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Effects of mental abacus training over cognitive flexibility: An exploratory study

Efecto del entrenamiento en ábaco mental sobre la flexibilidad cognitiva: un estudio exploratorio

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Abstract

Mental Abacus (MA) training teaches students to solve math problems by visualizing a physical abacus structure to perform arithmetic operations. Research shows that MA practice relates with enhanced working memory in children, but other cognitive processes that could mediate the benefits registered remain unknown. The aim of the study was to analyze the effect of MA training in a cognitive flexibility task in twelve-year-old children, and compare it with a control group. 121 children from the sixth course of primary education were recruited. 54 students received MA training added during the academic year, while the control group received normative arithmetic instruction. MA training was provided by UCMAS Mental Arithmetic Spain S.L. To assess cognitive flexibility, we used the Trail Making Test (TMT). Data analysis entailed parametric assumptions check and a one-way ANOVA between MA and control group. There were no differences between groups in age. There were statistical differences in TMT-A (Z=-5,78, p<,001, d=,67) and TMT-B scores (Z=-2,24, p=,021, d=,08). Our data suggest that MA enhances cognitive flexibility in children. MA is a promising tool teaching math which benefits go beyond arithmetic calculation.

Key Words

Mental Abacus, Cognitive Flexibility, Arithmetic Computation

Resumen

El Ábaco Mental (AM) enseña a los estudiantes a resolver problemas matemáticos visualizando la estructura de un ábaco para realizar operaciones aritméticas. Estudios previos muestran que el AM se relaciona con mejor memoria de trabajo verbal en niños, pero otros procesos cognitivos no han sido estudiados aún. El objetivo del estudio fue analizar el efecto del entrenamiento en AM sobre la Flexibilidad Cognitiva (FC) en niños de doce años, y compararlo con un grupo control. 121 niños de sexto curso de primaria fueron reclutados. 54 estudiantes recibieron entrenamiento en MA durante el año académico, proporcionado por UCMAS Mental Arithmetic Spain S.L., mientras que el grupo control recibió clases de aritmética enseñadas con el método normativo. Para evaluar la FC se usó el Trail Making Test (TMT). El análisis de datos implicó evaluación de criterios paramétricos y un ANOVA de una vía sobre las puntuaciones del TMT. No hubo diferencias de edad entre grupos. Se encontraron diferencias en TMT-A (Z=-5,78, p<,001, d=,67) y TMT-B (Z=-2,24, p=,021, d=,08). Los datos sugieren que el AM mejora la FC en niños. AM es una técnica prometedora cuyos efectos van más allá del cálculo aritmético.

Palabras clave

Ábaco Mental, Flexibilidad Cognitiva, Cálculo Aritmético

1. INTRODUCTION

Abacus is a physical device that allows to perform arithmetic calculation −addition, division, subtraction, multiplication and root calculations (Li, Chen & Huang, 2016; Stigler, 1984)− with multiple digits. Abacus has a long history in Asian countries: dating 1200 AD, it probably derives from Roman counting boards and was employed for accurate and rapid calculation along the history (Frank & Barner, 2012; Li et al., 2016; Menninger, 1969). Nowadays, abacus has been converted into an educational tool to improve arithmetic abilities in children, especially in Asian cultures (Cui et al., 2020). Several abacuses are available for arithmetic calculation, but the most frequent is the Japanese *soroban* abacus. Abacus is constituted by columns of beads divided by a horizontal beam on the top, the reckoning bar. Each column represents a place value (e.g., ones, tens, hundreds, thousands, etc.) and increases from right to left (see Figure 1). When performing a computation, the beads are moved towards the central beam associating each place to a value. Users of abacus can perform calculation mentally using mental image of an abacus and without the support of the physical device. This method is known as Mental Abacus (MA) calculation (Hatano, Miyake & Binks, 1977). Evidence in literature show that MA improves arithmetic abilities (Barner, Álvarez, Sullivan & Frank, 2016; Chen, Wang & Wang, 2011; Cui et al., 2020; Hanakawa, Okada, Fukuyama & Shibasaki, 2003; Stigler, 1984) and mental calculation in trained subjects compared to not-trained participants (Chen et al., 2011; Du et al., 2014; Stigler, 1984).

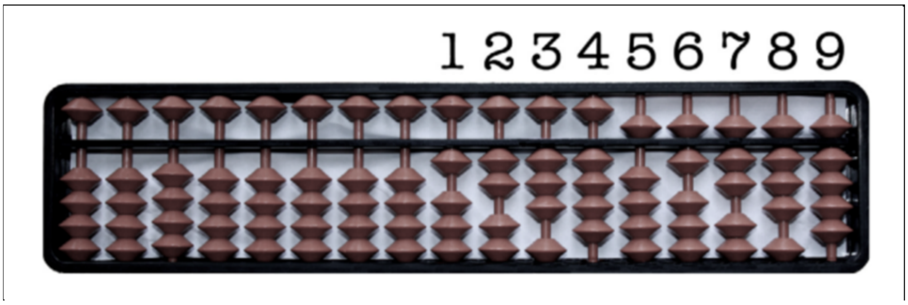

Figure 1. *Soroban* abacus used for MA training. Adapted from Frank & Barner (2012)

As described by Hatano, Miyake & Binks (1977), MA students first learnt to do calculation on a physical abacus using their fingers, then students leave the physical help to start imagining the beads and moving them using fingers in the air. Finally, when students are skilled enough performing arithmetic operations with the abacus, they calculate numbers without any support. During mental calculation, MA users perform a sequence of visual manipulations of an abacus image (Brooks, Barner, Frank & Goldin-Meadow, 2018) which recruits visual imagery and representation processes. Therefore, MA calculation entails multiple cognitive processes, such as number recognition, working memory and manipulation of mental representation (Hanakawa et al., 2003). In this regard, prior works have found differences between people trained in MA and no-trained in cognitive processing during mental calculation (Frank & Barner, 2012), as well in strategies used for calculation: MA subjects rely in visuospatial clues rather than semantic strategies (Li et al., 2016). Taken together, these results point to an implication of executive functioning as there is a need of coordination of cognitive processes.

Executive functions are a set of coordinated top-down processes which drive daily performance of several cognitive domains (Miller & Cohen, 2001). Executive functions have a strong relation with reading and math performing in children, as children with poor executive functions perform worse compared than children with higher executive functioning (Clair-Thompson & Gathercole, 2006; Roebers, Cimeli, Röthlisberger & Neuenschwander, 2012). A key element of executive functions is cognitive flexibility which refers to the ability to shift between discrepant tasks or goals (Buttelmann, Karbach & Bastian, 2017). Cognitive flexibility is particularly relevant in math tasks due subjects are required to explicitly switch between different aspects of arithmetical strategies (Agostino, Johnson & Pascual-Leone, 2010; Stad, Heijningen, Wiedl & Resing, 2018; Yeniad, Malda, Mesman, Ijzendoorn & Pieper, 2013). Research showed that MA leads to changes in basic cognitive capacities such as working memory (Barner et al., 2016), which function is to maintain temporary information during a cognitive performance (Baddeley, 2003; Lee, Lu & Ko, 2007). Also, there is evidence pointing to a positive effect of MA over verbal working memory. Dong et al. (2016) reported improvements of both verbal and visuospatial working memory in people trained in the use of MA. In sum, the findings suggest that MA practice has a positive effect over the putative cognitive process underlying mathematic abilities. However, to our best knowledge none study has addressed its effects over cognitive flexibility in children. This is an important issue as cognitive flexibility is a key process in arithmetic computation in children (Stad et al., 2018).

Based on the suggestive findings of the literature reviewed above, our study aims to assess how MA training could enhance cognitive flexibility development in children of eleven to twelve years old. To face this challenge, we designed a cross sectional study where two groups of children of the same course and age, but one with experience in MA calculation, were compared in a cognitive flexibility task.

2. METHODS

2.1. Design

121 students from the sixth course of primary education were recruited from two different centers. Fifty-four students from the center “El Centro Inglés” received MA training to learn arithmetic. MA training was delivered by specialist teaching staff from UCMAS Mental Arithmetic Spain S.L. Data from the control group was gathered from

a prior unpublished work and consisted in 67 students from a public school that received classic arithmetic lessons delivered by routinely staff.

2.2. Procedure

Centers were contacted by the research team assisted by UCMAS Mental Arithmetic Spain S.L. staff. Assessment was conducted during standard classroom hours to minimize the effect over daily students' routines. One member of the research team, assisted by the math teacher of each classroom, delivered the instruments sheets to the participants and asked them to fulfill the demographic questionnaire and get ready fot the TMT test. Once ready the researcher started the clock and participants had 30 seconds to complete TMT-A. Then, after two minutes for resting, participants started TMT-B for another 30 seconds. The process was repeated for each classroom, and students were separated by a minimum of one meter to avoid distraction.

2.3. Intervention

Control arithmetic teaching followed the recommendations of Spanish Ministry of Education and County Office Education for arithmetic contents of the subject Math corresponding to the sixth grade of primary education. Control arithmetic was taught by routinely teaching staff.

MA group received additional training in arithmetic with UCMAS Mental Arithmetic Spain S.L. abacus Training. Academic board from “El Centro Inglés” introduced use of UCMAS Mental Arithmetic Spain S.L. teaching in the curriculum design of the primary education. As such, students spend one hour and fifteen minutes each week to the MA training, in two weekly sessions. Participants in the MA group of the study were taught to combine positive and negative integers, as well addition and subtraction arithmetic operations using the UCMAS Mental Arithmetic Spain S.L. methodology. MA intervention was delivered by routinely teaching staff from “El Centro Inglés” specifically trained by UCMAS Mental Arithmetic Spain S.L.

2.4. Instruments

Assessment battery comprised:

- Sociodemographic questionnaire to collect age. Gender, and classroom of each participant.
- To assess cognitive flexibility Trail Making Test (Army Individual Test Battery, 1944) was used. This well-established test comprises two parts, A and B. In part A, the task is to use a pencil to connect consecutively numbered circles presented on an A4-sized sheet as quickly as possible. This provides a measure of visuo-motor attention and information processing speed. In part B, the task is to connect numbers and letters in an alternating sequence. Part B hence places additional demands on attentional switching, which is related with cognitive flexibility. Keeping in mind that the assessment procedure should be as shorter as possible, we decided to adapt TMT to perform a collective evaluation. Thus, the scores were computed as elements processed in 30 seconds, which were used as raw scores.

2.5. Data analysis

Descriptive statistics were generated for age and sex. Before proceeding any manipulation check, homoscedasticity and normality assumptions were checked using Shapiro-Wilk test and Levene's Test respectively. If parametric assumptions were not met Kruskall-Wallis was used to assess differences between groups. Group (MA vs Control) was set as independent variable, and performance in TMT-A and TMT-B was set as outcome variable. Effect size was estimated using Cohen's *d*. Analyses were carried over with jamovi software (The Jamovi Project, 2020).

3. RESULTS

There were no differences in age (t = 0,01, p = ,989) nor in sex distribution (χ^2 = 0,02, p = ,895). Table 1 shows detailed data about the demographic features of the sample, and performance in TMT-A and TMT-B as well.

	Total sample (*n* = 121)	Control group (*n* = 67)	MA group (*n* = 54)
Age (*mean*, SD)	10,52 (,5)	10,51 (,5)	10,53 (,5)
Sex (*n*, %)			
- Male	53 (42,7)	29 (43,3)	24 (42,1)
- Female	71 (57,3)	38 (56,7)	33 (57,9)
TMT-A (*mean*, SD)	22,6 (2,32)	21,5 (2,57)	24 (,74)
TMT-B (*mean*, SD)	20,3 (2,23)	19,9 (1,97)	20,7 (2,46)

Table 1. Demographic features and performance in cognitive tests of the sample

Normality assumption was not met in TMT-A (W= ,82, p < ,001) and TMT-B scores (W= ,95, p < ,001), and homoscedasticity as well for TMT-A (F= 57,56, p < ,001) and TMT-B (F= 5,32, p= ,023) scores. Therefore, the manipulation check was performed according to a non-parametric approximation. Figure 2 shows the density diagrams of the scores by intervention group.

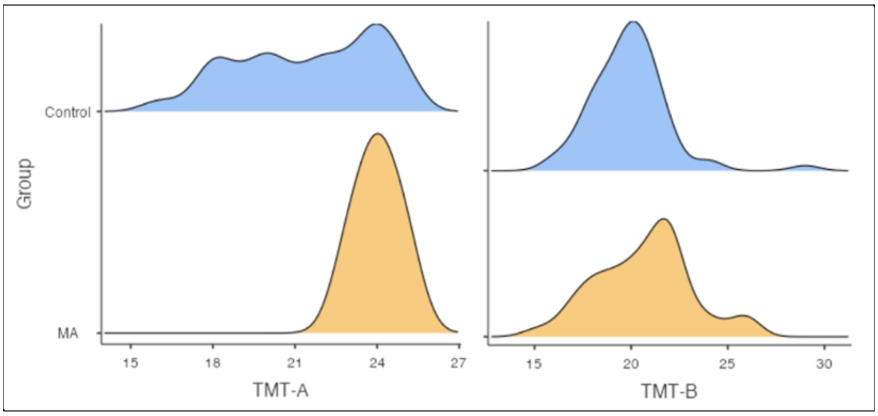

Figure 2. Density diagrams of TMT scores by intervention group

MA group performance in TMT-A (*Mdn*= 24) when compared with Control group (*Mdn*= 22) was found significantly higher TMT-A (Z= -5,78, p < ,001, d = ,67). Regarding TMT-B, the median performance of MA group (*Mdn*= 21) was higher (Z= -

2,24, = ,021, *d*= ,08) than Control group (*Mdn*= 20). Figure 3 displays visually the difference between groups.

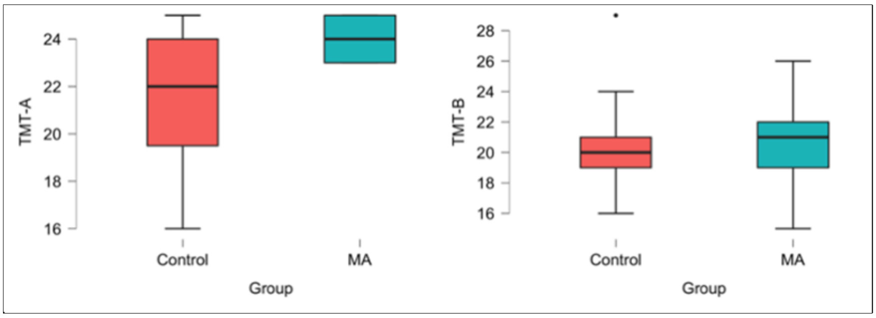

Figure 3. Boxplot of participants' performance in TMT-A and TMT-B

4. DISCUSSION

The main finding of our study is that MA training enhances cognitive flexibility in students from the sixth course of primary education. The benefits of MA training go beyond cognitive flexibility and also enhances psychomotor speed processing.

Children who were trained in MA, performed better in the cognitive flexibility test compared to their peers instructed with a regular computation teaching. The effect size registered in our study points to a small effect size. Cognitive flexibility is crucially involved in children's math ability, and children could benefit from MA training to strengthen their math abilities. Our research is consistent with previous findings which see cognitive flexibility a significant predictive value for young children's' math attainment in schools (Stad et al., 2018). Moreover, performance in cognitive flexibility is related in students with better probabilistic thinking (Feng, Perceval, Feng & Feng., 2020) which is a milestone of educational systems in developed countries. Although effect size was small, the relevance is highlighted by the difficult of alter the development rate speed of a basic cognitive process (Zelazo, 2013). Cognitive flexibility is a psychological process that reaches their maximum normative development at the age of 12 years (Anderson, 2002), therefore any intervention that could promote an enhancement in this domain should be considered.

Enhancement in cognitive flexibility and psychomotor speed as a consequence of MA training may be explained by the cortical areas involved in the acquisition of MA skills. Neuroimaging studies reported a correlation between MA training and the activation of frontoparietal areas (Du et al., 2013; Hanakawa et al., 2003). Also, MA has been associated to greater activation in cortical areas related to visuo-spatial working memory, including the bilateral superior frontal sulcus and superior parietal lobule in abacus experts (Brooks et al., 2018; Du et al., 2013). As frontoparietal connectivity is associated with development of executive functioning, MA training could be a tool to foster maturation of these areas. On the other hand, recent research showed that modify how children code information in classroom leads to better performance in executive functioning tasks (Arfé, Vardanega, Montuori & Lavanga, 2019). Keeping in mind that MA entails a change in the strategy of represent mathematical symbols, then improvement in cognitive flexibility may be accounted to the switch in the coding information paired to MA training.

Our study has limitations that deserve mention. The sample size, although enough to carry over the analysis, should be larger to increase the statistical power of the findings. Also, students were not driven from the same school which limits the conclusions, though all of them were recruited from the same country and educational framework. Finally, while TMT is a reliable instrument to assess cognitive flexibility for an exploratory study, the collective setting for assessment does not prevent the influence of third variables that could confound the results. On the other hand, strengths of our study are the novelty of the cognitive domain assessed, the support of an educational-devoted company like UCMAS Mental Arithmetic Spain S.L, the assessment carried over in a familiar context for the participants, and be the first study analyzing the effects of MA over cognitive flexibility in children. Future research should address if these changes are maintained over time, as well replicate the findings using other instruments that assess cognitive flexibility.

Overall, the findings of the current study suggest that cognitive MA training is promising in enhancing cognitive flexibility in children of 12 years. Bearing in mind the relevance of cognitive flexibility in the cognitive development of children, use of MA should be considered as a topic to be included in primary education study programs.

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