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The role of fingers in the development of counting and arithmetic skills

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ABSTRACT

Interactions between fingers and numbers have been reported in the existing literature on numerical cognition. The aim of the present research was to test whether hand interference movements might have an impact on children performance in counting and basic arithmetic problem solving. In Experiment 1, 5-year-old children had to perform both a one-target and a two-target counting task in three different conditions: with no constraints, while making interfering hand movements or while making interfering foot movements. In Experiment 2, first and fourth graders were required to perform addition problems under the same control and sensori-motor interfering conditions. In both tasks, the hand movements caused more disruption than the foot movements, suggesting that finger-counting plays a functional role in the development of counting and arithmetic.

1. Introduction

Following the observation that children use their fingers at an early age (Butterworth, 1999a,b) while learning counting (Fuson, 1988; Gelman & Gallistel, 1978) and basic arithmetic operations (Geary, 2004, 2007; Geary & Hoard, 2005), a large amount of research started to study the role that fingers play in the acquisition of the number concept. While fingers have traditionally been seen as the "missing tool" (Andres, Di Luca, & Pesenti, 2008) that sustains the assimilation of basic numerical abilities or the "missing link" (Fayol & Seron, 2005) that permits the connection between non-symbolic numerosities and symbolic numbers, new and compelling evidence which constrains this hypothesis has now been highlighted in the literature (see Crollen, Seron, & Noël, 2011 for a review).

Lafay, Thevenot, Castel, and Fayol (2013) for example developed a task in which preschoolers (between 4 and 5 years) were presented with sets of pictures. Participants were first asked to name the pictures one by one and just after to give the cardinal number of pictures in the collection. A very high correlation was observed between the frequency of finger use and the percentages of correct responses, thus supporting the idea that fingers are a useful tool in the development of the counting system. However, despite this correlation, the authors (Lafay et al., 2013) also reported that some children who never used their fingers were nevertheless able to perform optimally in the enumeration task. These observations, suggesting that finger-counting is not a necessary step for the acquisition of good counting abilities, are quite in line with the data reported by Crollen, Mahe, Collignon, and Seron (2011) These authors indeed demonstrated that blind children who did not use finger-counting could nevertheless develop their counting skills quite normally.

It has also been repeatedly observed that children use their fingers while learning to solve simple addition and subtraction problems (Jordan, Huttenlocher, & Levine, 1992; Jordan, Levine, & Huttenlocher, 1994). Accordingly, performance on finger gnosia tasks (i.e., the ability to distinguish which fingers have been lightly touched without visual feedback) was shown to be a good predictor of arithmetic performances: children with a weaker ability to identify and discriminate their fingers appeared to be less efficient in mathematical tasks than children with a high finger gnosia (Costa et al., 2011; Fayol, Barrouillet, & Marinthe, 1998; Noël, 2005). The specific sub-base-five structure of the finger-counting system (i.e., numbers larger than 5 always include a full hand representation) also appears to induce a disproportionate number of split five errors (i.e., errors deviating by the correct result by exactly ±5) when children (Domahs, Krinzinger, & Willmes, 2008) perform mental calculation. Finally, the act of making passive (Imbo, Vandierendonck, & Fias, 2011) and active (Michaux, Masson, Pesenti, & Andres, 2013) hand movements appears to disrupt basic arithmetic problem solving in adults.

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In this paper, we wanted to directly evaluate the impact of hand interference movements on the child's performance in counting and basic addition problem solving. To do so, 2 experiments were created. In Experiment 1, 5-year-old children were asked to perform a one-target and a two-target counting task in three different conditions: 1) a control 'resting' condition allowing an investigation of the spontaneous use of the fingers in the task; 2) a condition requiring concurrent hand movements which prevented the use of a finger-counting strategy; and 3) a condition requiring concurrent foot movements in order to assert the specificity of the putatively disruptive impact of hand movements on counting. If fingers are functionally related to the counting process in young children, then: 1) hand movements should be more disrupting than the interfering foot movements; 2) fingers should be used more frequently during a highly-demanding task (i.e., more in the two-target than in the one-target counting task); and 3) the hand interference movements should be more disrupting in the two-target task.

Experiment 2 was designed to measure the impact of hand interference movements on basic arithmetic. To do so, first-grade and fourth-grade children were asked to solve addition problems under the same three experimental conditions as described in Experiment 1 (control, hand interference and foot interference). While first graders were tested twice (at the beginning and at the end of the school year), fourth graders were only tested once. In this sense, we were able to perform a longitudinal as well as a transversal evaluation of children's performance. First graders were selected as they are at the beginning of the single-digit additions learning process. At the beginning of this school year, children mostly use counting strategies to solve additions (Carpenter & Moser, 1984; Geary, 1990) but they also learn to use more and more mature strategies along the year (e.g., from the counting all to the counting on procedure; Fuson, 1982). Accordingly, we wanted to examine the possible changes that occur in finger use while doing additions during grade 1. Fourth graders were tested as, at that age, children are supposed to retrieve simple addition solutions from long-term memory (Bailey, Littlefield, & Geary, 2012). As counting procedures are progressively replaced by memory retrieval through arithmetical fact learning (Siegler, 1987), we expect that the hand condition would be less interfering 1) for easy additions than for large additions and 2) at the end of the learning process (i.e., less disrupting for fourth graders than for first graders) rather than at the beginning of this process. Yet, as significant hand interference is still visible in adults (Imbo et al., 2011; Michaux et al., 2013), we expected a decrease but not a disappearance of that hand interference effect over development. In this experiment, we also tested children's finger gnosis as well as their memory skills in the phonological loop, visuo-spatial sketchpad and central executive. These measures were taken to examine their relations with arithmetic fact learning and the use of finger-counting.

2. Experiment 1

2.1. Method

2.1.1. Participants

We recruited 30 kindergarteners from 2 Belgian schools. However, 7 participants were discarded because they were unable to follow the instructions of the tasks. The remaining participants therefore included 10 girls and 13 boys between the ages of 5 years and 1 month and 6 years and 2 months ($M \pm SD = 5.6 \pm .4$), six of whom were left-handed. Written informed parental consent was obtained for all of the children.

2.1.2. Procedure

Children were required to perform two different counting tasks. In the *one-target counting* task, they had to count the number of times that a particular sound was presented within a sequence. In the *two-target counting* task, they were exposed to a series of 2 different but intermixed sounds and were asked to keep track and separately count the number of items of each of the 2 category lists.

As stimuli, we used two animal sounds (a dog and a horse) and two object sounds (a telephone and a fire alarm). The total number of sounds in both tasks was beyond the subitizing range: we used 2 different sequences of 6, 7 and 8 sounds and thus played a total of 6 sequences. In the one-target task, the sequence comprised either an animal sound or an object sound. Participants had to count and, at the end, report the number of sounds presented within the sequence. In the two-target task, each sequence was made of one animal sound and one object sound. The number of appearances of each target item ranged from 2 to 5 within a sequence. This was chosen in order to allow children to represent all the target quantities with their fingers. As shown in Table 1, three lists of stimuli pairs were used. Each item began with the presentation on the computer screen of a green light and ended with the presentation of a red light, both for 2000 ms, indicating respectively the beginning and the end of the sequence. Every sound lasted 1 s. In the one-target counting task, the inter-stimulus interval within each sequence varied between 600 and 1900 ms so that all sequences (of 6, 7 and 8 sounds) lasted 13,100 ms. In the two-target counting task, the inter-stimulus interval varied between 600 and 2400 ms so that all sequences lasted 16,600 ms. This was done to prevent children from using the duration of the sequence as a cue to approximate their count.

Each sequence in both tasks was also repeated in three different conditions: a control condition and two interference conditions. In the control condition, children were required to perform the counting tasks without any additional constraints. In the hand interference condition, children had to perform the counting task while repeatedly squeezing a ball in each hand. In the foot interference condition, children had to perform the task while repeatedly squeezing a ball with their feet. Contrary to the sound sequence, the rhythm of the interference movements was imposed as regular (one squeeze every second). To assist the children in maintaining this rhythm, a video representing the interference movements (i.e., a hand or a foot squeezing a ball every second) was shown in the center of the computer screen and children were asked to follow the rhythm of the video. The video was presented alone 8 s before the experimental trials began so that the children could practice the movements, and kept showing up until the end of the trial. During the experimental trials, the video lasted 25,000 ms in the one-target counting task and 28,000 ms in the two-target counting task. The experimenter checked whether the children were correctly following the imposed rhythm of the interference movements. Children who could not manage to do it were discarded ($n = 7$). The three different lists of items were counterbalanced across conditions. The order of tasks and conditions was counterbalanced across participants. The experimenter noted the children's responses and then calculated their accuracy scores. One point was given for each correct response. The experimenter also noted the number of times that a child used his fingers to perform the task (this number was divided by the total number of items in the task and multiplied by 100 to give a percent measure). Procedures were approved by the Research Ethics Boards of the University of Louvain, Belgium.

Table 1
Lists of items used in the two-target counting task.

List 1		List 2		List 3	
Target 1	Target 2	Target 1	Target 2	Target 1	Target 2
Horse (4)	Phone (4)	Dog (3)	Alarm (3)	Dog (3)	Phone (3)
Phone (5)	Horse (2)	Horse (5)	Phone (2)	Phone (5)	Dog (2)
Horse (3)	Alarm (3)	Alarm (4)	Dog (3)	Horse (4)	Alarm (3)
Phone (4)	Dog (2)	Horse (4)	Alarm (4)	Phone (5)	Horse (3)
Alarm (5)	Dog (3)	Phone (4)	Horse (2)	Dog (4)	Alarm (4)
Dog (4)	Alarm (3)	Phone (5)	Dog (3)	Alarm (4)	Horse (2)

The number of target sounds is in parentheses.