The measurement of enhancement in mathematical abilities as a result of joint cognitive trainings in numerical and visual- spatial skills: A preliminary study

2015 J. Phys.: Conf. Ser. 588 012041

(http://iopscience.iop.org/1742-6596/588/1/012041)

The measurement of enhancement in mathematical abilities as a result of joint cognitive trainings in numerical and visual-spatial skills: A preliminary study

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Abstract. A body of literature shows the significant role of visual-spatial skills played in the improvement of mathematical skills in the primary school. The main goal of the current study was to investigate the impact of a combined visuo-spatial and mathematical training on the improvement of mathematical skills in 146 second graders of several schools located in Italy. Participants were presented single pencil-and-paper visuo-spatial or mathematical trainings, computerised version of the above mentioned treatments, as well as a combined version of computer-assisted and pencil-and-paper visuo-spatial and mathematical trainings, respectively. Experimental groups were presented with training for 3 months, once a week. All children were treated collectively both in computer-assisted or pencil-and-paper modalities. At pre and post-test all our participants were presented with a battery of objective tests assessing numerical and visuo-spatial abilities. Our results suggest the positive effect of different types of training for the empowerment of visuo-spatial and numerical abilities. Specifically, the combination of computerised and pencil-and-paper versions of visuo-spatial and mathematical trainings are more effective than the single execution of the software or of the pencil-and-paper treatment.

1. Introduction

Mathematics is one of the basic school subjects that involves different psychological factors [1, 2, 3]. The most relevant factors seem to be motivation [for a review see 4], maths self-confidence [5] and cognitive components, such as working memory [e.g. 2, 4, 5]. A body of studies identifies the cognitive processes underlying the development of numerical knowledge, showing the key role played by semantic, syntactic, lexical, and counting processes [e.g. 6, 7]. Working memory is involved in controlling, regulating, processing and actively maintaining related information to carry out different cognitive tasks (e.g. mathematical processing) [7]. In this regard, visual-spatial working memory efficiency is an important factor in understanding individual differences in mathematic achievement in children [3]. Furthermore, there is evidence that visual-spatial skills are crucial in the development of mathematical skills since pre-school age [e.g. 8, 9, 10]. Indeed, visual mental images and non verbal reasoning are strictly related to higher performance in mathematical problem solving tasks [e.g. 9, 10]. In this regards, the use of visual aids favours the development of the quantity concept in early primary school grades. Holmes and colleagues [11] state that when children are presented with mathematical tasks, they convert visual-spatial data into verbal mental representations (i.e., symbols). From a developmental perspective originally pre-schoolers use the visuo-spatial format to manipulate quantities, later on they learn to use verbal representations (e.g. digit numbers, algebraic signs) [11,12].

During the last decade, a new trend of research has been developed to propose educational solutions aimed at favouring the scholastic achievements of children with typical and atypical developmental paths. In this regard, several studies suggest the use of trainings to enhance specific cognitive processes in childhood. Nowadays, many technological tools have been introduced in educational environments and there has been a strong increase in research on the potentialities of computer-assisted interventions to support educational activities [13,14]. ICT is however an excellent tool to develop computer-assisted psycho-educational interventions that can be proposed at school. There is also a body of studies suggesting that visuo-spatial pencil-and-paper and/or computerised trainings can contribute to the development of mathematical skills [13]. Räsänen et al. [15] show the positive effect of computer-assisted interventions in the development of numeracy skills in pre-schoolers; and also Van Garderen [10, 11] found a similar pattern of results in students with learning disabilities, average achievers and gifted sixth graders.

2. Aim and method

The aim of the current investigation was to evaluate the impact of single and combined visuo-spatial and mathematical trainings, respectively presented in computer-assisted or pencil-and-paper modalities on the development of numeracy skills in second graders. Therefore, at pre-test and post-test children were collectively presented with a battery of tests assessing mathematical and visuo-spatial problem solving abilities, respectively.

2.1. Participants, instrument and procedure

One hundred and forty six 7 year old children were recruited in several Italian primary schools located in Sardinia (Italy). The participants (47.9% female) were divided into seven experimental groups that followed one or combined type of trainings, in pencil-and-paper and/or computerised formats.

In order to assess respectively the numerical and visuo-spatial abilities, at pre and post-test, our participants compiled a battery of standardised tests (Calculation Ability – MT Group - AC-MT 6-11 [16]; Coloured Progressive Matrices – CPM [17]). After that, children were presented the numerical training “Sviluppare l'intelligenza numerica vol. II” developed by Lucangeli et al. [18] and/or the visuo-spatial psycho-educational programme “Recupero in … abilità visuo-spaziali” by Fastame and Antonini [19] for 10 weekly sessions. Specifically, the experimental groups carried out the following treatments: G1 was presented with the mathematical training in computerised format (n=24); G2 carried out the mathematical training in computerised format and visuo-spatial training in computerised format (n=32); G3 was given the mathematical training in the pencil-and-paper format (n=17); G4 carried out the visuo-spatial training both in the pencil-and-paper and computerized formats (n=17); G5 carried out only the visuo spatial training in the pencil-and-paper modality (n=13); G6 was presented with the mathematical training in pencil-and-paper format and computer-assisted modalities (n=13); G7 was presented the visuo spatial training in the pencil-and-paper format and the mathematical training in computerized modality (n=30). The teachers and their pupils voluntarily participated in the research (non-probabilistic sampling). Overall, one hundred and thirty seven children completed the battery of cognitive tests that was presented at pre-test and post-test.

We applied the MANCOVA and a Two Step Cluster Analysis in order to evaluate and describe the gain in the numerical and visuo-spatial abilities in each experimental condition.

3. Results

We analysed the data on participants from the seven groups. The mean and standard deviations for the scales of AC-MT (*Written calculation, Accuracy, Speed, Semantic and Syntactic numerical knowledge*) and CPM were examined; then we evaluated the Pearson *r* correlation to investigate the linear relationship between dimensions inquired in two moments (pre and post training); as expected, we also observed positive correlations among mathematical and visuo-spatial abilities.

We calculated the gain between post and pre evaluations, in relation to CPM and to each scale of AC-MT (*Written calculation, Speed, Accuracy, Semantic and Syntactic numerical knowledge*); this index is the difference between post and pre measurement of each dimension. Moreover we applied a MANCOVA on the gain scores of the AC-MT and CPM with the 'training group' as the factor, using the pre-test measures in numerical and visuo-spatial abilities as covariates. The multivariate tests were significant for the covariates and for the factor 'training group' (Wilks' lambda $_{[30, 490]}$ = .678, p=.016). Then univariate tests indicated a significant effect of 'training group' in terms of *Written calculation* ($F_{(6, 126)}$ = 2.251, MSE = 180.719, p=.042, partial ηp^2 = .096) and *Speed* ($F_{(6, 126)}$ = 3.892, MSE = 267.066, p = .001, partial ηp^2 = .156). With the application of Post Hoc Comparison of Fisher's Least Significant Difference, we observed specifically the differences between the training groups. Table 1 summarises the main results.

Table 1. Main results of Post Hoc Comparison LSD

group		**group**	**Dependent variable**
G1 mathematical training in computerised format	>	G3 mathematical training in paper format	*Written calculation, Speed*
G2 mathematical training in computerised format and visuo spatial training in computerised format	>	G1	*Written calculation*
G6 mathematical training in paper format and mathematical training in computerised format	>	G1	*Written calculation*
	>	G4 visuo spatial training in paper format and visuo spatial training computerised format	*Written calculation, Speed*

Furthermore to describe the potential effects of different trainings, we performed the Two Step Cluster Analysis (combination of the hierarchical and partitioning methods) [20]. This statistical method applies a two-stage approach: Firstly, the algorithm is similar to the application of k-means cluster analysis; then, on the base of these results, the successive analysis is based on the application of a procedure similar to the hierarchical agglomerative methods. Thus, we have identified 2 clusters. The first cluster was constituted by the groups realizing a single or combined training to the same matter (G1, G3, G4, G5, G6); the second cluster was established by the pupils that assisted the combined trainings in mathematical and visuo spatial abilities (G2, G7) (Table 2).

Table 2 . Two Step Cluster Analysis – Cross tabulation between Cluster and training groups

TRAINING GROUP	Cluster 1	Cluster 2	Total
G1 mathematical training in computerised format	24	0	24
G2 mathematical training in computerised format and visuo spatial training in computerised format	0	32	32
G3 mathematical training in paper format	17	0	17
G4 visuo spatial training in paper format and visuo spatial training computerised format	17	0	17
G5 visuo spatial training in paper format	9	0	9
G6 mathematical training in paper format and mathematical training in computerised format	13	0	13
G7 visuo spatial training in paper format and mathematical training in computerised format	0	25	25
Total	80	57	137

In relation to each dimension, examining the cluster centroids, we observe a stronger improvement in numerical abilities related to *Written calculation* and *Speed* in the second cluster (Table 3). These results are consistent with our MANCOVA results.

Table 3. Two Step Cluster Analysis - Centroids

		Written calculation	Numerical knowledge	Speed	Accuracy	Visuo-spatial ability
		Mean (sd)	Mean (sd)	Mean (sd)	Mean (sd)	Mean (sd)
Cluster	**1**	-1.63 (12.78)	-1.08 (6.87)	-1.07 (8.43)	.58 (11.43)	1.12 (9.29)
Cluster	**2**	2.85 (12.02)	1.81 (8.49)	2.87 (10.02)	-1.45 (9.10)	-1.33 (6.68)
	Combined	.23 (12.62)	.11 (7.69)	.56 (9.30)	-.26 (10.54)	.10 (8.37)

4. Discussion

The main goal of the present research was to investigate the part played by single or combined visuo-spatial and mathematical trainings in favouring the enrichment of numerical knowledge. Therefore, computerised-assisted and/or paper-and-pencil single or combined treatments were proposed to 146 second graders, attending several Italian primary schools.

A large group of studies suggests that the psycho-educational programmes for the empowerment of cognitive functions can contribute massively to school achievements, both for typically developing children and those showing learning disabilities [e.g. 21, 22].

Overall, the current findings are consistent and extend previous results. Indeed, our outcomes suggest at least five different conclusions. First, the use of computer-assisted mathematical trainings is more effective than the paper-and-pencil mathematical treatments, whereas the paper-and-pencil mathematical training combined with the software for the mathematical skills is more effective than the use of the single computer-assisted mathematical training. Furthermore, although the use of computer-assisted software is very effective in empowering cognitive abilities in primary school [23], our study suggests that the use of the computer *per se* is not sufficient to enrich numeracy knowledge in second graders. Indeed, we found that children trained by a computer-assisted and pencil-and-paper mathematical treatment outperformed children trained by a combined computer-based and pencil-and-paper visuo-spatial trainings in terms of processing speed for number manipulation. Therefore, the 'pure' computerised and pencil-and-paper mathematical training is more effective than the 'pure' computerised and pencil-and-paper visuo-spatial treatment in empowering number processing in second graders. However, regardless the modality (i.e., computer-assisted versus pencil-and-paper) in which the trainings were presented, the combination of visuo-spatial and mathematical materials was as much effective as the 'pure' combined (i.e., computer-assisted and pencil-and-paper) mathematical treatment.

Therefore, we can conclude that our findings are consistent with those by previous researches [e.g. 13, 15, 23] sustaining that the use of a computer-assisted intervention supports the development of numerical knowledge in children, especially when the training is combined with mathematical and visuo spatial abilities.

In summary, the current results suggest that the combined computerised and pencil-and-paper mathematical treatment developed by Lucangeli and collegues [18] is very effective for the empowerment of numeracy skills in primary school. Moreover, a similar positive effect is also found when the computerised version of the training developed by Lucangeli et al. [18] is combined both with the computerised version or the pencil-and-paper visuo-spatial trainings proposed by Fastame and Antonini [19].

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