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Simple arithmetic development in school age: The coactivation and selection of arithmetic facts

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A B S T R A C T

We evaluated the possible inhibitory mechanism responsible for selecting arithmetic facts in children from 8 or 9 years to 12 or 13 years of age. To this end, we used an adapted version of the negative priming paradigm (NP paradigm) in which children received additions and they decided whether they were correct or not. When an addition was incorrect but the result was that of multiplying the operands (e.g., 2 + 4 = 8), only children from 10 or 11 years of age onward took more time to respond compared with control additions with unrelated results, suggesting that they coactivated arithmetic knowledge of multiplications even when it was irrelevant to perform the task. Furthermore, children from 10 or 11 years of age onward were slower to respond when the result of multiplying the operands was presented again in a correct addition problem (e.g., 2 + 6 = 8). This result showed the development of an inhibitory mechanism involved in the selection of arithmetic facts through formal education.

Introduction

In the field of numerical cognition, it is assumed that arithmetic facts are stored in long-term memory within an associative network whose nodes are interrelated. When a simple problem is presented

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(e.g., an addition, 2 + 4), nodes that represent the operands of the problem (2 and 4) and that representing the solution (6) are activated, so people can provide the correct solution directly by retrieving the problem from memory (Campbell & Graham, 1985).

During early years of schooling, children expend a lot of time memorizing multiplication facts to solve the problems by the retrieval of the stored answers in memory (Siegler, 1986). Several studies have evaluated the changes in the use of retrieval of arithmetic facts with age (Cooney, Swanson, & Ladd, 1988; Imbo & Vandierendonck, 2007, 2008; Lemaire & Siegler, 1995). Imbo and Vandierendonck (2008) examined this question in children from second, fourth, and sixth grades of elementary school and showed that the use of retrieval from memory to resolve multiplication and addition problems increased with the educational level in a progressive manner (60.0%, 80.5%, and 79.5% in second, fourth, and sixth grades, respectively). Hence, the probability of using the retrieval from memory seems to increase when children advance in educational cycles.

When the associative network of arithmetic facts is established, adult individuals coactivate several related nodes during the resolution of mathematical problems (Ashcraft, 1992). Hence, when two operands of an addition are presented (e.g., 2 + 4), the result of multiplying the two operands (8) is activated even when the multiplication result is not needed to resolve the addition problem. Thus, when individuals are solving additions, the coactivation of the arithmetic fact associated with the multiplication would compete and an interference effect would be observed, so the participants' performance in the addition task would be impaired.

There is empirical evidence to support the concurrent coactivation of arithmetic facts associated with additions and multiplications in adults (Winkelman & Schmidt, 1974; Zbrodoff & Logan, 1986; see Grabner, Ansari, Koschutnig, Reishofer, & Ebner, 2013, for the neural correlate of this coactivation effect). One procedure frequently used to corroborate this coactivation is the verification of additions (Winkelman & Schmidt, 1974; Zbrodoff & Logan, 1986). In this task, a simple addition is presented (i.e., a pair of one-digit operands and a result), and participants have to decide whether the result is the correct solution of the addition problem. The critical trials are those associated with negative responses (incorrect addition problems). In these trials, participants show an interference effect, so they take more time to respond when the result presented with the addition is incorrect but it is the one of multiplying the operands (2 + 4 = 8) relative to a control condition in which the result is unrelated (2 + 4 = 10). This longer reaction time when the incorrect addition result is the one of multiplying the operands has been taken as an index of the simultaneous activation of addition and multiplication arithmetic facts (Grabner et al., 2013; Lemaire, Fayol, & Abdi, 1991; Winkelman & Schmidt, 1974; Zbrodoff & Logan, 1986).

With regard to child population, Lemaire and colleagues (1991) found that children in fourth and fifth grades (9–10 years of age) already presented interference effects due to the coactivation of arithmetic facts when they had to verify simple addition and multiplication problems. Moreover, these authors showed that this phenomenon was partially automatic because the activation of related answers was produced unintentionally in all cases after the presentation of the operands and only *partially* because the coactivation effect disappeared when the experimental procedure included a delay between the operands and the result of the problem above 300 or 500 ms. This abolishment of the coactivation effect depended on grade; fourth-grade children showed the interference effect when the delay between the operands and the result was 500 ms but not with a small delay (300 ms), whereas the interference effect was eliminated with both delays in fifth-grade children. These results suggest that when educational grade increases, the strength of associations between operands and answers becomes stronger. Thus, children in a higher grade can select the correct answer quickly. Furthermore, the authors proposed that suppression of irrelevant answers underlies the selection of correct arithmetic facts; however, they did not explore this conclusion. The current study aimed to address this mechanism and its development with age.

It is difficult to answer a problem whose result is the one of multiplying the operands (e.g., 2 + 4 = 8). Nevertheless, people are able to resolve it correctly most of the time (i.e., to say that 2 + 4 = 8 is incorrect). It has been proposed that the conflict produced by the coactivation of several arithmetic facts is solved by an inhibitory mechanism (Campbell & Dowd, 2012; Campbell & Thompson, 2012; but see Censabella & Noël, 2004, for an alternative explanation). Campbell and colleagues (Campbell & Dowd, 2012; Campbell & Thompson, 2012) used an adaptation of the retrieval