EMBODIED NUMEROSITY: EXPLORING VARIABILITY IN FINGER COUNTING METHODS OF 6-7-YEAR-OLD CHILDREN

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Neuropsychological research has established the value of finger-number representations in mathematical development, yet indecision remains in education. The responses of 31 children (age 6/7 years) when asked to show how they count to ten using their fingers, were videoed, and six months later the task was repeated. Micro-analysis of the Time 1 video clips revealed substantial variety in finger-counting methods, and Time 2 analysis showed that most children changed their method. We argue that more education-focused research is needed to resolve questions such as whether a stable finger-counting pattern is needed to maximise learning benefits.

INTRODUCTION

The representation of number magnitude using fingers, referred to by Moeller et al. (2012) as *embodied numerosity*, is a specific case of embodied cognition, meaning that numerical representations are not purely abstract but innately "intertwined with the finger sensorimotor system" (Barrocas et al., 2020, p.1). There are three main ways in which fingers are used to represent numbers; a) Counting reflects the ordinal aspect of number knowledge where each number word is sequentially mapped one-to-one with a finger; b) The cardinality concept can be embodied through displaying fingers to directly represent number magnitude; c) Part-whole number relations utilises the previous two finger uses to combine and separate numbers (early addition and subtraction) (Roesch & Moeller, 2015). Despite the accumulated evidence from neuropsychological research of the value of finger-number representations in children's mathematical development, the role of finger counting in the teaching and learning of early number has remained contested by educators (Krenger & Thevenot, 2025; Moeller et al. 2011; Poletti et al., 2023). We suggest that some key educational questions remain open. For example, is it better to encourage young children to 'naturally' develop their own finger-counting methods or to explicitly teach a particular finger-counting pattern? Is there a stage in schooling at which students should have established a stable pattern of finger counting? As an initial step towards investigating these questions in the Australian context, the present study explores the finger-counting methods of Grade 1 children learning under a curriculum that does not specify the use of finger-number representations.

THE ROLE OF FINGERS IN NUMERICAL DEVELOPMENT

The naturalness and variability of finger-counting methods

Finger counting appears to come naturally to most children. Although the relationship between finger awareness and numerosity emerges in infancy and is world-wide, there

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is substantial cultural variation in the level of use and in patterns of number representation with fingers (Bender & Beller, 2012). For example, when finger-counting, there is a tendency for Europeans to begin with a closed fist and raise fingers beginning with the thumb on each hand. Whereas people from the Middle East are likely to begin with the little finger, and Japanese are likely to begin with an open hand and start by lowering the little finger. Starting the count with the pointing (index) finger is the preference of many Chinese and North American people (Bender & Beller, 2012). In a multicultural country such as Australia, a variety of finger-number practices might be likely in children entering formal schooling at 5/6 years of age, because of the home-cultural influence.

Some studies have explored the relationships between 'handedness (left/right hand preference for manual tasks such as writing) and the hand naturally used to begin the count or the 'direction of the count', but findings have been somewhat inconsistent. For example, Sato & Lalain (2008) found that Italian children and adults (age range 4 to 47 years) were influenced by their 'handedness', that is, right-handed people mostly began the count on their right hand, and left-handed people typically began with their left hand. In contrast, Fischer (2008) found that American children aged 4 to 8 years tended to begin the count with their left hand regardless of their left/right handedness. Such variety in finger-counting habits raises questions about whether different directions and patterns of finger-counting might support mathematical thinking in different ways. It has been suggested (e.g., Fischer, 2008) that left-to-right finger counting might support the development of the 'mental number line', that refers to the tendency to think of numbers of greater magnitude being spatially-directionally 'located' to the right. However, this proposition was not supported by an experimental study with Italian participants by Di Luca et al. (2006) who found that using a person's habitual sequencing in figure-counting enabled faster processing in number matching tasks.

Di Luca and Pesenti (2011) argue that "using the same finger configuration repeatedly to represent a given numerosity" (p.1), produces a representational stability that helps children establish a one-to-one-correspondence between the count and the finger to support memory, ordinality and cardinality. Developing schema to physically represent numbers and relationships between numbers through finger movement seems to support working memory and facilitate problem-solving capacity (Dupont-Boime & Thevenot, 2018). Does this mean that children's individual finger-counting habits should be encouraged rather than attempting to standardise the sequence of finger movements? Little is known about if or when a stable finger-counting pattern emerges in children, or indeed whether a habitual method is more effective than varying/adaptive methods for supporting the further development of number thinking, such as basic arithmetic.

Neuropsychological research on relationships between finger awareness and numerical skills

Substantial neuropsychological evidence has accumulated on the connections between finger gnosis (awareness and mental representation of one's fingers) and fine-motor skills (finger control and movement to represent number) in early number development and subsequent performance in number skills and problem-solving (Barrocas et al., 2020; Krenger & Thevenot, 2025). From a neuroscience perspective the strong connection between fingers and numbers is largely explained by the overlapping neural pathways in the brain that are activated when thinking about our own fingers and thinking about numbers, as identified through functional neuroimaging studies (Chinello et al., 2013; Penner-Wilger & Anderson, 2013). However, there is some debate about whether the relationship is correlation, directly casual or indirectly casual because of the "neural resource shared by finger representation and number representation" (Penner-Wilger & Anderson, 2013, p.1).

Developmental studies and classroom-based research

Three main types of education-focused studies have contributed to our understanding about the role finger-number representation in early number learning: a) observation of what children do with their fingers in response to number tasks - usually individual interview/testing (e.g., Jordan et al. 2008); b) intervention experiments focused on developing finger gnosis (not directly targeting numeric representation) (e.g., Gracia-Bafalluy and Noël 2008); c) intervention studies focused on increasing children's use of embodied numerosity and the effect on their number skills such as basic calculation (e.g., Ollivier et al., 2020). Broadly, such studies have concluded that teachers should explicitly support children's development of finger awareness, fine-motor dexterity and finger-number representations (including finger-counting) to enhance their number skills such as basic addition and subtraction. A recent longitudinal study by Krenger and Thevenot (2025) with Swiss children aged 4.5 to 7.5 years established that children who use (or have previously used) finger counting strategies consistently perform better in addition tasks than children who have never use (or have only just begun to use) finger-based strategies. For many children, the application of finger counting strategies to basic calculations commences around age 6 (Grade 1), with a decline in the prevalence of finger strategies beginning around age 7, as the early adopters (e.g. age 5) of finger-counting transition to more abstract mental strategies (Jordan et al., 2008: Krenger & Thevenot, 2025). While there is consensus that finger-based numerosity can and should be explicitly taught to children from about age 5, there is a lack of research-based advice about whether instruction should promote specific finger-use patterns or encourage children's self-invented finger-number strategies. Nor is there advice about whether children's finger-use methods need to have stabilised into a pattern to most effectively achieve the benefits of embodied numerosity for accurately solving number problems.

FOCUS AND CONTEXT OF THE CURRENT STUDY

Of interest in our study are the methods that children use when counting to ten using their fingers, at around age 6 when it is anticipated that most children will be engaging with this form of embodied numerosity. In the Australian context, it is unlikely that children of this age will have experienced instruction in specific ways to use their fingers for number representation, as the Australian Curriculum for Mathematics makes no mention of promoting finger counting, and the accompanying National Numeracy Learning Progression (ACARA, 2020) only makes very brief mention of fingers as potential countable objects. The absence of references to finger-number practices in official documents means that no expectation is placed on teachers to teach finger counting techniques, nor to assess students' facility with representing numbers with their fingers.

This paper is focused by the research questions: *What finger-counting methods do children age 6-7 years use?* and, *How stable are the finger-counting methods after 6-months?*

METHODS

The study is qualitative and interpretive in nature as it relies on the observation and interpretation of the phenomenon of individual children responding to a task during an interview situation. Inherent in the interpretation is the theoretical perspective of embodied cognition and the assumption that the child's hand movements are conceptual and are therefore external representations intertwined with internal mental processes.

The participants were 31 Grade 1 students (average age of 6.6 at Time 1, 20 boys and 11 girls) randomly drawn from seven different classes at three different schools in the metropolitan area of Sydney, Australia – with 14 students from School A, 11 from school B and 6 from School C. The three schools were located in communities with differing demographics in terms of socio-economic status and non-English speaking backgrounds.

The study was approved by the University of Sydney Human Research Ethics Committee and the NSW Department of Education. Both parental consent and each child's assent were obtained before data collection.

Data collection and analysis

Time 1 data collection took place near the middle of the school year and Time 2 occurred 6-months later. The data were extracted from video-recorded task-based interviews in which the students were asked to "*Show me how you can count to 10 using your fingers*". Micro-analysis was conducted on the 62 video clips using a previously developed framework (Way & Cartwright, 2024) – see Table 1. The child's 'handedness' was determined by observing their choice of hand when creating a drawing during another task in the same interview.

Table 1: Characteristics of finger counting analysis framework

Hand orientation	Movement type	Finger sequence
PFV – palms facing the child, held vertically **PFH** – palms facing the child, held horizontally (fingers parallel to table) *Example of PFH* **BFV** – backs of hands facing child, held vertically **BFH** – backs of hands facing child, held horizontally (palms on or near table) *Example of BFV*	**Raise** – start with closed fist and raises fingers **Lower** – start with open hand and lower fingers **Wiggle** – start with open hand twitch or wiggle fingers **Touch** – use a finger to touch-count other fingers **All raised** – simultaneous display of fingers with no one-to-one counting. *Example of Touch counting*	**Start finger 1** – first finger counted (matched with 1) **Start finger 2** – first finger counted on the second hand (matched with 6) **End finger** – last finger counted (matched with 10) **LT/RT** – left or right Thumb relative to child's perspective **LP/RP** – left or right Pointer **LM/RM** – left or right Middle finger **LR/RR** – left or right Ring finger **LL/RL** – left or right Little finger

FINDINGS

Hand orientation

About two-thirds of the 31 students held their hands with palms facing towards themselves (Time 1=19, Time 2=20), and at least half of this group held their fingers vertically (T1=14, T2=10). Most other students (T1=11, T2=7) had the backs of their hands facing themselves, the majority with vertical fingers. In Time 1, one student flipped her hands into different orientations during the count. In Time 2, the hand orientation of four students was indeterminate.

Movement to track the count

Most students started with a closed fist and raised fingers one at a time (T1=26, T2=23). A few children raised all fingers on one hand at the start then used a finger on the other hand to point/touch each finger to track the count (T1=3, T2=2). An additional two students in Time 2 used touch-counting but started with a closed fist and raised each finger before pointing to it to count. In Time 1, one student raised all fingers then slightly twitched (wiggled) each finger, and one raised all fingers and declared "10" without using a counting process. For Time 2, one student used the 'Wiggle' movement, one raised all fingers and said "5, 10" without counting, one raised all fingers then did not move them, instead shifting gaze to count, and one would not clearly demonstrate any method.

Finger sequences and patterns

Only four students were left-handed, and two-thirds of the 31 students started finger counting on their preferred hand in both Time 1 and 2. All students who actually performed counting completed the 1-to-5 count on one hand before moving to the other hand for the 6-to-10 count. The most common pattern (T1=19, T2=16) was to begin the count with a Thumb and continue across to the Little finger, then mirror the sequence (Thumb to Little finger) on the other hand. When the hand orientation was 'backs of hands facing' the directionality of the count was from the centre outwards (Figure 1a), and when palms were facing, inward towards the centre. Some students (T1=5, T2=6) started from an outer finger and continued in the same direction across to the second hand. Depending on the hand orientation and the start-finger (Right/Left Thumb or Little) this pattern produced either a continuous Right-to-Left or Left-to-Right count (Figure 1b). Four students in Times 1 and 2 started the count with a Pointer finger, then used a variety of finger-raising sequences to complete the count – see for example, Figure 1c. One student in Time 1, and a different student Time 2, 1 counted by twos, raising a pair of fingers together.

Figure 1: Examples of finger sequences

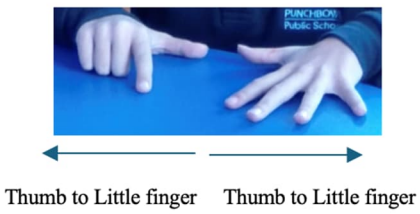

Figure 1a

Figure 1b

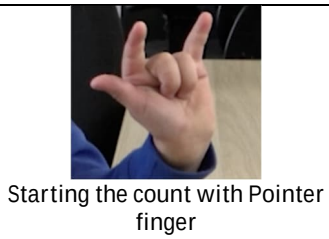

Figure 1c

Stability vs variation

Although the numbers of students presenting each type of hand orientation, finger movement and finger sequence were relatively stable across Time 1 and 2, this disguises the substantial changes that individual students made from Time 1 to Time 2. In fact, only six students produced the same finger-counting representation in Time 2 as they had in Time 1, and six students changed all the characteristics. About a third of the 31 students (22) changed their hand orientation, though surprisingly five of these maintained the same sequence of finger-movement for counting. Ten students changed the way they moved their fingers to track the count, and 12 changed the hand on which they started their count (five changing away from their preferred hand, both L and R handed). Two-thirds (20) of the students changed the sequence of fingers they used, though six of these were only a change in direction resulting from a change in hand orientation.

DISCUSSION AND CONCLUSION

This small exploratory study revealed substantial variety in the methods 6/7-year-olds used to finger-count to 10, which contrasts with the relative dominance of particular

methods reported in other cultures (Bender & Beller, 2012; Fischer, 2008; Sato & Lalain, 2008). There were also some commonalities in some of the counting characteristics, including the tendency to start with a closed fist and raise one finger at a time, and to use a thumb-to-little-finger sequence on both hands, which aligns with the typical European pattern (Bender & Beller, 2012). Analyse of changes in each child's finger-counting methods after six-months revealed the striking instability of their methods, with all except six students changing at least one characteristic of their method. According to previous research, finger numerosity may still be developing into an effective tool in many 6-year-olds, so changes that reflect the development of more efficient methods would be a reasonable expectation. While this could explain some of the changes we observed (e.g., one student went from making one-to-one matching errors to effective finger counting), reasons for most other changes are difficult to infer (e.g., reversing the hand orientation or the direction of the count, or changing the sequence of fingers). Indeed, we interpret the changes in nine students' methods to be regressive (e.g., from efficient finger movement to touch-pointing) which suggests a lessening of finger gnosis rather than improvement (Barrocas et al., 2020). The identification of substantial variation and instability of finger-counting methods in this age group strengthens the case for further education-focused research to better understand the consequences and to inform pedagogy that effectively supports the development embodied numerosity.

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