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Cognitive abilities, digital games and arithmetic performance enhancement: A study comparing the effects of a math game and paper exercises

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ABSTRACT

Besides entertainment, games have shown to have the potential to impact a broader variety of cognitive abilities. Research has consistently shown that several aspects in cognition such as visual short-memory, multitasking and spatial skills can be enhanced by game play. In a previous study, it was found that playing Monkey Tales, a game aimed at training arithmetic skills, helped second grade pupils to increase their accuracy in mental calculation as compared to paper exercises. In this follow up study we explore whether traditional methods and game training differ in terms of the cognitive processes that both are able to impact. We incorporated standardized measures of working memory and visuo-motor skills. Additionally, the mathematics game was modified and its contents extracted to allow precise comparison between the gaming and paper exercises condition. Thus each single math exercise, type of question (e.g., multiple choice), quantity and order was perfectly matched in the game training and the traditional training conditions. Gains in arithmetical performance, and self-reported measures of enjoyment were also investigated. We found some evidence suggesting that arithmetic performance enhancement induced by game play and paper exercises differ not only in terms of enjoyment but also of working memory capacity improvements.

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1. Introduction

Video games present themselves as one of the more interesting and promising means of improving cognitive abilities, particularly with children. One of their promises is that, compared to traditional training, they are more engaging and entertaining (Boot, Kramer, Simons, Fabiani, & Gratton, 2008). Moreover, besides entertainment, games have the potential to impact a broader variety of cognitive abilities. Recently, research has consistently shown that several aspects in cognition such as visual short-memory, multitasking and spatial cognition can be enhanced by game play (for a complete review, see Bavelier, Green, Pouget, & Schrater, 2012).

2. Study purpose

A previous study reported that playing Monkey Tales, a commercial game aimed at training arithmetic skills in children, helped second grade pupils to increase their accuracy in mental calculation as compared to paper exercises or no exercises. However, the extent to which the positive changes induced by gaming or by paper exercises in children differ in nature and extent is an issue that has not yet been explored. Specifically, based on previous research showing that video game playing can enhance working memory capacities and attention (Bavelier et al., 2012), we explore whether, by incorporating standardized measures of working memory and visuo-motor skills we can provide a more informed description of how arithmetic performance enhancement induced by these two methods might differ in terms of cognitive processes. Specifically, we investigate to what extent arithmetic performance enhancements induced by game play are modulated by improvements in the domains of visuo-motor skills and working memory.

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3. Background

Working memory is the ability to explicitly maintain a mental representation of a certain amount of information while being engaged simultaneously in other mental processes (Baddeley, 2000). Research has demonstrated that working memory capacity increases from preschool through the elementary school years. Preschool children can hold three to four items of information, such as numbers, in working memory, whereas a typical fourth grader can hold five to six items (Kail & Park, 1990). Although during the past decades it was traditionally assumed that working memory is highly heritable and unlikely to be influenced by environmental experience and opportunity (Campbell, Dollaghan, Needleman, & Janosky, 1997), recent findings have provided evidence suggesting that children's working memory can be enhanced by means of training (Klingberg et al., 2005; Turley-Ames & Whitfield, 2003). In fact, a recent review about the effects of cognitive training on children concluded that the training of core executive functions like working memory is most beneficial to 4–12 years-olds (Diamond & Lee, 2011).

Remarkably, a recent study of Holmes, Gathercole, and Dunning (2009) has demonstrated that attention training can lead to a significant boost in the academic mathematics performance of children (Holmes et al., 2009). This study showed that IQ scores (both verbal IQ and performance IQ scores) did not show a comparable boost after working memory training, suggesting that, rather than leading to global performance enhancement, improvements in working memory seem to act locally, boosting arithmetical performance. Likewise, studies in cognitive psychology support this critical role of working memory. There is converging evidence showing that working memory capacity closely relates to skill in arithmetic and, in particular, to the speed of solving arithmetic problems (Geary & Widaman, 1992; Lemaire, Abdi, & Fayol, 1996; Rubinsten & Henik, 2009) although it has also been shown that working memory training in 2nd graders results in improved reading skills, but no improvements in math skills (Karbach, Strobach, & Schubert, 2014). However, studies with clinical populations indicate the existence of a close relationship between working memory capacities and mathematical skills. For instance, studies investigating children with a mathematics learning disability (MD), have shown that they obtained diminished scores on a variety of working memory tasks when compared with their same age pairs (Mclean & Hitch, 1999).

Visuo-motor integration is another cognitive ability that has been linked with mathematical achievements. For instance, research has provided evidence showing that children who have difficulties in math (aged 7–13 years) – but with normal reading skills – had a much higher frequency of poor performance in a test aimed to map visual-motor deficits (Developmental Test of Visual-Motor Integration) (Siegel & Feldman, 1983). Likewise, research has demonstrated the existence of a close relationship between the Stanford total math standard score and the Developmental Test of Visual-Motor Integration when controlling for verbal ability and age (Sortor & Kulp, 2003). Also interestingly, a study that intended to predict reading and mathematics achievement in fourth-grade children from kindergarten scores in standardized tests, found that verbal skills uniquely predicted later reading achievement, whereas both verbal skills and visuo-motor skills uniquely predicted later mathematics achievement (Kurdek & Sinclair, 2001).

In addition, recent studies have reported evidence suggesting that working memory and visual-attention can be trained in normal adults by means of video gaming. For example, it has been found that video game players are faster and more accurate in the monitoring and updating of working memory than non-video game players (Colzato, Van Den Wildenberg, Zmigrod, & Hommel, 2012). Green and Bavelier (2003) conducted a series of experiments on the effects of video game playing on visual attention comparing action video game players and non-video game players, and found that video game playing experience enhances the capacity of the players' visual attention system (Green & Bavelier, 2003). Likewise some recent correlational studies have demonstrated that action video game players have the ability to switch faster between tasks compared with non-video game players (Boot et al., 2008; Karle, Watter, & Shedden, 2010). Importantly a recent experimental study has also demonstrated improved task switching and dual tasking in non-gamers trained in an action game, in contrast to non-gamers trained with Tetris (Strobach, Frensch, & Schubert, 2012). Finally, a recent study has shown that performance gains are not restricted to the action game genre, but that playing Tetris, a casual puzzle game, can also improve working memory and visuo-spatial ability in young adults (Nouchi et al., 2013).

Taken together, the results mentioned above suggest the existence of a close link between, working memory, visuo-motor skills and arithmetic skills, and that, remarkably, these cognitive abilities can be trained by means of game play, especially with young children. This presents important opportunities for using games for mathematics training but also questions as to how these different performance gains are related and how they compare with traditional methods for practicing mathematics. Hence, in the present study, we explore whether traditional methods and game training differ in terms of cognitive processes that both are able to impact. In order to do this, we compared the results that second graders achieved in a test made for assessing their math skills and the scores of standardized measurements of working memory and visuo-motor skills before and after game training and traditional training by means of math paper exercises.

Standardized assessments of children's working memory, planning and visuo-motor skills were conducted before and after training by means of the Digit Span and Mazes subtests of the WISC-III NL which is a battery that provides a measure of IQ (Kort et al., 2002). The Digit span subtest measures the capacity to hold numbers in working memory and the ability to work with them. More specifically, the repetition of the digits (especially backwards) demands concurrent mental operations like divided attention, allocation of multiple mental resources operations, and active control of conscious attention (Pisoni, Kronenberger, Roman, Ann Geers, 2011). The subtest of Mazes measures not only visuo-motor abilities (Sattler, 1988) but also forward planning and organization (Skuse, 2003).

Finally, the present work also aimed to explore the relationship between gains in arithmetical performance (reaction times and accuracy), working memory and visuomotor skills and their relationship to the enjoyment of game training in comparison with traditional training. To the best of our knowledge, this is the first time that the predictive value of enjoyment is investigated in relation to gains in objective measures of arithmetic performance and cognitive abilities. Also on a methodological level it is the first time that a mathematics game was modified and its contents extracted to allow precise comparison between the gaming and paper exercises condition. Thus each single math exercise, type of question (e.g., multiple choice), quantity and order was perfectly matched in the game training and the traditional training.

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