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Marc Sato, Muriel Lalain

ON THE RELATIONSHIP BETWEEN HANDEDNESS AND HAND-DIGIT MAPPING IN FINGER COUNTING

Marc Sato [1,2 *], Muriel Lalain [1]

[1] *GIPSA-Lab, Département Parole et Cognition, CNRS UMR 5216, Institut National Polytechnique de Grenoble & Université Stendhal, Grenoble, France*

[2] *Departimento di Neuroscienze, Sezione di Fisiologia, Universita di Parma, Parma, Italy*

*Correspondence: marc.sato@mail.mcgill.ca

Present address: Centre for Research on Language, Mind and and Brain, 3640 rue de la Montagne, McGill University, Montreal, Quebec, Canada H3G 2A8

ABSTRACT

The purpose of the current investigation was to evaluate hand-digit mapping in finger counting in French children and adults and whether handedness might constraint hand-digit mapping. To this aim, hand-digit mapping used when counting from one to ten by means of fingers, together with performance-based and preference-based measures of handedness, were evaluated in French individuals of four different age groups (4-5 years old, 6-7 years old, 10-11 years old and 24-47 years old). Irrespective of the age group, analyses revealed a strong tendency to use first the right hand to count from one to five and then the left hand to count from six to ten. In addition, a significant interaction between hand-digit mapping and hand preference was found, with participants who used first their right hand to count reporting higher right hand preference in unimanual activities. These findings are discussed in light of recent studies assuming a link between finger counting habits and numerical processing.

Keywords: Finger counting; Handedness; Manual asymmetry; Development; Numerical Cognition.

INTRODUCTION

In many cultures, the use of fingers appears as a natural means for representing, manipulating and communicating numbers. In childhood, this embodied strategy develops spontaneously and precedes the use of more abstract numerical codes, such as the verbal or written codes (Butterworth, 1999). The sequential ordering implied in finger counting may help children to grasp some primary components of number sense, such as the one-to-one correspondence principle or the understanding of cardinality. The finger counting method is therefore considered to provide a bridge between the child's likely innate capacity for numerosity and the development of a mature counting system (e.g., Gelman and Gallistel, 1978; Fuson, Richards and Briars, 1982; Fuson, 1988; Butterworth, 1999; Butterworth, 2005).

Considering the contribution of the finger counting strategy in the acquisition of numerical knowledges, it has been suggested that finger counting habits may influence the way that numbers are mentally represented and processed (Pesenti et al., 2000; Zago et al., 2001; Fias and Fischer, 2005; Di Luca et al., 2006; Fischer, 2006; Sato et al., 2007; Fischer, this issue). It is indeed conceivable that this strategy, constrained by our bodily experience and mapped within the sensorimotor system, may lead to a close relationship between finger and numerical representations. This assumption is indirectly supported by the fact that performance on finger discrimination tasks in 5- to 6-year-old children is considered as a good predictor of arithmetic abilities (Fayol, Barouilette and Marinthe, 1998; Noël, 2005). It has also been shown that a eight weeks training of finger differentiation in first-grade children improved finger gnosis as well as numerical performance (Gracia-Bafalluy and Noël, this issue). A possible relationship between fingers and numbers has also been reported in adults, where finger grip closure/opening as well as grasping movements are influenced by the perception of Arabic digit (Andres et al., 2004, Andres et al., this issue). Finally, several brain-imaging studies have shown that the part of the left precentral gyrus where hand movements are represented is activated during various numerical tasks, as in additions (Pesenti et al., 2000; Stanescu-Cosson et al., 2000), multiplications (Dehaene et al., 1996; Zago et al., 2001), subtractions (Rueckert et al., 1996), and number comparisons (Dehaene et al., 1996; Pesenti et al., 2000). From these results, some authors have suggested that the activation of the left precentral gyrus, together with those observed in the inferior parietal cortex, might be related to the involvement of a finger-movement neural network, and, by extension, might reflect a trace of a finger counting strategy (Pesenti et al., 2000; Zago et al., 2001; see also Kaufmann et al., this issue). This hypothesis has been investigated more directly in two recent studies, both testing right-handed Italian participants. In a behavioral study, Di Luca and colleagues (2006) asked participants to identify Arabic digits by pressing one of ten keys with one of their fingers. They showed that a right-to-left hand-digit mapping led to better performance than did a left-to-right hand-digit mapping. Using transcranial magnetic stimulation, Sato and colleagues (2007) reported, during a parity judgment task on Arabic numerals, an increase of corticospinal excitability of right hand muscles during the presentation of numbers from one to four, as compared to numbers from six to nine. Given that both studies reported a strong right-to-left hand-digit mapping preference in Italian participants when asked to count from one to ten (i.e., counting starts with the right hand from one to five and proceeds with the left hand from six to ten), these results thus likely suggest that hand-digit mapping used in finger counting may influence numerical processing.

Considering the suggested contribution of finger counting habits in numerical processing in both children and adults, the purpose of the current investigation was to examine a possible hand-digit mapping preference in finger counting in both French children and French adults. Concerning possible differences on hand-digit mapping in finger counting across development, it has been shown that between the ages of four and five, fingers are used in very different ways to keep track of number words while counting and solving additions (Fuson, 1988). Therefore, hand-digit mapping might be more variable in young children because of possible immature finger counting strategies. On the contrary, Conant (1892) found in four-to-eight years old American children a relatively uniform pattern of finger-digit mapping in finger counting (i.e., a preference for beginning to count with the thumb and then to proceed to the little finger), thus suggesting that a conventional sequence of counting words and the corresponding sequence of fingers has been already learned at age four. To disentangle these two alternative hypotheses, French participants of four different age groups (4-5 years old, 6-7 years old, 10-11 years old and 24-47 years old) were individually tested and asked to 'count with their fingers from one to ten', without indications concerning the hand(s) to be used.

Another goal of the present study was to test a possible relationship between handedness and hand-digit mapping. Considering previous studies (Di Luca et al., 2006; Sato et al., 2007) reporting a strong right-to-left hand-digit mapping preference in right-handed Italian adults, we hypothetized that handedness might constraint in some extent hand-digit mapping in finger counting. Given that human handedness is not a unidimensional trait and includes distinct behavioural characteristics, namely asymmetrical hand performance and hand preference in unimanual activities (e.g., Annet, 1970; Cavill and Bryden, 2003; Brown et al., 2004), both performance-based and preference-based measures of participants' handedness were evaluated by means of the standard Annett pegboard (Annett, 1970) and of an 8-item version of the Edinburgh Handedness Inventory (Olfield, 1971).

MATERIALS AND METHODS

Participants

One hundred and seventeen individuals, native French speakers, participated in the present study. Four different age groups were examined including 4-5 years old [AGE-1 group; mean age: 4.8; N=29; 13/16 males/females], 6-7 years old [AGE-2 group; mean age: 6.8; N=29; 11/18 males/females], 10-11 years old [AGE-3 group; mean age: 10.8; N=29; 13/16 males/females], and 24-47 years old [AGE-4 group; mean age: 35.6; N=30; 14/16 males/females]. All adult participants and children participant's parents gave informed consent, according to the requirements of the local ethics committee on research with human participants.

Materials and procedure

The experiment took place in a quiet room and consisted of a finger-counting task, a hand preference questionnaire and a hand performance task. All participants were tested individually, seated in front of the examinator, and underwent the three tasks in the following order.

At the beginning of the finger counting task, the hand posture of participants was fixed with both hand free and resting on a table. Participants were then asked to 'count with their fingers from one to ten', without indications concerning the hand(s) to be used. During the task, both the hand-digit and finger–digit mappings used to count and if the participant overtly verbalized the counting numbers were noted.

Then, they completed an 8-item questionnaire adapted from the Edinburgh Handedness Inventory (Olfield, 1971 – see Appendix A). To this aim, participants were asked to indicate their preferred hand for eight unimanual tasks. Each question permitted five responses with an associated score attributed to either the left hand (LH), the right hand (RH) or both. They were presented in the following order: 'use the left hand (LH: +1) or use the right hand (RH:+1)', 'always use the left hand (LH:+2) or always use the right hand (RH:+2)', or 'use both hands equally often (LH:+1 / RH:+1)'. Note that for young children, many cares were taken to administer the questionnaire. For all children, we first ensured that they understood the question and that they knew each action and object listed in the questionnaire. Furthermore, they were encouraged to mimic those actions for which they did not have a clear answer. Finally, in the very rare case they could not answer to a question, they were directly presented to the object and were asked to interact with it in order to determine a possible hand-preference.

Finally, participants were tested using the standard Annett pegboard (Annett, 1970). The pegboard was 32 by 18 centimeters (cm) with two rows of 10 holes drilled along each length. Each hole was approximately 1.2 cm in diameter, and the two rows were 15 cm apart. Ten pegs, 7.0 cm in length and 1.0 cm in width, were positioned along one length of the board. The pegboard was placed in front of the participants such that the row with pegs was farthest from them. The task consisted to move all 10 pegs as rapidly as possible, from the filled row to the empty row. Participants completed two trials with each hand, and the hand with which they began was randomized between them. They were timed using a stopwatch. If the participant dropped a peg, the trial was repeated.

In all the following analysis, the significance level was set at $p < .05$. When required, post-hoc analyses were conducted with Newman-Keuls tests.

RESULTS

Finger-counting analysis

During the finger-counting task, all participants but three (in the AGE-1 Group) showed the typical French finger–digit mapping where counting from 1 to 5, or from 6 to 10, starts with the thumb and proceeds to the little finger (i.e., thumb – fore finger – middle finger – ring finger – little finger). In addition, all participants but fourteen (12%) overtly verbalized the counting numbers. No significant effect of age group was observed when considering the percentage of participants who verbalized or not ($\chi^2(3) = 3.82$).

Considering hand-digit mapping, eighty-one participants (69%) used first their right hand to count from 1 to 5 and then their left hand to count from 6 to 10. Conversely, thirty participants (26%) used first their left hand to count from 1 to 5 and then their right hand to count from 6 to 10. The six other participants (5%) used a finger-counting strategy involving only the right hand, only the left hand or stopped counting after five. For further analyses, participants were divided in two sub-groups according to the hand-digit mapping used when counting (FC-L group: counting starts with the left hand; FC-R group: counting starts with the right hand). When considering the percentage of participants who start counting with their left hand or their right hand, a significant difference was observed ($\chi^2(1) = 25.85$, $p < .001$), although no significant effect of age group was found ($\chi^2(3) = 2.49$).

Preference score analysis

For each participant, a preference score was calculated from the questionnaire responses (corresponding to the difference between right and left hand scores divided by the sum obtained for the two hands: that is, (RH-LH) / (LH+RH)). Overall, a positive preference score was observed (+0.68), reflecting a strong dominance for the right hand. A one-way analysis of variance (ANOVA) of this measure revealed a significant age effect (AGE-1: +0.49; AGE-2: +0.65; AGE-3: +0.79; AGE-4: +0.80; $F(3, 113) = 5.34$, $p < .002$). Post-hoc analysis showed that the two older AGE-3 and AGE-4 groups exhibiting significantly higher positive preference scores than the younger AGE-1 group (all *p*'s < .005).

Participants were then classified as left-handers, mixed-handers or right-handers, when they achieved a preference score lower than -0.5, between -0.5 and +0.5, and higher than +0.5, respectively. According to these criteria, we found 3 left-handers (3%), 17 mixed-handers (15%) and 97 right-handers (83%). The proportion of participants who used first their left-hand or their right-hand to count differed significantly between left-handers, mixed-handers and right-handers ($\chi^2(2) = 8.60$, $p < .05$ – see Table 1), with the number of 'right starters' lower in the left-hander group than in the mixed-hander ($\chi^2(1) = 7.00$, $p < .02$) and right-hander ($\chi^2(1) = 8.25$, $p < .01$) groups (note that all the three left-handers began to count with their left hand).

Performance score analysis

For each participant, a performance score was calculated for each hand (corresponding to the mean movement time observed in the pegboard task averaged across the two trials – see Figure 1). A hand by age repeated measures ANOVA was conducted on these data. Main effects of hand ($F(1, 113) = 110.59$, $p < .0001$) and age group ($F(3, 113) = 177.45$, $p < .0001$) were found. The right hand (13.57 s) was signicantly faster than the left hand (15.25s). Post-hoc analysis revealed that all groups differed significantly from each other (AGE-1: 18.62s; AGE-2: 15.41s; AGE-3: 12.86s; AGE-4: 10.76s; all *p*'s < .0005). The interaction of age and hand was not significant ($F(3, 113) = 2.45$). Finally, in order to evaluate a possible relationship between the preference score (i.e., (RH-LH)/(LH+RH)) and the difference in hand performance as a ratio of movement time (i.e., (RH-LH)/(LH+RH)), four Pearson correlation tests were performed independently for each age group. A significant correlation between the two measures was found for the children's groups (AGE-1: $r = 0.49$, $p < .005$; AGE-2: $r = 0.65$, $p < .0001$; AGE-3: $r = 0.31$, $p = .05$) but not for adults (AGE-4: $r = 0.16$, $p > .19$). The absence of correlation in the adults' group is likely to reflect the strong right hand preference and right hand performance score observed for these participants.

Participants were then classified as left-handers or right-handers, according to a positive or a negative difference between the mean movement times between the left hand and the right hand. According to these criteria, we found 19 left-handers (16%) and 98 right-handers (84%). The proportion of participants who used first their left-hand or their right-hand to count was the same among these two groups ($\chi^2(1) = 0.30$ – see Table 1).

DISCUSSION

Two main results emerge from the present study. Firstly, a strong right-to-left hand-digit mapping preference was observed in the finger counting task. Secondly, a significant interaction between hand-digit mapping and hand preference was also found, with participants who used first their right (or conversely their left hand) to count exhibiting a higher (or lower) right hand preference for unimanual activities. These results were observed irrespective of the age group and suggest a connection between handedness and hand-digit mapping in finger counting in French individuals.

Before to discuss these findings, it is first important to note that the results from both the pegboard task and the questionnaire appear coherent with previous reports on manual asymmetry and on the development of hand preference and performance. The faster performance and larger preference scores observed for the right hand are of course compliant with the strong right hand dominance consistently reported in human populations. The fact that children aged from four to five years reported a much smaller right hand preference than that seen in children aged from ten to eleven years and in adults appears coherent with previous studies showing a smaller right hand preference in two to four years old children than in adults (De Agostini et al., 1992; Bryden et al., 2000). Finally, both the overall significant decrease in mean movement time across the age groups observed on the pegboard task and the fact that the difference between the hands did not fluctuate with age, as attested by the absence of interaction between hand and age, have also been previously reported (Annett, 1970; Kilshaw and Annett, 1983; De Agostini et al., 1992). In sum, the present results confirm a strong dominance of the right hand on both the performance-based and preference-based measures of handedness, irrespective of the age group.

The right-to-left hand-digit mapping preference in finger counting observed in both French children and adults has been previously reported in right-handed Italian adults (Di Luca et al., 2006; Sato et al., 2007). This preferential mapping seems however to contradict the findings of Conant (1896) and Fischer (this issue), suggesting that American children aged from four to eight years and English adults start counting by raising the fingers of their left hand. Conant's study was primarily designed to test for any uniformity in *finger-digit mapping* in finger counting. He found a preference for beggining to count with the thumb and then to proceed to the little finger, with only 57 on 206 children beginning with the little finger. Conant concluded that 'in finger counting, whether among children or adults, the beginning is made on the left hand'. However, despite this assertion, no indications concerning the instructions given to the children, the measures of handedness, and even, the frequency of the left-to-right hand-digit mapping in finger counting, are reported. It is therefore difficult to address the apparently opposite hand-digit mapping preference in finger counting between French and American children. One possible explanation might however come from the instructions given to the participants. Indeed, Conant argued that the left-to-right hand-digit mapping observed in finger counting is explained by the almost universal right-handedness in humans, the index finger of the right hand being used to mark the fingers counted on the left hand. However, in the present study, most participants began to count with their right hand <u>without</u> pointing with their left hand. Because such a pointing stategy was observed only in eleven participants (9%) in the present study, it is therefore conceivable that Conant asked participants something like to 'show *what* fingers they use to count', instead of asking them directly 'to count with their fingers' as in the present study. Hence, it seems that depending on the instructions, counting tool and tokens to be counted are separated limbs in the Conant's study (1896), while the same limber are agent and recipient of the process of counting in the present study.

In Fischer's study (this issue), a one-page questionnaire was used to estimate hand-digit mapping in English adults. To this aim, a schematic drawing of two supine hands with the thumbs pointing outwards was printed, together with the instruction to imagine counting with one's fingers from 1 to 10 and to then write the corresponding number next to each finger. In addition, a smaller set of data were collected by asking adult pedestrians to demonstrate how they count from 1 to 10 with their fingers. Results showed that 294 participants started to count with their left hand and only 151 with their right hand. However, because the data from counting demonstrations and written responses were not separately coded, an important limitation with this study, also mentioned by the author, is that the use of the questionnaire and the written response mode for the majority of participants may have induced a left-to-right bias. As previously discussed, another possibility is that instructions to either *count* or *show* the numbers on the hand might also be responsible for the apparently discrepant results observed between the two studies. Hence, given these opposite findings between Italian, French, American and English individuals, further studies using both questionnaires and counting demonstrations are required to further test possible cultural differences on hand-digit mapping in finger counting. In addition, it will be also useful to investigate whether participants would rely on the same counting strategy in a task where the use of fingers remains implicit (e.g., when counting months, days of the week, or letters) and whether finger counting habits for each individual would remain stable across trials and situations.

A second finding of the present study concerns the observed right-hand preference to start counting irrespective of the age group. As previoulsy mentioned, given that between the ages of four and five, fingers are used in very different ways to keep track of number words while counting and solving additions (Fuson, 1988), one could have expected hand-digit mapping to be more variable in young children because of possible immature finger counting strategies. However, the present task in which subjects were 'simply' ask to count from one to ten with their fingers clearly differs from that used by Fuson (1988). The fact that, in the present study, four-to-five years old children were able to correctly perform the finger counting task and overtly verbalized numbers likely suggests that both the conventional sequence of counting words and the corresponding sequence of fingers have been already learned at this age, although it does not necessarily mean that counting words have acquired a mathematical meaning for these children. In addition, the present study demonstrate that finger counting habits remain stable from childhood to adulthood, despite the less frequent use of fingers to count in adults (but see Kaufmann et al., this issue, for evidence for an age-dependent neurofunctional link between areas supporting finger use and nonsymbolic number processing). Finally, the fact that almost all participants overtly verbalized numbers while counting on their fingers is in keeping with with previous studies suggesting that the finger counting strategy provides a physical counterpart to number words and facilitates the acquisition of the one-to-one correspondence principle (Alibali and DiRusso, 1999; Andres, Seron and Olivier, 2007).

A last finding to be discussed is that participants who used first their right to count also exhibited a higher right hand preference for unimanual activities. This result thus likely suggests a connection between hand-digit mapping in finger counting and hand preference for unimanual activities. In light of recent studies suggesting a link between finger counting habits and numerical processing (Pesenti et al., 2000; Zago et al., 2001; Di Luca et al., 2006; Fischer, 2006; Sato et al., 2007; Fischer, this issue) and considering the left hemispheric dominance for manual coordination in right-handed people (e.g., Serrien, Ivry and Swinnen, 2006), this observed relationship between hand preference and hand-digit mapping used in finger counting appears coherent with the activation of the hand area of the left precentral gyrus observed during various numerical tasks (Dehaene et al., 1996; Rueckert et al., 1996; Pesenti et., 2000; Stanescu-Cosson et al., 2000; Zago et al., 2001) as well as the specific increase of the corticospinal excitability of the right hand muscles reported during both a parity judgment task (Sato et al., 2007) and a silent counting task (Andres, Seron and Olivier, 2007). They are however some clear limitations to this interpretation. Firstly, no interaction was found between hand-digit mapping and performances scores. In our view, this is likely due to the fact that preference-based data reflect a more cognitive and experience-based aspect of handedness, while the performance-based data rather reflect a pure motor component (Cavill and Bryden, 2003). Secondly, this result appears in conflict with Fischer's (this issue) report, showing that the proportion of left-starters and right-starters in a finger counting task was the same among left-handed and right-handed participants. As previoulsy mentioned, instructions to either count or show the numbers on the hand might be responsible for these differences. Finally, it is worthwhile noting that only three left handers were tested in the present study (note however that all three began to count with their left hand). Further studies testing a similar set of left-handed and right-handed participants are therefore required to confirm, or not, a relationship between hand-digit mapping in finger counting and hand preference for unimanual activities.

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APPENDIX

Appendix A. The 8-item questionnaire adapted from the Edinburgh Handedness Inventory (Olfield, 1971). Participants were asked to indicate their preferred hand for each unimanual tasks. Each question permitted five responses: ‘use the left hand’, ‘use the right hand’, ‘always use the left hand’, ‘always use the right hand’ or ‘use both hands equally often’.

Task
Writing
Drawing
Using scissors
Using a toothbrush
Using a knife (without fork)
Using a spoon
Using a broom (upper hand)
Opening a box (lid)

TABLES

Table 1. Participants' distribution of hand-digit mapping used in the finger-counting task in relation to participants' preferred hand (A) in the questionnaire and (B) in the pegboard task (see text for details).

(A).

Preferred Hand	Group	Left-hand first	Right-hand first
Left	AGE-1	1% (n=1)	0% (n=0)
Mixed	AGE-1	2% (n=2)	8% (n=9)
Right	AGE-1	2% (n=2)	13% (n=15)
Left	AGE-2	1% (n=1)	0% (n=0)
Mixed	AGE-2	1% (n=1)	3% (n=4)
Right	AGE-2	4% (n=5)	15% (=18)
Left	AGE-3	1% (n=1)	0% (n=0)
Mixed	AGE-3	0% (n=0)	0% (n=0)
Right	AGE-3	8% (n=9)	16% (n=19)
Left	AGE-4	0% (n=0)	0% (n=0)
Mixed	AGE-4	1% (n=1)	1% (n=1)
Right	AGE-4	7% (n=8)	17% (n=20)

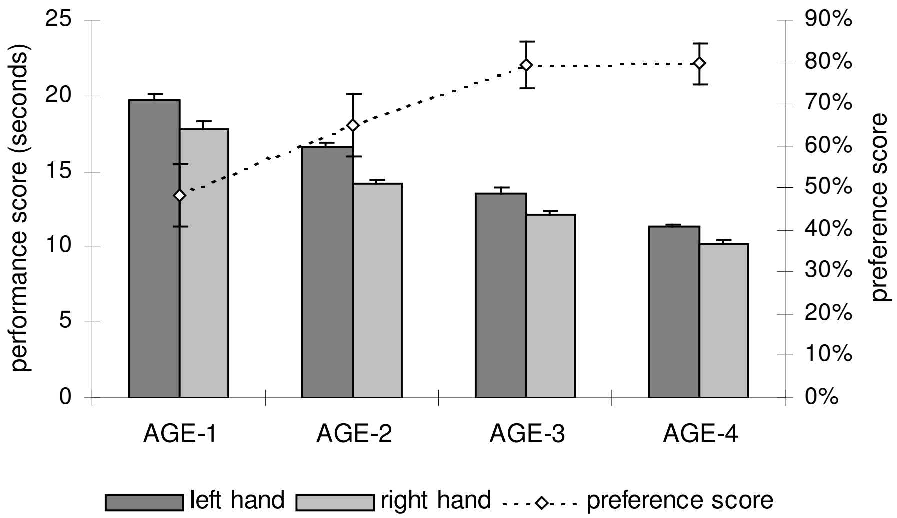
(B).

Preferred Hand	Group	Left-hand first	Right-hand first
Left	AGE-1	2% (n=2)	4% (n=5)
Right	AGE-1	6% (n=7)	14% (n=16)
Left	AGE-2	1% (n=1)	3% (n=3)
Right	AGE-2	8% (n=9)	14% (n=16)
Left	AGE-3	1% (n=1)	2% (n=2)
Right	AGE-3	5% (n=6)	17% (n=20)
Left	AGE-4	2% (n=2)	3% (n=3)
Right	AGE-4	3% (n=3)	18% (n=21)

FIGURES

Figure 1. Preference and performance scores according to (A) the four age groups and (B) the hand-digit mapping used in the finger counting task (A: FC-L group; B: FC-R group). The preference score was calculated from the questionnaire and corresponds to the difference between the right and left hand scores divided by the sum. The performance score corresponds to the mean movement time (in seconds) of the left and right hands observed in the pegboard task.

A)



B)