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How a Brain Says: Fingermath for Empowering Children's Creativity

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Abstract

Children typically learn basic numerical and arithmetic principles using finger-based representations. However, whether or not reliance on finger-based representations is beneficial or detrimental is the subject of an ongoing debate between researchers in neurocognition and mathematics education. From the neurocognitive perspective, finger counting provides multisensory input, which conveys both cardinal and ordinal aspects of numbers. Recent data indicate that children with good finger-based numerical representations show better arithmetic skills and that training finger gnosis, or "finger sense," enhances mathematical skills. Therefore neurocognitive researchers conclude that elaborate finger-based numerical representations are beneficial for later numerical development. However, research in mathematics education recommends fostering mentally based numerical representations so as to induce children to abandon finger counting. More precisely, mathematics education recommends first using finger counting, then concrete structured representations and, finally, mental representations of numbers to perform numerical operations. Taken together, these results reveal an important debate between neurocognitive and mathematics education research concerning the benefits and detriments of finger-based strategies for numerical development. In the present review, the rationale of both lines of evidence will be discussed.

Keywords*: Fingermath, neurocognitive, mathematics education*

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Introduction

In the early 1900s, Italian educator, Maria Montessori, who developed an educational method that builds on the way children naturally learn got young children to trace over letters of the alphabet made from sandpaper with their index fingers. This technique was based on the intuition that a multi-sensory approach (i.e., visual, auditory, tactile, and kinaesthetic) would benefit young children. Subsequent studies over the past 40 years have confirmed Montessori's intuitions for topics relevant to early childhood education, including letter recognition (Bara et al., 2004) and geometrical shape recognition (Kalenine et al., 2011).

Finger counting is an introductory skill, in order for children to have a visual understanding of number facts, not the final method to be used for calculations. According to mathematical development research, children generally move from the less-efficient strategies using their fingers, to the more efficient strategies without finger use (Geary,et al., 2007). Many things in life will need to be memorised in the future by your child, finger counting closes their mind to this essential skill. According to mental maths research, "When Chinese children could not retrieve an addition fact directly from memory, they tended to count verbally, whereas the American children tended to count on their fingers or guess." The Chinese children scored better in addition facts tests. Further adult numeracy research "noted that those who consistently relied on finger-counting were unable to increase their speed and/or were unable to complete of the problems within the time constraints. Fast recall of of arithmetic facts are essential for questions from. There are 8 eggs in a basket and 3 are taken out. How many are left?" through to "Solve 7x + 3 = 52" and beyond (Domahs, et al., 2008).

For most adults, adding small numbers requires little effort, but for some children, it can take all ten fingers and a lot of time. Research published online on 17 August in Nature Neuroscience suggests that changes in the hippocampus (a brain area associated with memory formation) could help to explain how children eventually pick up efficient strategies for mathematics, and why some children learn more quickly than others (Penner et al., 2007). Vinod Menon, a developmental cognitive neuroscientist at Stanford University in California, and his colleagues presented single-digit addition problems to 28 children aged 7–9, as well as to 20 adolescents aged 14–17 and 20 young adults. Consistent with previous psychology studies, the children relied heavily on counting out the sums, whereas adolescents and adults tended to draw on memorized information to calculate the answers (Klein et al., 2011).

The Method of Research

In our research, we had two preliminary stages in analyzing children's choices of counting in math.. This enabled us to focus on the collection of mathematically skill for children for further analysis and characterization according to other categories that emerged as we repeatedly looked into the data, in the spirit of the grounded theory approach (Strauss and Corbin 1998). We report on these categories in the findings section. One of the insights we gained as we examined the data relates to the unit of analysis. It turned out that it made a lot of sense to analyze the underlying considerations that led to a particular strategy of counting, rather than to try to characterize an strategy itself. These considerations reflected not only the mathematics, but also the brain's process that was employed.

In order to provide a stronger and unbiased picture of the data, and to better understand the phenomena that were examined, we used some simple statistics following Miles and Huberman (1987) and Wiersma (2000). There is no claim about generalizing beyond the scope of the study. However, given the limited number of studies that examined children's use of finger for counting in their any situation, this analysis may help form some hypotheses for future research.

For internal consistency we followed Wiersma (2000), who claims that "If two or more researchers independently analyze the same data and arrive at similar conclusions, this is strong evidence for internal consistency" (p. 211). Thus, for each stage that required some sort of coding according to a classification system that we applied, we had two researchers code independently at least 15% of the relevant data. In all cases we got at least 90% agreement, with no discussions between these researchers.

Result and Discussion

The index finger plays a vital role in early learning. The specific gesture of pointing with the index finger is common across all cultures as a means of guiding attention. As young as nine months of age, babies learn to manage their conversations with caregivers by pointing to things in the environment. When the caregiver names the object, this helps build the child's vocabulary. Hand movements (including tracing and pointing gestures) may also help us form and organize spatial images in our conscious mind.

We have evolved to pay close attention to things that our eyes can easily see. This means that objects near our hands are more quickly recognised and receive prolonged scrutiny. So, when using an index finger to physically touch while tracing visual stimuli, the stimuli receive processing priority. Gestures, including tracing, may play an important role in helping learners combine or “chunk” different sources of information (eg, text and diagrams) into an integrated, coherent understanding of a problem (Ping & Goldin-Meadow, 2010). Chunking acts to reduce the load on working memory, and can support more effective learning (Sweller, 1994).

The researcher saw this developmental change begin to unfold when they tested the same children at two time points, about one year apart. As the children aged, they began to move away from counting on fingers towards memory-based strategies, as measured by their own accounts and by decreased lip and finger movements during the task. Using functional magnetic resonance imaging (fMRI) to scan the children's brains, the team observed increased activation of the hippocampus between the first and second time point. Neural activation decreased in parts of the prefrontal and parietal cortices known to be involved in counting, suggesting that the same calculations had begun to engage different neural circuits.

Few previous fMRI studies have followed children at multiple time points in part because many youngsters have trouble staying still for the duration of a brain scan (Kaufmann et.al., 2008). Despite measuring an initial increase in hippocampal activation in children, Menon's team found that the strength of neural signalling was not itself the key to mathematical aptitude. In fact, addition problems appeared to engage the hippocampus less in adolescents and adults than in children. Instead, coordination of signals in the hippocampus with activity in the rest of the brain seemed most important, particularly with activity in the neocortex, which is involved in long-term memory storage. Children with stronger connections between the hippocampus and neocortex were more likely than others to answer problems with memorized maths facts.

Here are some ways to tap into children’s creativity:

Encourage Children to Question and Observe

“Asking mathematical questions is a form of creativity (Hill, 2009). Kids love to figure out how things work, so when teachers present a new concept, they should also build in time for children to make observations and ask questions. James uses prompts such as, “What do you notice about this [shape, number, story, or design]?” or “How else could we use [addition, graphing, or sorting] in the classroom?” to help children build these habits.

Pose Open-Ended Questions

Teachers can make a habit of posing inventive questions, said Hill — even something as simple as “How can we figure out whether to buy chocolate or vanilla ice cream for the class party?” The trick is letting kids decide for themselves how to figure out a solution. The teacher’s job, said Hill, is to make sure children have the tools they need to solve the problem and to ask clarifying questions during the problem-solving process. James said that when she poses questions that require “struggle and creative thinking instead of rote application of rules,” children are not only more engaged, she is also better able to assess their understanding of key concepts by observing in real time how they apply their math skills

Engage in Rich Conversation

One-on-one conversations help children articulate and extend their thought processes. As James circulates through the room, she uses prompts such as “Tell me about that; How did you think of that?; and What steps did you take?” to get kids talking. “I encourage children to share their thinking, and in turn I am open to the unexpected strategy,” according to James. “I am willing to say, ‘Wow, I never thought about that before.”

Apply Skills to New Contexts

During one lesson, James asked her kindergartners to write a number sentence and then invent a story based on that sentence. Children depicted their story in three ways: as an illustration, as a written sentence, and as a number sentence. James was surprised to find that a few kids who zoomed through their math facts really struggled to complete this task. “They wanted to give me a number sentence without a story,” said James. Being asked to manipulate and view numbers in this way “caused them a bit of internal conflict.” To help them through the process, James said she just sat with them wondering out loud and asking questions until they found their footing.

An activity like this is effective, said Hill, because it posed a question that “stretched kids outside of their comfort zone and called on them to think and invent.” James was asking her children to contextualize, which is “a core mathematical practice.” When young children are given opportunities to apply their math skills to novel situations, they take steps toward becoming confident and creative mathematical thinkers (Hill, 2009).

In a study published last year, the researchers Ilaria Berteletti and James R. Booth (2009) analyzed a specific region of our brain that is dedicated to the perception and representation of fingers known as the somatosensory finger area. Remarkably, brain researchers know that we “see” a representation of our fingers in our brains, even when we do not use fingers in a calculation. The researchers found that when 8-to-13-year-olds were given complex subtraction problems, the somatosensory finger area lit up, even though the children did not use their fingers. This finger-representation area was, according to their study, also engaged to a greater extent with more complex problems that involved higher numbers and more manipulation. Other researchers have found that the better children’ knowledge of their fingers was in the first grade, the higher they scored on number comparison and estimation in the second grade. Even university children’ finger perception predicted their calculation scores. (Researchers assess whether children have a good awareness of their fingers by touching the finger of a student without the student seeing which finger is touched and asking them to identify which finger it is.)

Evidence from both behavioral and neuroscience studies shows that when people receive training on ways to perceive and represent their own fingers, they get better at doing so, which leads to higher mathematics achievement. The tasks we have developed for use in schools and homes are based on the training programs researchers use to improve finger-perception quality. Researchers found that when 6-year-olds improved the quality of their finger representation, they improved in arithmetic knowledge, particularly skills such as counting and number ordering. In fact, the quality of the 6-year-old’s finger representation was a better predictor of future performance on math tests than their scores on tests of cognitive processing.

Many teachers have been led to believe that finger use is useless and something to be abandoned as quickly as possible. Neuroscientists often debate why finger knowledge predicts math achievement, but they clearly agree on one thing: That knowledge is critical. As Brian Butterworth, a leading researcher in this area, has written, if children aren’t learning about numbers through thinking about their fingers, numbers “will never have a normal representation in the brain.”

Stopping children from using their fingers when they count could, according to the new brain research, be akin to halting their mathematical development. Fingers are probably one of our most useful visual aids, and the finger area of our brain is used well into adulthood. The need for and importance of finger perception could even be the reason that pianists, and other musicians, often display higher mathematical understanding than people who don’t learn a musical instrument. Teachers should celebrate and encourage finger use among younger learners and enable learners of any age to strengthen this brain capacity through finger counting and use. They can do so by engaging children in a range of classroom and home activities (Brissiaud, 2010).

The finger research is part of a larger group of studies on cognition and the brain showing the importance of visual engagement with math. Our brains are made up of “distributed networks,” and when we handle knowledge, different areas of the brain communicate with each other (Andres, et al., 2008 ; Butterworth et.al., 2011). When we work on math, in particular, brain activity is distributed among many different networks, which include areas within the ventral and dorsal pathways, both of which are visual. Neuroimaging has shown that even when people work on a number calculation, such as 12 x 25, with symbolic digits (12 and 25) our mathematical thinking is grounded in visual processing. A striking example of the importance of visual mathematics comes from a study showing that after four 15-minute sessions of playing a game with a number line, differences in knowledge between children from low-income backgrounds and those from middle-income backgrounds were eliminated (Di Luca, et al., 2010 ; Fischer & Brugger, 2011).

Number-line representation of number quantity has been shown to be particularly important for the development of numerical knowledge, and children’ learning of number lines is believed to be a precursor of children’s academic success. Visual math is powerful for all learners. A few years ago Howard Gardner proposed a theory of multiple intelligences, suggesting that people have different approaches to learning, such as those that are visual, kinesthetic, or logical (Gardner, 2008). This idea helpfully expanded people’s thinking about intelligence and competence, but was often used in unfortunate ways in schools, leading to the labeling of children as particular type of learners who were then taught in different ways. But people who are not strong visual thinkers probably need visual thinking more than anyone. Everyone uses visual pathways when we work on math. The problem is it has been presented, for decades, as a subject of numbers and symbols, ignoring the potential of visual math for transforming children’ math experiences and developing important brain pathways (Iversen, et.al., 2006).

Conclusion

Using the index finger to trace over advanced and multi-step maths problems can help children with problem solving. Fingermath can assist learning not only for spatial topics such as triangles and angle relationships, but also for non-spatial tasks such as learning the order of tasks in arithmetic problems. We also found that children who traced over key elements of maths problems (eg, the arithmetic symbols +, -, ÷, x, and brackets used in order of operations problems) were able to solve other questions that extended the initial maths problem further. Superior performance on such "transfer" problems indicates children who traced weren't simply memorising solutions to problems. Instead, tracing was helping them develop a deeper, more flexible understanding of the problem-solving methods.

One of the recommendations of the neuroscientists conducting these important studies is that schools focus on finger discrimination, not only on number counting via their fingers but also on helping children distinguish between those fingers. Still, schools typically pay little if any attention to finger discrimination, and to our knowledge, no published curriculum encourages this kind of mathematical work. Instead, thanks largely to school districts and the media, many teachers have been led to believe that finger use is useless and something to be abandoned as quickly as possible. Kumon, for example, an after-school tutoring program used by thousands of families in dozens of countries, tells parents that finger-counting is a "no no" and that those who see their children doing so should report them to the instructor.

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