symbolic	11.61 (4.0)	9.70 (4.1)	15.81 (3.2)	11.54 (3.0)	12.44 (3.7)
Finger gnosis	20.86 (4.2)	20.91 (3.4)	20.41 (4.3)	22.43 (4.2)	21.89 (4.3)
Post intervention					
Maths Achievement Score	67.96 (27.8)	60.65 (23.0)	68.29 (24.9)	80.64 (16.5)	82.51 (24.2)
Non-symbolic magnitude	13.11 (5.5)	12.48 (5.3)	14.22 (4.6)	15.50 (3.9)	15.63 (4.4)
Symbolic/Non-symbolic	13.57 (4.1)	11.74 (4.3)	14.44 (3.4)	16.96 (2.8)	16.81 (3.2)
Finger gnosis	22.00 (5.2)	20.43 (4.3)	22.63 (4.4)	23.11 (3.7)	24.26 (2.8)

Figure 1: Means and standard deviations (in brackets) for pre-and post-intervention results

In order to control for the pre-intervention differences, the post intervention outcomes were analysed by means of one way between groups analysis of covariance (ANCOVA) with class as the between subjects factor and pre-intervention scores the co-variants. The ANCOVA performed on the maths achievement scores revealed a significant group effect, $F(4, 127) = 15.155$, $p < 0.01$.

		Mean Difference	Sig.
Teacher-led: fingers & games	Control	9.392	.006
	Teacher-led: fingers only	9.237	.005
	Teacher-led: games only	8.737	.013
Teacher-led: games only	Control	.655	1.000
	Teacher-led: fingers only	.500	1.000
Researcher-led: fingers and games	Teacher-led: fingers & games	6.563	.119
	Control	15.956	.000
	Teacher-led: fingers only	15.800	.000
	Teacher-led: games only	15.300	.000

Figure 2: Pairwise comparisons for post-intervention mathematical achievement scores

Pairwise comparisons with Bonferroni adjustment for multiple assessments indicated significantly better performance for the two full intervention groups than the single intervention or control groups (Figure 2). The teacher-led and the researcher-led full intervention groups performed significantly better than the control, the fingers only and games only groups. There was no significant difference between the teacher-led and researcher-led full intervention groups. There was also no significant difference between the control group and either the finger only or games only groups.

The ANCOVA for the non-symbolic magnitude comparison test indicates greater gains for all groups in comparison to the control group particularly for the full intervention groups, but the result was not significant, $F(4, 127) = 2.040$, $p = 0.093$.

The ANCOVA for the symbolic to non-symbolic magnitude comparison was significant, $F(4, 127) = 15.547$, $p < 0.01$. Pairwise comparisons indicated significantly better performance for the games and researcher led full intervention groups than the teacher led full intervention, the finger or control groups.

The ANCOVA for the finger gnosis test was significant, $F(4, 127) = 3.026$, $p = 0.02$, with pairwise comparisons revealing a significant difference between the researcher-led full intervention group and the control, mean difference = 3.264, $p = 0.012$.

Conclusions

In this study an intervention programme which had been designed to help students develop connections between the symbolic and non-symbolic representations for number was evaluated. The hypothesis was that the full intervention would help students make better connections between the symbolic and non-symbolic representations of number leading to greater gains in mathematical achievements.

As expected the results demonstrated a link between the mathematical achievement, the non-symbolic magnitude comparison and the finger gnosis ability for the children prior to any intervention. This adds to the body of evidence which suggests that the symbolic and non-symbolic abilities of children are correlated and that finger gnosis is also linked to these mathematical abilities. The main finding when testing the overall differences in maths achievement was that the full intervention groups made significantly greater increases than either of the interventions performed individually or than the control group. This could suggest that the full intervention may enable pupils to make more connections between the symbolic and non-symbolic representations of number. The use of fingers and games may well act as the mediators for a faster deeper understanding of number.

The non-symbolic comparison test results displayed greater gains for the two full intervention groups and for the games only group. This could be expected and reinforces the view of Skwarchuk et al., (2014) that playing board games is related to non-symbolic maths ability. However these results were not significant and further studies would need to be undertaken to see if greater differences could be seen over a longer period of intervention. Testing on the finger gnosis scores showed greater gains for the researcher-led full intervention group and the finger gnosis only group than the control but with only a significant difference for the researcher-led group. The gains made by the games only group were very similar to the teacher-led full intervention which is surprising as the games only group received no finger training. Within the non-symbolic to symbolic comparison test, only increases for the researcher-led full intervention group and the games group were at a significant level. It could be argued that the games part of the intervention had facilitated greater gains between the symbolic and non-symbolic representations of number.

There are differences between the two full intervention groups and further analysis of the way in which the intervention was used by the teacher and the researcher would be necessary to look for other factors that might have influenced the differing results. It could be due to the familiarity with the programme of its designer in comparison to a teacher trained to use it or possibly the language used in delivery.

In summary, this study showed that a four-week intervention programme which combined finger gnosis training with playing mathematical games led to significant improvements in mathematical achievements, symbolic to non-symbolic magnitude comparison and finger gnosis for 6 - 7 year-old pupils. The results from this study are encouraging and a longitudinal follow up would be valuable to see if the gains made are maintained.

References

Bonny, J. W., & Lourenco, S. F. (2013).The approximate number system and its relation to early math achievement: Evidence from the preschool years. *Journal of Experimental Child Psychology, 114*, 375–388.

Dehaene, S., Piazza, M., Pinel, P. & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology* 20 (3/4/5/6), 487-586.

Di Luca, S., & Pesenti, M. (2011).Finger numeral representations: More than just another symbolic code. *Frontiers in Psychology, 2: 272*.

Fazio, L. K., Bailey, D. H., Thompson, C. A., & Siegler, R. S. (2014). Relations of different types of numerical magnitude representations to each other and to mathematics achievement. *Journal of Experimental Child Psychology, 123,* 53–72.

Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: A 5-year longitudinal study. *Developmental Psychology, 47,* 1539–1552.

Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number.* Cambridge, MA; Harvard University Press.

Gracia-Bafalluy, M., Noel, M. P. (2008). Does finger training increase young children's numerical performance? *Cortex* 44, 368-375.

Holloway, I. D., & Ansari. D. (2009). Mapping numerical magnitudes onto symbols: The numerical distance effect and individual differences in children's mathematics achievement. *Journal of Experimental Child Psychology, 103,* 17–29.

Mundy, E., & Gilmore, C. K. (2009) Children's mapping between symbolic and non-symbolic representations of number. *Journal of Experimental Child Psychology, 103,* 490-502.

Nosworthy, N., Bugden, S., Archibald, L., Evans, B., & Ansari, D. (2013). A two-minute paper-and-pencil test of symbolic and non-symbolic numerical magnitude processing explains variability in primary school children's arithmetic competence. *PlosOne, 8, 7,* p. e67918.

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development, Vol. 79, 2,* 375-394.

Skwarchuk, S. L., Sowinski, C., & LeFevre, J. A. (2014). Formal and informal home learning activities in relation to children's early numeracy and literacy skills: The development of a home numeracy model. *Journal of Experimental Child Psychology, 121,* 63–84.

Westwood, P. (2000). *Numeracy and learning difficulties: Approaches to teaching and assessment.* Victoria: Australian Council for Educational Research.