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ORIGINAL ARTICLE

# The impact of finger counting habits on arithmetic in adults and children

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**Abstract** Here, we explored the impact of finger counting habits on arithmetic in both adults and children. Two groups of participants were examined, those that begin counting with their left hand (left-starters) and those that begin counting with their right hand (right-starters). For the adults, performance on an addition task in which participants added 2 two-digit numbers was compared. The results revealed that left-starters were slower than right-starters when adding and they had lower forward and backward digit-span scores. The children (aged 5–12) showed similar results on a single-digit timed addition task—right-starters outperformed left-starters. However, the children did not reveal differences in working memory or verbal and non-verbal intelligence as a function of finger counting habit. We argue that the motor act of finger counting influences how number is represented and suggest that left-starters may have a more bilateral representation that accounts for the slower processing.

## Introduction

It has been assumed that fingers play a significant role in the development of a mature counting system (Butterworth, 1999, 2005; Fuson, 1982). However, the precise role that fingers play is unclear. There are a number of hypotheses to account for the role of fingers in number processing: they are a memory aid during counting (Fuson, 1982); they aid in understanding cardinality (Fayol & Seron, 2005) and in the development of the one-to-one correspondence principle (Alibali & DiRusso, 1999), among others. In addition, Pesenti, Thioux, Seron, & Volder (2000) proposed that the visuo-motor structure and movement of fingers support the creation of number representation.

Finger counting habits also appear to play a role in number processing; however, its precise role is unclear. Finger counting habits may influence the way numbers are represented and processed (Di Luca, Grana, Semenza, Seron, & Pesenti, 2006; Domahs, Moeller, Huber, Willmes, & Nuerk 2010; Fias & Fischer, 2005; Pesenti et al., 2000; Sato, Cattaneo, Rizzolatti & Gallese, 2007). For example, Fischer (2008) suggested that finger counting habits influence the spatial representation of number and found that the SNARC effect—large numbers correspond to the right side of space while small numbers the left—was mediated by whether participants started counting with their left or right hand (the effect was diminished in right-starters). Domahs et al. (2010) examined the impact of culturally different finger counting habits on a number comparison task in which participants compared two numbers with a distance of two digits (e.g., 4–6; 2–4). German participants (using two hands to count from 1–10; five on each hand) were compared to Chinese participants (using one hand to count from 1 to 9). The study found a significantly larger sub-base five effect—longer reaction times when the number pairs crossed five—for the German group indicating that finger counting contributes to number processing. In addition, a recent study found that fMRI-measured brain activation when viewing number words was linked to

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whether the participant was a left- or right-starter, left-starters showed increased activation in the right motor cortex while right-starters the left motor cortex (Tschentscher, Fischer, & Pulvermüller 2012).

What is the mechanism that may account for the interaction between finger counting habits and number representation? The answer may be found in recent studies examining the effect of writing on letter processing. Recent findings show that the sensory-motor experience of writing effects how letters are represented and that it may account for functional specialization (James & Atwood, 2009; James, 2010). Neural functional specialization, or responding more to one category of stimuli than others, is well documented and number is one such category (Park, Hebrank, Polk, & Park, 2011; Polk et al., 2002). Functional specialization is thought to be developed through extensive experience, particularly sensory-motor experience (Gauthier, Skudlarski, Gore, & Anderson, 2000; James, James, Jobard, Wong, & Gauthier, 2005), suggesting that habitual finger counting strategies may interact with number representation. It has also been found that brain activation patterns change after motor experience with an object (Butler and James under, review; Chao & Martin, 2000) and that differences in the motor experience can lead to differences in neural activation (Butler and James under, review). Therefore, the sensory-motor experience of finger movement and counting may be expected to influence the neural representation of number the same way that writing impacts the neural representation of letter.

These previous studies suggest that the motor experience of finger counting is important to the neural functional specialization of number and that a particular finger counting habit may influence that specialization. This is precisely the explanation proposed by Domahs et al. (2010); there it was suggested that the differential effects for German and Chinese counting systems were due to the interhemispheric processing necessary for German that resulted directly from the two-hand finger counting strategy. Also, like letter processing, many studies have found the activation of premotor cortex during number processing in both children (Cantlon & Brannon, 2007) and adults (Park et al., 2011), suggesting a sensory-motor role. The results from Tschentscher et al. (2012) completely support this theory and not only show that fingers play a role in number representation, but also the importance of the role of a particular sensory-motor experience on number with different experiences resulting in different neural activation patterns.

The question addressed here is does the differential representation of number resulting from differences in finger counting habit impact arithmetic performance, specifically addition. As mentioned, previous studies have found a differential SNARC effect, differences in magnitude processing, as well as differential neural activation as a function of finger counting habit, suggesting differences in number representation and processing. Interestingly, in a recent study by Kline et al. (2011) it was found that adults showed differential performance when the problem had a sub-base five break (e.g., $3 + 4 = 7$) compared to without a break (e.g., $5 + 2 = 7$), even when controlling for overall unit sum—the sub-base five-break problems resulted in slower reaction times. Similar results in children have been interpreted as being the result of a difficulty in keeping track of the number of fives (during finger counting; Domahs et al., 2008); however, this does not necessarily hold for adults. Finding similar effects in adults suggests that the sub-base five-break effect is not a transient developmental phenomenon but is instead a result of the persistent influence of finger counting habits. In addition, a recent study by Imbo, Vandierendonck and Fias (2011) showed that passive hand movements interfered with addition, particularly when using a counting strategy. Interestingly, while not significant, differences were also observed when using the retrieval strategy. Together, these previous findings support a prediction that finger counting habits indeed contribute to arithmetic processing.

A possible mechanism that may account for the role of finger counting in arithmetic processing is differences in interhemispheric communication. Arithmetic is considered to be a left hemisphere process (Chochon et al., 1999; Pinel & Dehaene, 2010). In fact, Gerstmann's syndrome is due to damage to the left parietal cortex. Also, it has been shown that there is a disadvantage for bimanual as compared to unilateral movement possibly due to the interhemispheric coordination that is required (Aglioti, Berlucchi, Pallini, Rossi, & Tassinari 1993). As a result, it could be argued that left-starters, due to the increased involvement of the right motor cortex, may be at a greater disadvantage than right-starters during number tasks including arithmetic. To test this hypothesis the current study reports two experiments that compared left- and right-starters. In the first we explored the addition of 2 two-digit numbers in adults. It is expected that finger counting habits are stable in adults and that knowledge of addition facts and addition procedures is also more stable in adults; although there is some suggestion of systematic variation in the use of finger counting strategies during addition (Geary et al., 2004; LeFevre et al., 1996). The second experiment explores the relationship between finger counting habits and arithmetic in children where finger counting habits are rather stable but arithmetic facts are not necessarily as well learned as in adults.

## Experiment 1

### Methods

#### Participants

120 adults (age, $M = 20.8 \pm 3.5$, 69 females) from the Indiana University community participated in this study. Participants were right-handed, native English speakers with no reported neuropsychological conditions. Each participant was tested in a quiet room for approximately 1 h. All participants gave written, informed consent approved by the Indiana University Institutional Review Board.

#### Measures

*Finger counting habits* Participants first completed an information survey that included a finger counting habit assessment. Finger counting habits were obtained by asking participants to demonstrate, using their fingers, how they count from 1 to 10. The experimenter then made note of the strategy used. Left-starters began counting with their left hand while right-starters began with their right hand. For the current study the order of finger use in counting (e.g., starting with the thumb or index finger) was not taken into consideration.

*Handedness* To reduce the variance due to handedness, only participants who reported being right-handed were examined. The Edinburgh Handedness Inventory (Oldfield, 1971) was administered to ensure that all participants were indeed right-handed. The range of scores was between 16.67 and 100 with a mean of $72.3 \pm 18.5$.

*Digit span* The forward (FDS) and backward digit-span (BDS) tasks were administered to assess working memory capacity. During the digit-span task the subjects were first shown a series of single-digit numbers, one at a time, on a computer screen. They then were asked to report the digits back (either in the same order as presented for forward digit span or in reverse order for backward digit span) using the number pad on the keyboard and their right hand. The task started with a series of three numbers. Once the subject reported back two series of 3 single-digits successfully, they were given a series of four single-digit numbers and so on. Failure to report a series twice consecutively terminated the task. The last series that was reported back successfully twice was considered the participant's digit span.

*Spatial ability* The Vandenberg mental rotation task (Vandenberg, 1971) was administered to measure spatial ability. The task is a timed test that involves choosing the rotated versions of a three-dimensional figure.

*Addition task* Participants completed an addition task in which they added 2 two-digit numbers between 11 and 99, excluding and ties (e.g., 23 + 23). Two digit numbers were used to prevent retrieval processes and encourage calculation. Questions never involved adding two double-digit numbers that were both multiples of 5 or 10, but we did allow for one of the numbers to be a multiple of 5 or 10. The result never exceeded 99 and was never less than 30. The addition problem was presented at the top of the screen with four possible answers presented horizontally in random order at the bottom. The four possible answers included: the correct answer; one answer with the same first digit as the correct answer or one with the second digit being one or two more or less than the correct answer's second digit; the second incorrect answer had the same second digit as the correct answer or as the incorrect answer described above; and finally there was a completely random choice. Participants responded to the addition trials by pressing the "a", "s", "d", or "f" buttons on the keyboard (matching the position of the 4 possible choices), using their pinky, ring, middle, and index fingers, respectively. The addition task was composed of 20 trials.

### Results and discussion

For the addition reaction time measures, all trials with RT values outside the mean ± 2 standard deviation range were not included in the analysis. The range was calculated separately for each participant. Only correct trials were used in the RT analysis.

Of the 120 participants 62 were left-starters and 58 right-starters. Reaction time was found to be different between the two groups with left-starters ($M = 5.3$ s $\pm$ 1.9) being slower to respond than right-starters ($M = 4.7$ s $\pm$ 1.5) [$F(1,119) = 3.79$, $p = 0.05$, MSe = 11.07]. Accuracy, however, failed to show an effect of finger counting habit [$F(1,119) = 1.48$, $p = 0.23$, MSe = 0.0188; left-starters $M = 92.4 \pm 1$ %; right-starters $M = 89.9 \pm 1.3$].

The digit-span and handedness measures were also compared across the two groups. Digit span for 15 participants (7 left-starters) was not acquired due to time constraints. Forward and backward digit spans were found to be different between the two groups with the right-starters (FDS: $M = 6.8 \pm 1.1$; BDS: $M = 5.4 \pm 1.4$) having a higher span than the left-starters (FDS: $M = 6.4 \pm 1.2$; BDS: $M = 5.0 \pm 0.8$) [FDS: $F(1,103) = 4.5$, $p = 0.036$, MSe = 5.94; BDS: $F(1,103) = 3.77$, $p = 0.055$, MSe = 4.66). However, there was no significant difference between left- and right-starters in spatial processing

($p > 0.2$; left-starters $M = 18.2 \pm 10.4$; right-starters $M = 21.1 \pm 9.1$) or degree of handedness ($F < 1$; left-starters $M = 71.2 \pm 22.8$; right-starters $M = 72.8 \pm 15.9$).

Because working memory measures were different between the two groups the correlation between working memory measures and addition RT was computed. The correlations between RT and forward ($r = -0.07$, $p > 0.5$) and backward digit span ($r = 0.14$, $p > 0.14$) were found to not be significant. In addition, a subset of the two groups was examined in order to equate digit span (46 participants in each group with BDS = 5.51 in both groups and FDS = 6.64 and 6.91 in the left- and right-starter groups, respectively). In this subset of participants an effect of RT remained such that the right-starters ($M = 4.6$ s) were faster than the left-starters ($M = 5.3$ s; $t = 1.9$, $p < 0.034$). Together this suggests that working memory differences do not explain the RT differences between the two groups.

There are two potential confounds in Experiment 1. Because of the working memory difference between the left- and right-starters, it may be that the left-starters in the population examined have poorer domain general cognitive functioning that interacts with arithmetic performance. However, the additional analyses suggest that finger counting habits have an influence independent of working memory. In addition, the spatial ability of these two groups was not different suggesting that there are no IQ differences. Nonetheless, ideally additional intelligence measures should be acquired. A second concern is related to the procedures used. The participants responded to the addition task with their left hands. As a result, if finger representations are involved in number processing, the left-starters are essentially using the same hand to respond and to process number. This explanation suggests that (1) the adult participants used a finger counting strategy to perform the addition task or like the findings of Tschentscher et al. (2012) the fingers are activated whenever the numbers are presented and (2) having their left fingers in use interfered with these processes suggesting that they may be necessary, even in adults. Similar interference effects have been observed in a dual-task study in which participants performed a finger tapping task with their right hand and responded to addition problems with their left (Soylu & Newman, 2011). Experiment 2 is designed to alleviate these potential confounds.

## Experiment 2

### Method

*Participants*

Sixty-nine children (5–12 years of age) participated in the study for pay. Thirty-seven were left-starters (8.4 ± 1.9-year old; 14 male) and 32 right-starters (8.9 ± 1.8-year old; 20 male). Two additional participants were excluded from analysis due to poor addition performance (<50 accuracy; one left- and one right-starter). Participants had no history of neurological or psychiatric disorders and written informed consent was obtained from parents and assent from participants, as approved by the Institutional Review Board of Indiana University, Bloomington.

*Measures*

*Finger counting habits* The hand used to initiate finger counting was determined. Participants were asked to count with their fingers from 1 to 10.

*Handedness* To ensure that all participants were right-handed, the Edinburgh Handedness Inventory (Oldfield, 1971) was administered. Each question was read to the participant and they demonstrated how they would perform the task. For example, for the question which hand do you use to throw a ball? The participant was encouraged to simulate throwing. The scores ranged from 33.33 to 100 with a mean of 81.7 ± 15.4.

*Digit span* The forward (FDS) and backward digit-span (BDS) tasks were administered. This task was different from that used for adults; the stimuli were presented aurally and the response was also vocal. For both FDS and BDS a series of digits were read to the participant at a constant pace starting with two digits and increasing by a single digit until failure to recall occurs twice. For the FDS participants were told to repeat the digits in the order read. For the BDS they were told to repeat the digits in the reverse order read.

*Word attack* The word attack (Woodcock, McGrew, & Mather, 2001) task was administered to assess phonological processing ability. The initial items require participants to produce the sounds for single letters. Afterwards, difficulty increases. For the remaining items they were required to read aloud letter combinations that are phonically consistent patterns in English but are non-words or low frequency words. The scores were adjusted for age.

*Vocabulary* The vocabulary subtest of the Wechsler Intelligence Scale for Children was administered. This test measures verbal fluency, concept formation, word knowledge and usage. It is an untimed test in which participants are read a word and are asked to define it. The scores were adjusted for age.

*Matrix reasoning* The matrix reasoning subtest of the Wechsler Intelligence Scale for Children was administered. This test measures visual processing and abstraction and spatial perception. Children are shown colored matrices or visual patterns with something missing. They are then asked to select the missing piece from a range of options. The scores were adjusted for age.

*Timed addition test* Because of the age range of the children a single-digit non-computerized addition task was used. Participants were presented with 40 single-digit addition problems and given 1 min to compute the solutions for this paper and pencil task. The problems were presented all on a single sheet of paper. They were presented with one operand on top of the other with the larger being on top. Participants were able to use the fingers of both hands even though they recorded their response with their right hand. While younger children were more likely to use their fingers to solve the problems, their finger counting use was not recorded in this study. Two measures were obtained: the number of problems attempted in 1 min and the percent correct of those attempted.

### *Procedures*

All testing sessions were administered in the Cognitive Neuroimaging Laboratory at Indiana University by a trained experimenter in a quiet room.

## Results and discussion

Like the adults, the children revealed a significant difference in addition performance for left- and right-starters with right-starters having a higher accuracy than left-starters [$F(1, 68) = 5.14$, $p < 0.05$; left: $M = 94\ \% \pm 9.6$; right: $98.1\ \% \pm 3.7$].

While the right-starters did show a higher digit span than did the left-starters, unlike the adult group digit span failed to show statistically significant differences between the right starters and left starters in children (see Table 1).

**Table 1** Experiment 2 results

| | Mean ± standard deviation | | $F(1,68)$ | $p$ |
|---|---|---|---|---|
| | Left-starter | Right-starter | | |
| Age | 8.4 ± 1.9 | 8.9 ± 1.9 | 1.09 | 0.3 |
| Handedness | 81 ± 15.7 | 82.3 ± 15.8 | <1 | 0.74 |
| Word attack | 6.9 ± 4.4 | 7.3 ± 4.9 | <1 | 0.73 |
| Forward DS | 0.62 ± 0.15 | 0.67 ± 0.19 | 1.19 | 0.28 |
| Backward DS | 0.35 ± 0.15 | 0.4 ± 0.17 | 1.77 | 0.19 |
| Vocabulary | 54.8 ± 10.2 | 56.8 ± 9 | <1 | 0.41 |
| Matrix reasoning | 53.3 ± 11.6 | 55.4 ± 7.5 | <1 | 0.4 |
| Addition: attempted | 18.1 ± 8.8 | 20.4 ± 8.7 | 1.24 | 0.27 |
| Addition: % correct | 94 ± 9.6 | 98.1 ± 3.7 | 5.14* | 0.027* |

There are two possible explanations for the difference between the two experiments. First, the sample size is significantly smaller for the child study. Therefore, even though, on average, the right-starters have a higher digit span there may be insufficient statistical power to detect those differences. Second, the digit-span tasks were different with the children responding aurally while the adults manually (using their fingers). This difference in response modality may have affected the performance in adults.

Finally, the control measures—verbal and non-verbal intelligence—failed to show a significant difference between left- and right-starters ($F$'s $< 1$) indicating that the differences in addition performance are not due to intelligence differences between groups. Instead, the effect of finger counting habit on addition performance is independent of these domain general cognitive processes.

## General discussion

Finger counting habits have been shown in previous studies to impact number representation (Fischer, 2008; Domahs et al., 2010). The current study demonstrates that finger counting habits also affect arithmetic performance. Adult right-starters solved addition problems faster and had a higher working memory capacity than left-starters. The children also showed differences as a function of finger counting habit with right-starters out performing left-starters. Below is a discussion of how these results fit into the current literature.

### *Interhemispheric communication*

One potential way in which number and arithmetic may be affected by finger counting habit is the laterality of its representation. We suggest here that the hand in which individuals begin counting may influence the role of the right hemisphere (RH) in the representation of number. Left-starters have been shown to activate RH motor codes when passively viewing numbers (Tschentscher et al., 2012). Motor regions have often been found to be involved in number tasks (Park et al., 2011) with Andres et al. (2007) showing hand excitability in adults during a counting task. In addition, Domahs et al. demonstrated sub-base five differences as a function of finger counting habit with the effect being significantly smaller in groups that count from 1 to 9 using only one hand, thereby reducing interhemispheric communication. Together these results indicate that (1) sensory-motor processing is involved in number processing and (2) finger counting habits influence the interhemispheric representation of number.

Previous research suggests that addition is primarily a left hemisphere (LH) function (Kucian, von Aster, Loenneker, Dietrich, & Martin, 2008; Newman, Willoughby,

& Pruce, 2011; Pesenti et al., 2000). For example, Kucian et al. (2008) examined exact and approximate calculation of single-digit addition problems as well as magnitude estimation in both adults and children. There they found that while magnitude estimation and approximate calculation resulted in bilateral activation, exact addition resulted in more left lateralized activation of inferior parietal and premotor cortices in both adults and children. This also fits with the findings of Gerstmann in that Gerstmann's syndrome is the result of damage to the left parietal cortex.

As mentioned in the "Introduction", behavioral performance is negatively impacted by bimanual compared to unimanual processing (Aglioti et al., 1993). Aglioti et al. (1993) demonstrated that asymmetrical bimanual hand movements resulted in slower reaction times due to callosal transmission. The hypothesis proposed here is that number processing engages motor codes in the RH in left-starters regardless of whether the number is less than or greater than 5. Because addition is considered to be a LH process, this activation of RH motor codes may set up a network that involves greater interhemispheric coordination than that of a right-starter. As a result of the increased interhemispheric coordination, processing speed would be expected to be slower in left-starters. This is what was observed, particularly in the adults—left-starters responded more slowly to addition problems. What is interesting here is that the effects observed persist into adulthood and therefore suggest that embodiment is important in the representation of cognitive constructs and that its influence does not disappear with development. The results presented here demonstrate the large gaps in our understanding of how sensory-motor experience interacts with cognition, generally, and more specifically how finger counting habits impact how the number network gets "wired." Given the importance of rapid, automatic access to number knowledge in math problem-solving (National Mathematics Advisory Panel, 2008), understanding this relationship is an important next step.

### *Working memory*

A second potential explanation for the RT differences between the left- and right-starters in adults relates to the working memory differences between the two groups. The adults did show a significant effect of finger counting habit on WM measures while the children showed mean differences in the same direction but the differences were not significant. A number of studies have linked working memory capacity (WMC) to arithmetic processing (Imbo & Vandierendonck, 2007; DeStefano & LeFevre, 2004; Seyler, Kirk, & Ashcraft, 2003; De Smedt et al., 2009; Passolunghi & Siegel, 2004). For example, in a study by De Smedt et al. (2009) exploring the predictive role of working memory in later mathematical performance in first- and second-grade children, they reported that the central executive, as measured in part by the backward digit span, was a significant unique predictor of mathematics achievement. Therefore, the differences in WMC may have affected the performance differences between these two groups.

While WMC differences may contribute to the interaction between finger counting habit and addition performance, the results reported here suggest that finger counting habit makes a unique and independent contribution. First, the adult results failed to show a correlation between WMC and RT; in addition, when WMC was controlled by equating it across the two groups an RT effect was still present. Finally, the child study failed to show significant WMC differences between groups or differences in verbal and non-verbal intelligence measures. Together, these findings indicate that while WMC may also affect arithmetic performance, finger counting habit's influence on addition performance is independent of WM and general intelligence.

### *Prevalence of left-starters*

A brief discussion of the prevalence of left- versus right-starters is warranted. There are some discrepancies in the literature regarding the prominence of right-starters. For example, a strong right-to-left hand-digit mapping preference was found for right-handed French children and adults (Sato & Lalain, 2008) and for Italian adults (Di Luca et al., 2006; Sato et al., 2007). However, in a study of 445 British adults two-thirds were left-starters regardless of their handedness (Fischer, 2008). Interestingly, it has been suggested that finger counting habits are a cultural construct (Lindemann, Alipour, & Fischer 2011). Lindemann et al. (2011) found that Western individuals were more likely left-starters while Middle Easterners were right-starters. In the current study, with participants from a small mid-western college town, an almost equal number of left- and right-starters were examined in both experiments. There are also suggestions that handedness (either direction or degree) may interact with finger counting habit (Sato & Lalain, 2008). The current study examined only individuals who reported being right-handed. It appears that further work is necessary to determine whether left- or right-starters are more common, what factors contribute to finger counting strategy, and the role of handedness.

## Conclusions

The present study has resulted in the emergence of a number of questions, some of which have been mentioned above. Another question this research begs is related to the relationship between finger counting habit, operational momentum and the SNARC effect. Operational momentum is a leftward bias during subtraction and a rightward bias during addition (Siegler & Opfer, 2003; Lindemann & Tira, 2011; Pinhas & Fischer, 2008). The SNARC effect is faster responding to large numbers with the right hand and small numbers with the left (Dehaene, Bossini & Giraux, 1993). Both of these effects are related to the spatial representation of number. While there are studies that have examined both effects, and there is a study examining the interaction between the SNARC effect and finger counting habit (Fischer, 2008), no study, to our knowledge, has investigated the relationship between all three—finger counting habit, operational momentum, and SNARC. It may be that the sensory-motor experience of finger counting significantly effects the spatial representation of number and therefore, may be at the heart of both phenomena. Unfortunately, we were unable to explore the relationship between finger counting habit and operational momentum here. Further investigation of the relationship between finger counting, the spatial representation of number and the mental number line is essential for understanding how sensory-motor experiences interact with number, mathematical performance and cognition, generally.

In conclusion, we are not arguing that the use of fingers is necessary for the development of number or arithmetic; however, current research does suggest that it may affect how number is represented and therefore impact arithmetic performance. The reliable finding of performance differences between left- and right-starters in two different populations provides further support for a link between finger and number, and furthermore that this difference has an influence on arithmetic performance. This is an important area of research as it could have an immediate impact on our understanding of the importance of finger on number representation and arithmetic skill.

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