Learning Math as you Play: An explorative study

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Abstract: One of the promises of video game training is that, compared to traditional training, it can be more engaging and entertaining (Boot et.al., 2008). However, besides entertainment, games have shown to have the potential to impact a larger variety of cognitive abilities. Previous research has consistently shown that several aspects in cognition such can be enhanced by game play. The present study aimed to explore how arithmetic performance enhancement induced by game play and paper exercises differs. In order to do this, we performed a combined analysis of the changes in two behavioral measurements: accuracy and reaction times. Children were tested at two points in time: before and after the three week period. We compared the reaction times and the accuracy improvements between these two moments and compared different items types (e.g. understanding tenths, understanding hundreds, even or odd up to 100 among other types). We found indirect evidence suggesting that arithmetic performance enhancement induced by game play and paper exercises might rely on slightly different cognitive mechanisms.

Keywords: arithmetic training, mental calculation, educational game, traditional training, reaction times, accuracy

1. Introduction

Video games are one of the more interesting and promising means to improve cognitive abilities, particularly with children. One of its promises is that, compared to traditional training, can be more engaging and entertaining (Boot et al., 2008), and effective (Wouters et al., 2013). Moreover, besides entertainment, games have the potential to impact a larger 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 et al., 2012).

In a previous study (Nuñez Castellar et al., submitted), we 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 differ in its nature and characteristics 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), in the present paper we explore whether by a detailed, combined analysis of the changes in accuracy and reaction times after game training and traditional training by means of math paper exercises, we can provide more informed description of how arithmetic performance enhancement induced by these two methods might differ.

Specifically, there are reasons to believe that arithmetic performance enhancement induced by game play might be modulated by improvements in the domains of attention and working memory. Working memory is the ability to explicitly maintain a mental representation of some 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, 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 (see Campbell et al., 1997), recent findings have provided evidence suggesting that children's working memory can be enhanced by means of training (Klingberg et al., 2005; Holmes, Gathercole and Dunning, 2009; Turley-Ames and Whitfield, 2004).

Remarkably the study of Holmes, Gathercole and Dunning (2009) has demonstrated that attention training can lead to a significant boost of the academic mathematics performance of children. 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. Moreover, 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 receive diminished scores on a variety of working memory tasks when compared with their same age pairs (Hitch and McAuley, 1991; McLean and Hitch, 1999; Siegel and Ryan, 1989; Swanson, 1993). Furthermore, recent studies have reported evidence suggesting that working memory and attention can be trained in normal adults by means of video gaming. For instance, 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 et al., 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. Likewise several recent studies have demonstrated that action video game players have the ability to switch faster between tasks compared with non-video game players (Karle, Water and Shedden, 2010, and Boot et al., 2008). 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 attention, working memory and visuo-spatial ability in young adults (Nuchi et al., 2013).

Taken together, the results mentioned above suggest the existence of a close link between, working memory, attention and arithmetic skills, and that, remarkably, these cognitive abilities can be trained by means of game play. This creates 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 the 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. We conducted a combined analysis of the changes in accuracy and reaction times whilst considering different item types (e.g. understanding tenths, understanding hundreds, even or odd up to 100, etc.). Moreover, we explored whether the type of item that showed the largest improvements differed between game training and the traditional training group. Finally, results are compared with the ones of a group that did not receive any assignment (control group).

2. Methods

2.1 Participants

Participants were drawn from a previous study. Overall arithmetic performance in a math test, as well as subjective measures like math anxiety, enjoyment and perceived competence from this sample have already been reported (Nuñez Castellar et al., submitted). However, that report did not examine individual reaction times and accuracy rates per type of arithmetical problem or item type.

Children were recruited by sending letters to schools in the area of Ghent, Belgium. The parents interested in participating, registered via the Computer-Aided Registration Tool for Experiments (CORTEX) (Elson and Bente, 2009). Parents gave written informed consent for their child's participation.

Children were tested at two points in time: before and after the three-week period (Pre- and Post-testing). During the first evaluation 88 second graders were tested. At the second moment of measurement, 84 were assessed (one child could not participate because of illness and three parents did not react to the repeated calls for post-testing). From this sample some participants were excluded from the analyses because they were clinically diagnosed with disorders listed in the Diagnostic and Statistical manual of Mental disorders (DSM-IV) (American Psychiatric Association, 2000), namely learning disability, ADHD, and dyslexia. Also participants who could not complete the task assignment and all participants who performed the computer math test at chance level or below, either in the pre- or the post-test, were excluded from the analyses. In the present study data of 74 children are reported. As can be seen in Table 1, the groups did not differ significantly in terms of age, gender or game and study habits (see Table 1).

Table 1. Socio-demographic data and study and game habits by group.

	Educational Game (N=25)	Paper Exercises (N=23)	Control (N=26)		
	n	**n**	**n**	**Chi²**	**p**
Male gender	18	15	18	0.26	.88
	Mean	**Mean**	**Mean**	**F**	**p**
Age	7.52	7.26	7.35	1.33	.27
Level education parents	**Median**	**Median**	**Median**	**Chi²**	**p****
Education level father*	4	4	4	1.30	.52
Education level mother*	4	4	4	4.51	.10
Study and game habits	**Mean**	**Mean**	**Mean**	**F**	**p**
Homework hours per week	2h 02min	2h 10min	1h 30min	0.87	.42
Math homework hours per week	0h 53min	1h 08min	1h 05min	0.49	.61
Gaming hours during the week	3h 41min	3h 42min	3h 11min	0.48	.62
Gaming hours during the weekend	2h 48min	2h 23min	2h 21min	0.53	.59

*Four levels: Primary = 1, Junior High School/Middle School = 2, High School = 3, College/University = 4.

** Independent Sample Kruskall-Wallis Test

2.2 Design

Children were randomly assigned to three groups. One group was instructed to play through the entire educational game Monkey Tales in three weeks' time (gaming group). A second group was instructed to complete a set of math drill exercises in the same period, equivalent in quantity and basic level of difficulty to the exercises in Monkey Tales (paper exercises group). Additionally we included a group that did not receive any assignment (control group).

2.3 Stimulus material

2.3.1 Educational Game

We used the 3D video game Monkey Tales (Larian studios, 2011), which exists in different versions for second to sixth grade and is used to support the learning of math. The main goal of this educational game is not to instruct but to improve mental arithmetic of children by motivating them to engage in drill exercises with increasing time pressure. Only by being faster than a monkey (artificial intelligence) they can go through all the game levels. Importantly, the game uses an algorithm that tries to establish where a child is on the learning curve, and then stimulates the child to make progress by progressively augmenting the difficulty of the exercises. For the present study we selected the Museum of Anything, which is meant for children in the 3rd grade (ages 8+) to repeat what they have learned in the 2nd.
The educational game is divided into chapters and levels in which the player has to solve 3D puzzles (moving something that blocks the way or neutralize a laser for instance) and is challenged by a monkey to take part in a minigame (an educational math exercise in classic game format, e.g. 2D shoot 'em up) which the player has to win to get to the next level (see figure 1). The game contains 42 basic and one final level. In order to complete all the levels of the game, children need to finish 322 math exercises whereby the exact number depends on how many times they need to replay a minigame because of mistakes.

Figure 1: Screenshot Monkey Tales

2.3.2 Paper exercises

As one of the goals of the present study was to compare Monkey Tales with paper exercises, the latter needed to be as similar as possible to the former. Therefore, the educational publisher of the game, Die Keure, provided us with exercises based on their educational method that are equivalent in basic level of difficulty to the exercises included in Monkey Tales. Of around 1000 exercises we received, a sample of 340 exercises that were representative of the Belgium math curriculum for second graders were selected. The exercises were organized in ascendant order of difficulty (as it is done in the educational game), and were given to the parents of the children in a folder that they gave back to us at the post-test.

2.4 Measurement of Math performance: accuracy and speed

Two equivalent versions of exams (test A and test B) for assessing the math skills of children of the second grade were provided by publisher Die Keure. These test were based on the academic curriculum for second grade in Belgium. We used the questions of these two tests to program a computerized version that allowed us to automatically measure not only the accuracy rates but also the reaction times of each item of the test in milliseconds. We programmed this computerized version using Tscope. Tscope is a C/C++ experiment programming library for cognitive scientists. It provides functions for graphics, sound, timing, randomization and response registration (Stevens et al., 2006). After a number of practice trials to become familiar with the multiple choice task, all children performed the computer math test in the pre- and post-session. In each group, half of the children performed test A as pre-test measurement and test B as post-test measurement. The other half performed the tests in the opposite order.

2.5 Procedure

The participants were tested at the beginning of May 2012 for the pre-test session and at the end of May for the post-test session. As previously described, children were randomly assigned to three groups. One group of children was instructed to finish the educational game Monkey Tales in three weeks' time (Gaming group). Parents were instructed to help with the software installation and support the children while playing the game tutorial. However, they were explicitly asked not to help children with the math exercises. Moreover, the parents were asked to monitor on a weekly basis how far the children had progressed in the game, and to motivate them to play if needed. Importantly they were briefed about how to check the progress and detect when children had completed all the levels of the game. Finally, one week before the post-test an e-mail was sent as a reminder that, by the end of the week, the children should have completed the game.

A second group of children was instructed to complete a set of math drill exercises on paper in three weeks' time of equivalent quantity and basic level of difficulty as the exercises in Monkey Tales (Paper exercises group). Similarly to the parents of the group of children that was asked to play the educational game, the parents of this group were instructed to check and motivate the children to do the math drill exercises, but not to help them. One week before the post-test, an e-mail was sent as a reminder that by the end of the week children should have completed the math drill exercises.

Additionally, we included a group that did not receive any assignment (Control group) but served as a comparison. The parents of this group were asked not to change anything from their normal routine and specifically they were asked not to let their children play any educational math games.

All parents received the instruction to let the children continue to do their math homework as usual. The group that completed the paper exercises and the control group received the educational game at the end of the post-test as a reward. All the parents were rewarded with 15 euros for their participation.

2.6 Data Analysis

2.6.1 Accuracy improvements per item type

In order to investigate whether the items in which the largest improvement was observed differed between groups (e.g. understanding tenths, understanding hundreds, even or odd up to 100, divide into equal parts, multiplication tables from 2 up to 10, we compared the accuracy in the pre-test and the post-test measurements for each item type. All the items of the Math test were included in the analyses except one for which in the pre-test session 100% of the children gave a correct answer and therefore no improvement was possible. Afterwards we made a ranking based on the percentage of improvement including all the items to identify the ones in which the largest accuracy improvement was registered.

2.6.2 Correlation between accuracy and reaction time improvements

Similarly to the accuracy improvements analyses, we compared the reaction times in the pre-test and the post-test measurements for each item type. Only reaction times for correct responses were included in the analyses. Additionally, too fast reaction times (< 300ms) and reaction times slower than 60 seconds were excluded.
After calculating the reaction time improvements, we investigated the relationship between the accuracy improvements and the reaction time improvements. Therefore we performed a correlational analysis separate for each group: Monkey Tales, paper exercises and control. A significance level of 0.05 was used.

3. Results

3.1 Accuracy improvements

Figure 2 shows the accuracy improvements per item type ordered by percentage of improvement for the three groups whereby the improvement of the control group can be considered as a baseline to interpret the improvement of the two experimental groups. As can be observed in the figure, when considering only the items ranked in the first positions, the graph shows that the largest accuracy improvement is observed for the group that made the paper exercises. For instance, the first ranked items on that group show an accuracy improvement above 30%. However, interestingly, when considering the pattern more globally, the results show that overall playing Monkey Tales lead to a larger sustained accuracy improvement in most of the items included in the math test. When we look at the number of items scoring accuracy improvements of 6% and above, we see that there are 18 for the Monkey Tales group as compared to only 13 in the math exercises group.

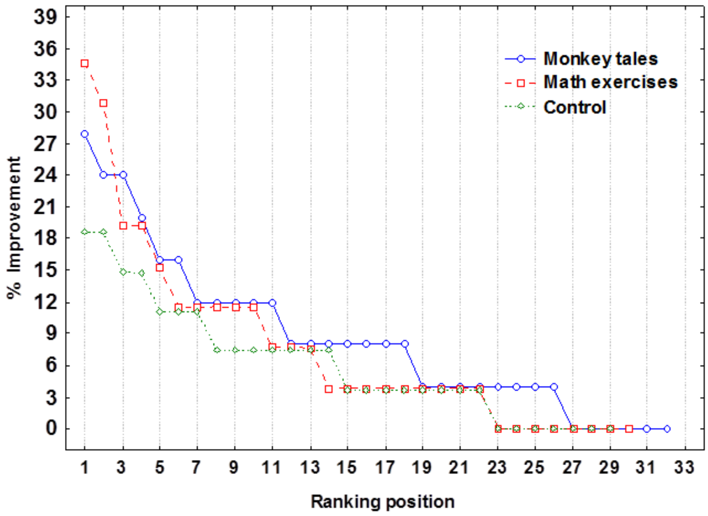

Figure 2: Accuracy improvements per item type

3.2 Correlation between accuracy and reaction time improvements

Since not only accuracy but also reaction times can be analyzed to investigate performance enhancement we conducted correlation analysis between these two behavioral measures. The results revealed that for the group that played monkey tales, accuracy and reaction time improvements were strongly correlated r(37) = .46, p < .001. Likewise, for the group that made the paper exercises, reaction time improvements were correlated r(37) = .33, p < .05, but less strongly than for the game group. Additionally, when analyzing the relationship between accuracy and reaction time improvements for the control group, the association between these two measurements was found to be non-significant r(37) = .08, p = 61.

Based on the correlation analysis we selected for each group the 5 items in which the largest accuracy and reaction time improvement were observed. The results of this ranking can be found in table 1. As can be observed, there are important differences between the types of items that are ranked for each of the three groups. The results revealed that doing the paper exercises predominantly lead to improvements on items where second graders were required to solve addition problems. Playing Monkey Tales, on the other hand, lead to improvement in a variety of items including items that require second graders to make parity judgments and rehearse the multiplication tables of 7 and 8. The graph also shows the ranking for the group that got no assignment (control group).

Table 2: Ranking items with the largest accuracy and reaction time improvements. T = tens and U = units.

Ranking	MONKEY TALES	PAPER EXERCISES	CONTROL
1	*Even or odd up to 100* (e.g. select the odd number)	*Divide into equal parts* (e.g. Find the correct number: 12= . + . + .)	*Multiplication table 7* (e.g. 7 x 5)
2	*Tens and units* (e.g. Which number has 7 units?)	*Addition TU+TU up to 100 with regrouping* (e.g. 55 + 29 =)	*Addition TU+TU up to 100 with regrouping* (e.g. 55 + 29 =)
3	*Multiplication table 8* (e.g. 8 x 8)	*Addition TU+TU up to 100 with regrouping* (e.g. 55 + 29 =)	*Subtraction with 1 multiple of 10 up to 100* (e.g. 86 – 10 =)
4	*Multiplication table 7* (e.g. 7 x 5)	*Addition TU+TU up to 100 with regrouping* (e.g. 55 + 29 =)	*Subtraction TU+TU = T* (e.g. 45 + 25 =)
5	*Subtraction with up to 3 multiples of 10 up to 100* (e.g. 75 – 30 =)	*Subtraction TU-U up to 100 with regrouping* (e.g. 63 – 6 =)	*Multiplication table 6* (e.g. 6 x 5)

6. Discussion and conclusions

In spite of the fact that the present study was explorative in nature, our results point to three interesting findings. First, our accuracy improvement analysis showed that, when considering only the items ranked in the top positions, the largest accuracy improvement can be observed in the group that made the paper exercises. Playing Monkey Tales, however, lead to a larger sustained accuracy improvement in terms of number of items included in the math test. In other words, rather than acting locally (leading to the improvement in few item types), playing the game had a global impact on the accuracy performance in a large variety of items. Although these results should be interpreted with caution given the exploratory nature of this study, an interesting venue for future research would be to investigate whether this global impact might be the result of secondary effects of the arithmetical training in other cognitive domains like working memory and attention. Since the content of the paper exercises and the game exercises were carefully matched - not only regarding content but also in number - it is unlikely that the differences we observed between groups relies on the type of arithmetical exercises. Rather, we suggest that there might be other mediating factors associated with game play that could better explain this pattern. For instance, an increased capacity to hold information items, such as numbers, in working memory could explain the broader positive impact for the game group in terms of variety of arithmetical problems for which improvement occurred.

Secondly, the correlation analysis performed between accuracy and reaction time improvements, revealed that, although for both groups, Monkey Tales and paper exercise, the correlation between these two behavioral markers was significant, this association was stronger for the gaming group. Moreover, this relationship was absent for the children who only went to school and did not receive any kind of repetition exercises during the three-week period. This is an important finding considering that, in order to be effective, a game aimed to train mathematical skills in children would be expected to have a positive impact for both behavioral measurements. The present study shows that, similar to the traditional method of paper math drills, Monkey Tales can lead to performance enhancement by making children perform faster and more accurate in mental calculations.

Thirdly, a ranking of the five items in which the largest accuracy and reaction time improvement were observed, revealed that doing the paper exercises lead to improvements predominantly on items where children were required to solve addition problems while playing Monkey Tales lead to improvement in a broad range of item types. These findings provide indirect evidence for the idea that arithmetic performance enhancement induced by game play and paper exercises might rely on slightly different mechanisms. For instance, previous research in the field of cognitive psychology has shown that information about the parity of numbers is associated with their arabic representation and directly retrieved from long-term memory when needed (Dehaene, Bossini, and Giraux, 1993). Thus, the parity judgment task involves memory retrieval as well as the selection of the response induced by the retrieved information. Interestingly, it was a parity judgment item that showed the largest accuracy improvement after playing through Monkey Tales. This suggests that videogame training boosted cognitive processes like memory retrieval and response selection - according to Miyake (2000) one of the three major cognitive control functions - being both crucial for parity judgment. Whilst listing the cognitive processes and the working memory load involved in the arithmetical problems reported in the present study is not at the core of this study, the previous example shows the utility of this kind of exhaustive analysis. Since previous research has shown that arithmetic, and more specifically numerical calculation, involves the use of working memory (i.e., keeping information available in the cognitive system) and attention (Rubinsten and Henik., 2009), we are convinced that detailed analyses of improvement considering different categories of arithmetical problems can be informative about the underlying mechanisms of performance enhancement.

Finally, some limitations of the present study have to be acknowledged. Given its explorative nature, it provides a very first examination about how, in terms of cognitive processes, arithmetic performance enhancement induced by game play and paper exercises might be different, but also that there are several ways this study could be improved. First of all, our results strongly suggest that learning mathematics through game play might be mediated by improvements in the use of working memory resources and attention. This partly remains speculative, however, because we did not apply tests that measured working memory and attention directly and thus have only presented indirect evidence. Future research could incorporate such standardized measurements to further investigate this issue.

Additionally, rather than aiming to be conclusive, the present study explored whether we could find indications that performance gains differ between traditional learning methods and game training. Consequently, several questions could be now experimentally investigated, for instance the extent to which are results are generalizable to other games and whether similar positive effects can be found with children of different ages. Finally, future research could investigate the impact of arithmetical training through games for children disadvantaged by learning difficulties or socioeconomic status.

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