THE ROLE OF FINGER GNOSIS IN THE DEVELOPMENT OF EARLY NUMBER SKILLS

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The role of fingers in the development of early number skills has often been the focus of discussion in mathematics education, psychology and neuroscience. This study describes the findings of a longitudinal exploration of the mathematical development of children with Apert syndrome. Children with Apert syndrome are born with their fingers fused and even after surgery to separate them, do not often use their fingers spontaneously in activities involving number. Through observations over a 2 year period, the role of fingers in supporting learning and activities in numerical aspects of mathematics was seen to be complex and requiring good finger awareness and finger mobility. The findings suggest a possible explanation for the observation that some children who are low-attaining in mathematics are over-dependent on finger-use.

WHAT CAN CHILDREN WITH APERT SYNDROME TELL US ABOUT THE ROLE OF FINGERS IN THE DEVELOPMENT OF EARLY NUMBER SKILLS

The work discussed here describes the findings of a longitudinal 2-year study on the mathematical development of 10 children with Apert syndrome, between the ages of 4 and 9 years at the beginning of the study (Hilton, 2017). Apert syndrome is a rare syndrome which was first described by Wheaton in 1894, and investigated further by Apert in 1906 (Patton, Goodship, Hayward and Lansdown, 1988). There is an estimated a birth prevalence of Apert syndrome of approximately 1 in 65000, in North America and Europe (Cohen et al., 1992; Tolorova, Harris, Ordway and Vargervik, 1997). Children with Apert syndrome are born with complex fusions of their fingers and although they usually have surgery to release their fingers, they do not always gain five fingers (digits including thumbs) on both hands. In addition, children with Apert syndrome usually have limited mobility in their fingers, as the interphalangeal joints do not work properly. Although there is only limited literature on the mathematical development of children with Apert syndrome, the literature that does exist suggests that for these children, numerical activities are a particularly area of difficulty (Sarimski, 1997; Fearon and Podner, 2013). The present study shines a new light on the mathematical development of children with Apert syndrome and especially on the role of fingers in the development of early number concepts and early arithmetic. It also highlights the complex nature of the relationship between the use of fingers and problem solving in numerical calculations.

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The original research explored the strategies children with Apert syndrome use to help them solve numerical problems in mathematics and whether the children's hand anomalies impacted the range of strategies available to them.

THE THEORETICAL FRAMEWORK

The theoretical framework for the process of data collection was informed by constructivist grounded theory (Charmaz and Bryant, 2011) as it allowed for the possibility of unexpected and unanticipated findings. For the process of data analysis, the methods used were drawn from discursive analysis and thematic analysis. In order to collect data, a case study approach was adopted.

LITERATURE REVIEW

There have been a number of studies that have explored the link between finger gnosis and skills in arithmetic. It has been shown that touching objects when counting helps pre-school 4 year old children to count correctly (Alibali and DiRusso, 1999). This can help children to understand one-to-one correspondence and can relieve the pressure on working memory. Fingers can also help when trying to keep track of items and during calculations. With practice, children learn to map particular patterns on to particular numbers (Morrissey, Liu, Kang, Hallett and Wang, 2016). In other words, through repetition and practice, fingers can provide a sensorimotor embodied mapping of number patterns and their associated numerical relationships (Rinaldi, Di Luca, Henik and Girelli, 2016).

For these mappings to be effective requires an awareness of one's own fingers, or "finger sense", otherwise known as finger gnosis (Gerstmann, 1940) and finger mobility (Berteletti and Booth, 2015). Without this finger sense, it may be hard to identify one's own fingers in response to touch and request; make individual finger movements; and mirror the finger actions of others (Gerstmann, 1940).

In typically-developing children, finger gnosis develops quickly up to the age of 6 years and then continues to develop more slowly up to the age of 12 years (Strauss, Sherman and Spreen, 2006). Berteletti and Booth (2015) argue that the embodied actions of moving fingers as well as finger gnosis are significant in determining the role of fingers in early arithmetic. In addition, fingers are useful to keep track of items in a count (Andres, Seron and Olivier, 2007) or compare numbers presented symbolically (Sato, Cattaneo, Rizzolatti and Gallese, 2007). This evidence supports the findings from observational studies such as those by Hughes (1986) and Jordan, Huttenlocher and Levine (1992). However, this should be viewed within the context of finger-use in arithmetic being a learned, and not a spontaneous, activity (Crollen, Seron and Noel, 2011).

While there are cultural differences in the ways that children learn and are taught to use their fingers (Di Luca and Pesenti, 2011), it has also been suggested that "personal finger-counting habits influence the way numerical information is mentally represented and processed" (Berteletti and Booth, 2015, p.111) and stored in long-term memory (Di Luca and Pesenti, 2008). It seems likely that if fingers are used as a tool to support numerical calculations, the most significant factor is *whether* children learn to use their fingers rather than *how* they use them.

Jordan, Kaplan, Ramineni and Locuniak (2008) found that in kindergarten, children who used their fingers in calculations provided more accurate answers to questions. However, by the end of Year 3, those children who tended to be more accurate, used their fingers less frequently than those who made more calculation errors. As in the earlier study, Jordan et al. (2008) found that children from low-income families started kindergarten with less confident finger-use than their middle-income peers. Consequently, as the children from middle-income families were beginning to use their fingers less, children from low-income fingers continued to depend on their fingers for performing calculations. This suggests that it takes a considerable amount of time (in the region of 2 to 3 years) for children to transition from relying on fingers to help with arithmetic calculations to confidently using known facts and other strategies to support work with numbers.

Kaufmann et al. (2008), in a study involving 8 year old children and adults, used brain imaging techniques to explore the areas of the brain that are recruited when performing simple tasks involving number. In tasks involving non-symbolic representations of number, they found that although the children and the adults were able to complete the tasks successfully, children took longer. To explain this, the authors suggest that when making numerical comparisons using images of hands showing differing numbers of fingers, the children (but not the adults) recruited additional areas of the brain normally used for fingers. The authors suggest that fingers are an important stepping stone in the development of an abstract understanding of number.

Finger gnosis and fine motor skills have also been implicated in supporting the development of arithmetic and mathematical skills (Noel, 2005; Gracia-Bafalluy and Noel, 2008). Noel (2005) carried out assessments of finger gnosis with 41 children in Grade 1 and compared this with an assessment of their skills in mathematics one year later. A correlation was found between the children's level of finger gnosis in Grade 1 and their achievements in tasks involving number identification and simple arithmetic one year later. In fact, the relationship between finger gnosis and their achievement in mathematics was stronger than the relationship between tests of general cognitive ability and achievement in mathematics between Grades 1 and 2. This was followed up with an intervention study in which children were provided with a finger-differentiation intervention, twice a week for a period of 8 weeks. The children's finger gnosis and their numerical skills both improved, when compared to a control group (Gracia-Bafalluy and Noel, 2008).

Subitising, counting and the approximate number system

When children learn to make sense of numbers, there are many aspects of number that they need to come to understand. Subitising refers to the ability to enumerate small groups of objects without counting (Fuson, 1988). By the age of 3 years, children can usually subitise up to three objects. For adults, the maximum number is usually four (Hughes, 1986). Beyond subitising, it has been argued that there is a distinction between the ability to count and the ability to compare quantities (Dehaene, 2011).

Learning to count is no trivial task (Fuson, 1988) and all the principles of arithmetic that children learn at school are underpinned by an understanding of counting. The ability to count, though, is a human creation while the ability to compare quantities is a matter of survival (Dehaene, 2011). When we compare quantities we use our approximate number system (ANS) - a nonverbal mechanism for estimating the number of items in a set (Dehaene, 2011). This capacity is one that we also share with animals and must be distinguished from any symbolic or verbal representational system requiring accuracy. It has been suggested that there is a relationship between children's ANS and their attainment in mathematics (Halberda, Mazzocco and Feigenson, 2008) and that children who struggle with mathematics are more likely to have a poor ANS (Mazzocco, Feigenson, and Halberda, 2011).

RESEARCH METHODS

Semi-structured interviews and clinical interviews (Ginsburg, 1981) were used together with in-class observations of the children. The semi-structured interviews were designed to assess number knowledge, arithmetic skills and mathematical understanding.

Six or seven school visits were made to each of the children over the 2 year period of the study. When interviewing the children, the clinical interview approach made it possible to gain more in-depth understanding of the children's thinking. The interviews were audio recorded and later transcribed.

For the purpose of reliability, the mathematics-focused questions were based on existing assessments that had been reported in the literature. Due to the age range and developmental range within the children studied, a range of assessments was used. The assessments selected focused on number system knowledge, skills in arithmetic and strategies used for solving problems.

The children's Approximate Number System (ANS) was explored using "Panamath" (Halberda, Mazzocco and Feigenson, 2008), in order to establish whether there was a relationship between children's skills in this area and their knowledge and understanding in work on number and arithmetic.

The children's working memory was assessed, as this has been implicated as a potential reason for children's low attainment in mathematics (Raghubar, Barnes and Hecht, 2010). This was done with the "Working Memory Test Battery for Children (WMTB-C)" (Gathercole and Pickering, 2001)

Finally, the children's finger gnosis was assessed, as this was likely to be delayed in children with Apert syndrome and has been associated with knowledge and skills in number and arithmetic. For this an assessment of finger gnosis based on Gracia-Bafalluy and Noël (2008) was used.

FINDINGS

In the study group there was no relationship between ANS and attainment in mathematics. One of the lowest attaining children had the highest ANS scores. The children displayed a range of strengths and weaknesses in their working memory assessments, but an area of strength for all the children was the area of visuospatial skills. In terms of the mathematics assessments, there was enormous variation, but the focus for the purpose of this discussion will be on the use of fingers to support calculation.

Only one of the 10 children began to use his fingers without prompting and even he started very late (at 9 years of age). Initially school staff said that they did not encourage children to use their fingers because the children found it hard to move their fingers. The consequence of this was that when calculations took them beyond their working memory capacities, they were often unable to complete the activities. Joe, aged 7 years (who had four fingers on his left hand and five fingers on his right hand and good working memory skills) provides a good example of this:

> Caroline: Right, which number is closer to seven, is it four or nine? [using visual array]
>
> [9 second pause and then Joe points to the 9]
>
> Caroline: Nine is closer. Why?
>
> Joe: Because...ummm…nine minus two is seven
>
> Caroline: Yep and what about the four?
>
> Joe: Four…plus three
>
> Caroline: So is that why nine is closer? [Joe nods]

Having seen this confidence the next example was a surprise:

> Caroline: OK, how much is two plus four? [Joe is still for 5 secs] you can use your fingers, or I can give you some counters. How much is two plus four? [pause]
>
> Caroline: Do you know what it would look like? Should I write it down for you?
>
> Joe: Yeah [I write 2+4 on a piece of paper]
>
> Caroline: Do you know how to do it?
>
> Joe: No

Joe had a good working memory in most areas and he seemed to rely on this very heavily when doing numerical calculations. However when his working memory failed, he had no strategy to fall back on. He did eventually do this particular calculation with counters, but he needed prompting in order to see that this was a possible means of solving the problem.

Compare this with Emily, also aged 7 years (who had five fingers on her left hand and four fingers on her right hand) who had been doing finger gnosis training for at least 4 months and had then continued to use her fingers for mathematical calculations:

Caroline: Can you work out thirteen add 39? You can write it down if it helps…thirteen add thirty nine [spoken slowly as Emily writes 13+39] [pause]

Caroline: Do you know what it will be?

Emily: No I don't know what the answer is because…the trouble is the twelve….and I've got to add another ten on

Caroline: Yeah so what do you think this might be? [as I point to the calculation that Emily has written down] [pause] What's the strategy you could use to work it out?

Emily: Umm...nine and three...nine, ten, eleven, twelve [using fingers]. Now…fifty add two is fifty two [writes = 52]

For Emily fingers were a tool that she could use effectively to support with her calculation and to enable her to offload some of the work away from her working memory. This flexible use of fingers, as one tool among many, enabled Emily to complete the calculation quickly and efficiently.

CONCLUSIONS

Fingers seem to have a particular role to play in the development of children's early number skills. This study provides a new perspective because of the opportunity it provided to observe the implications on children's mathematical development when fingers were not used as a means of accessing and supporting numerical activities. When they were used, fingers provided a more reliable model than tools such as counters.

As the children in the study began to "know" their fingers, they could use them as tools to access the mathematical problems they sought to solve. This method was more reliable and easier than asking children to count out a given number of counters, especially as once children "know" their fingers, they do not need to count and so do not make the errors that often occur when counters, or similar tools, are used to help with solving numerical problems.

This study highlights in great detail, the special role that fingers can play in supporting children with arithmetic calculations. It identifies the need for practice in using fingers and specifically in developing finger gnosis at an early age in order to support sensorimotor development and to optimise the opportunities for children to develop mathematical confidence and competence.

The present study also suggests that if finger gnosis is not well-developed, children can experience a mismatch between their visual finger representations and the sensorimotor experience. If children's finger gnosis is poorly developed, it seem likely that their fine motor skills will also be affected, as they will find it hard to identify individual fingers. This is an area that deserves further exploration as a potential explanation for the observation that some children fail to use their fingers to help with mathematics, while others become over-dependent on the visual representation without a genuine "feel" for the numbers that their fingers represent.

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