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Enhancement of numeric cognition in children with low achievement in mathematic after a non-instrumental musical training

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ABSTRACT

Studies suggest that musical training enhances spatial-temporal reasoning and leads to greater learning of mathematical concepts. The aim of this prospective study was to verify the efficacy of a Non-Instrumental Musical Training (NIMT) on the Numerical Cognition systems in children with low achievement in math. For this purpose, we examined, with a cluster analysis, whether children with low scores on Numerical Cognition would be grouped in the same cluster at pre and post-NIMT. Participants were primary school children divided into two groups according to their scores on an Arithmetic test. Results with a specialized battery of Numerical Cognition revealed improvements for Cluster 2 (children with low achievement in math) especially for number production capacity compared to normative data. Besides, the number of children with low scores in Numerical Cognition decreased at post-NIMT. These findings suggest that NIMT enhances Numerical Cognition and seems to be a useful tool for rehabilitation of children with low achievement in math.

What this paper adds?

This study focused on a very important topic that has theoretical and practical implications for Mathematical Learning disabilities (i.e. whether there might be an effect of musical training on numerical cognition). Specifically, the authors aimed to show beneficial effects of a (non-instrumental) musical training on children's performance on numerical tasks. And results showed that children who exhibited deficits in numerical tasks at pre-test showed fewer deficits at post-test, precisely for Number Production following Musical training.

1. Introduction

Numerical Cognition, such as number-processing and calculation, is indispensable for daily life. According to McCloskey, Caramazza, and Basili (1985) number-processing can be divided into two components: number comprehension, which involves the understanding of numeric symbols, and number production that includes reading, writing, and counting numbers. By contrast, calculus is a system necessary to perform mathematical operations using symbols or words (addition, subtraction, multiplication, and division).

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In terms of neurodevelopment, the five systems of Numerical Cognition gradually increase in a dynamic way: (i) the cardinal system, which is an innate system for concrete numerical representation and *subitizing*; (ii) the linguistic system, which associates a verbal code for numbers of objects or events; (iii) the Arabic system, which establishes a relationship between numbers and digits in Arabic form and supports the development of numeric symbolization; (iv) the visuospatial system, which aids the development of the mental number line along with formal education and the passage of time, and finally; (v) the ordinal system, which upon acquisition becomes the central system of numeric representation and mathematical thinking (Von Aster & Shalev, 2007). On the other hand, the presence of numeracy deficits classified as Low Achievement in Math (LA) or Developmental Dyscalculia (DD) on the childhood may have deleterious impact on schooling and future professional careers.

DD is a disorder of arithmetical skills (F81.2) (ICD-10 – WHO, 2004) characterized by difficulties in performing basic operations such as addition, subtraction, multiplication and division. DD is not attributable to educational failures, intellectual disability or sensory problems (WHO, 2004). Primary DD can be understood as a heterogenic Numerical Cognition disorder whose effects can be observed at the behavioral, cognitive, and neuronal levels, whereas Secondary DD also generates numeric and arithmetic dysfunctions, which are related to non-numeric cognitive deficits or to comorbidity with disorders such as ADHD, dyslexia, and anxiety (Kaufmann et al., 2013). Moreover, it is important to observe substantial variations on criteria for DD before this categorization (Butterworth, 2010; Murphy, Mazzocco, Hanich, & Early, 2007; Landerl, Bevan, & Butterworth, 2004; Wilson & Dehaene, 2007).

Despite the fact that DD occurs in approximately 5% to 6.5% of school-age children (Gross-Tsur, Manor, & Shalev, 1996; Kaufmann & von Aster, 2012), there are few studies focused on its diagnosis and rehabilitation in Brazil (see Kranz and Healy, 2013; for review), where it seems to have a slightly higher prevalence (Bastos, Cecato, Martins, Grecca, & Pierini, 2016). European studies have investigated the effects of interventions on the persistence of DD in children of primary school (Kucian et al., 2011; Praet & Desoete, 2014; Re, Pedron, Tressoldi, & Lucangeli, 2014; for review see Cohen Kadosh, Dowker, Heine, Kaufmann, & Kucian, 2013). These studies showed that children with DD may improve some Numerical Cognition abilities through adapted training (Praet & Desoete, 2014; Re et al., 2014).

As for assessing the effects of rehabilitation in children with numeracy disorders, the study design usually compares a clinical group and a non-clinical group performing the procedure. For instance, Ashkenazi and Henik (2012) assessed nine children diagnosed with developmental dyscalculia and other nine age- and sex-matched controls with no disabilities. All of them participated in an attentional training which enhanced the performance in addition problems in both the DD and control groups. Kucian et al. (2011) developed a 5-week computer-based math training for children with DD aged 8–10 years and showed that the training improved spatial representation of the mental number line. Although these findings are promising, the effects of a virtual environment on the development of numeracy skills in children with DD depends on effective teaching strategies and the monitoring of teachers to use it as an individual approach (Moeller, Fischer, Nuerk, & Cress, 2015).

There is evidence to suggest that music can increase higher brain functions required for mathematics, chess, science, and engineering (Davis, 2000). Schellenberg (2006) demonstrated associations between music lessons and academic performance such as mathematics, reading, and spelling in children aged 6–11 years. Moreover, Thornton (2013) compared test scores of 6.966 students in reading and math skills, and found significantly higher scores for students involved in musical classes (e.g. school band, choir, and orchestra) contrasting with students not engaged in music classes.

Willis (2016) found a significant connection between music education and student achievement in math, for those students who were provided music education at school. In fact, processing music and solving algebra problems trigger similar brain pathways in the prefrontal cortex and the parietal lobe (Schmithorst & Holland, 2004). Moreover, music training could contribute to improve activations in encephalic areas such as planum temporale and the left dorso-lateral prefrontal cortex, areas which are considered important during mental arithmetics (Desmet et al., 2012).

Substantial evidence suggests that when children are enrolled in musical training, they exercise cortical neurons involved in music but they also refine circuits implicated in Numerical Cognition and spatial reasoning, which, consequently, develops the capacity to handle complex reasoning tasks (Wenger & Wenger, 1990; Cheek & Smith, 1998; Grandin, Shaw, & Peterson, 1998). Importantly, spatial reasoning is subsidized in transforming and relating mental images in space and time, symmetries of the inherent cortical firing patterns used to compare physical and mental images, and natural temporal sequences of those inherent cortical patterns (Gentner, 2001). Correlational studies indicated that spatial ability is related to math ability throughout development since early elementary grades (Cheng & Mix, 2014). Research also attested that quantities are represented in spatial formats (i.e., the mental number line and object files) beginning in early childhood and persisting into adulthood (Landerl, 2013).

The Miendlarzweska and Trost's (2013) review suggests that the improvement in math scores after music training could be due to near and far transfer effect skills. Indeed, it produces an increase in children's listening skills (as auditory discrimination) and verbal short-term memory (Forgeard, Winner, Norton, & Schlaug, 2008; Moreno et al., 2011), executive functions (Hannon & Trainor, 2007; Zuk, Benjamin, Kenyon, & Gaab, 2014), and WM (Ribeiro & Santos, 2012). Besides, musical training could be used as a tool to produce fast and permanent changes in cognitive abilities and has demonstrated an enhancement in visuospatial ability (Costa-Giomi, 1999; Rauscher et al., 1997; Ribeiro & Santos, 2012; Ruscher & Zupan, 2000; Rauscher & Shaw, 1998; Yang, Lu, Gong, & Yao, 2016).

Nutley, Darki, and Klingberg (2013) found music training to be related to greater performance on tests of reasoning, processing speed, WM, and numeracy ability, and there was a significant positive association between musical training and