Cognition 133 (2014) 91–96

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Brief article

Visual experience influences the interactions between fingers and numbers

Virginie Crollen[a,b,*], Marie-Pascale NoëL[a], Xavier Seron[a], Pierre Mahau[a], Franco Lepore[b], Olivier Collignon[c,*]

[a] Institut de Recherche en Sciences Psychologiques (IPSY), Centre de Neuroscience Système et Cognition (NeuroCS), Université Catholique de Louvain, Belgium
[b] Centre de Recherche en Neuropsychologie et Cognition (CERNEC), Université de Montréal, Canada
[c] Centre for Mind/Brain Science, University of Trento, Italy

ARTICLE INFO

Article history:
Received 16 September 2013
Revised 13 May 2014
Accepted 7 June 2014

Keywords:
Finger-counting
Blindness
Grounded cognition

ABSTRACT

Though a clear interaction between finger and number representations has been demonstrated, what drives the development of this intertwining remains unclear. Here we tested early blind, late blind and sighted control participants in two counting tasks, each performed under three different conditions: a resting condition, a condition requiring hands movements and a condition requiring feet movements. In the resting condition, every sighted and late blind spontaneously used their fingers, while the majority of early blind did not. Sighted controls and late blind were moreover selectively disrupted by the interfering hand condition, while the early blind who did not use the finger-counting strategy remained unaffected by the interference conditions. These results therefore demonstrate that visual experience plays an important role in implementing the sensori-motor habits that drive the development of finger–number interactions.

1. Introduction

The finger-based representation of numbers has often been advocated as an instance of grounded cognition (e.g., Fischer & Brugger, 2011; Wilson 2002). Since performance on finger discrimination tasks was shown to be a good predictor of arithmetic abilities (Fayol, Barrouillet, & Marinthe, 1998; Noël, 2005), it has indeed been argued that fingers may be 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 arithmetic. Developmental (Butterworth, 1999a; Costa et al., 2011), neuroimaging (Harrington et al., 2000; Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004; Tschentscher, Hauk, Fischer, & Pulvermüller, 2012), and neuropsychological (Barnes, Smith-Chant, & Landry, 2005; Gerstmann, 1930; Thevenot et al., 2014) evidence demonstrating the close intertwining between fingers and symbolic numbers have accordingly been accumulated over the last two decades.

Recently, however, it has been highlighted that blind children used the finger-counting strategy less spontaneously than their sighted peers despite achieving similar level of counting and finger gnosis (i.e., finger recognition and localization) performance (Crollen, Mahe, Collignon, & Seron, 2011). This study has far-reaching implications since it presumes that the development of finger–number interactions (i.e., the associations between symbolic

* Corresponding authors. Address: Institut de Recherche en Sciences Psychologiques (IPSY), Centre de Neuroscience Système et Cognition, Université Catholique de Louvain, Place Cardinal Mercier 10, B-1348 Louvain-la-Neuve, Belgium. Tel.: +32 10 47 40 89 (V. Crollen). Address: CIMeC – Center for Mind/Brain Sciences, University of Trento, via delle Regole 101, Mattarello, TN, Italy. Tel.: +39 0461 282778; fax: +39 0461 883066 (O. Collignon).

E-mail addresses: virginie.crollen@uclouvain.be (V. Crollen), olivier.collignon@unitn.it (O. Collignon).

http://dx.doi.org/10.1016/j.cognition.2014.06.002
0010-0277/© 2014 Elsevier B.V. All rights reserved.

numerical processing and finger movements) relies on sensori-motor habits that are driven by vision. In this paper, we examined the impact of hand interference on the counting performance of blind adults. This experiment will therefore allow us to exclude the idea that finger-counting develops later in blind people on the basis of non-visual cues (e.g., kinematic/proprioceptive). It will also allow us to exclude the idea that finger-counting was present in blind children but that it did not manifest by an explicit motor behavior (e.g., absence of voluntary motor activity but increased cortico-spinal activity of hand muscles; Andres, Seron, & Olivier, 2007). If finger and number representations actually share common cognitive and/or brain resources, a motor interference task involving the fingers should disrupt counting abilities by adding noise in the shared system.

In the present research, early blind (EB), late blind (LB) and sighted control adults (SC) were tested with 2 counting tasks and 1 memory task carried out under 3 different conditions: (1) a control 'resting' condition; (2) a condition requiring the realization of hand movements unrelated to finger-counting; and (3) a condition requiring the realization of feet movements. If early vision does not shape the interaction between fingers and the symbolic representation of numbers, all participants should spontaneously use their fingers to count and should manifest a hand interference effect (i.e., the hand interfering condition should be more disrupting than the feet condition). In contrast, if early vision is important for the development of the finger–number interactions, early blind individuals should less use their fingers and the hand interfering condition should not be more disrupting than the feet condition in this population. Moreover, as participants were also involved in a working memory task (listening span test) under the same control and sensori-motor interference conditions, our experiment allowed us to test whether hand interference effects (Imbo, Vandierendonck, & Fias, 2011; Michaux, Masson, Pesenti, & Andres, 2013) would disrupt participants' counting performance more than their performance in the listening span test.

2. Method

2.1. Participants

One group of 15 sighted and two groups of blind participants (11 early and 14 late blinds) took part in the study (see supplemental Table 1 for a detailed description of the different groups). In terms of age, the SC did not statistically differ from the EB ($p > .2$) and LB ($p > .1$) groups. Unlike the EB, all LB participants had experienced functional vision before sight loss. At the time of testing, the participants in both blind groups were totally blind or had, at the utmost, only rudimentary sensitivity for brightness differences and no patterned vision. In all cases, blindness was attributed to peripheral deficits with no additional neurological problems. Procedures were approved by the Research Ethics Boards of the University of Montreal. Experiments were undertaken with the understanding and written consent of each participant. Sighted participants were blindfolded when performing the tasks.

2.2. Conditions

Each of the three tasks (see the tasks section below) was performed in three different conditions. In a control condition, participants were required to perform the tasks without any constrain. In the hand interference condition, participants had to perform the tasks while pressing a ball placed in each hand. Finally, in the foot interference condition, participants had to perform the tasks while pressing a ball placed beyond each foot.

The rhythm of the interference movements was irregular (between 1500 and 2400 ms) and imposed by a vibrotactile bracelet which was carried on the wrist in the hand interference condition and on the ankle in the foot interference condition (see supplemental data for a detailed description of the bracelet).

Before the realization of the experimental tasks, a 5-min training session was performed with the bracelet alone so that participants could train themselves on the movements. During the experimental tasks, the tactile stimulations stopped as soon as participants reported the completion of one trial and started as soon as a new trial was initiated.

2.3. Tasks

2.3.1. Enumeration task

In order to test the ability to keep track of a number of enumerated items, participants were required to name a specific number of exemplars from 10 different target categories (e.g., can you give me 9 names of boys). The target number ranged from 5 to 9. Three lists of items were created and counterbalanced across participants and conditions. Within a list, each target number was repeated twice, once in a semantic condition (e.g., can you give me 7 names of tools) and once in a phonological condition (e.g. can you give me 7 words which begin with the letter O). Four training trials were presented before the experimental ones. During the instructions, experimenter emphasized that participants had to stop the enumeration process (by saying "STOP") as soon as they thought achieved the required target number of words. Participants were instructed to emphasize accuracy over response speed. Experimenter noted the number of words uttered by the participants. As the three lists of stimuli involved different reaction times in the baseline condition of the task, only accuracy scores (i.e., number of trials correctly completed – maximum score of 10) were analyzed for each participant in each condition.

2.3.2. Ordered series manipulation task

In order to test participants' ability to count a particular number of items, participants were asked 15 questions requiring the manipulation of the letters of the alphabet (e.g., how many letters are there between 'c' and 'h'?) and 15 questions requiring the manipulation of the months