

Research paper

Structured versus free block play: the impact on arithmetic processing

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A B S T R A C T

Block play is one type of intervention that improves visuospatial skills. There are multiple forms of block play and it is unclear whether they have differential cognitive effects. Given the importance of visuospatial skills for mathematical performance, we studied the differential impact of two types of block play—structured (copying a block design) and free (building from imagination)—on arithmetic processing, using behavioral and fMRI methods. Forty-three children aged 8.3 ± 0.8 years participated (21 free play and 22 structured block play). Results showed that while both groups showed behavioral improvements, only the structured block play group showed significant improvements in both addition and subtraction performance. Additionally, the structured block play group showed increased activation in several regions linked to memory, motor, and arithmetic processing after training. The results inform choices for activities used in the classroom to improve visuospatial skills and suggest structured block play may be beneficial for arithmetic processing.

1. Introduction

Given the importance of science and technology to societal issues, environmental sustainability, and economic competitiveness, it is becoming increasingly important for children to attain more advanced levels of mathematical and science competence. How can we as a nation help alleviate this growing crisis? A potential answer to this is to engage children in spatial thinking early. Past research has shown that spatial thinking plays a critical role in STEM success. Research as far back as Bingham's 1937 Aptitudes and Aptitude Testing reported that one's abilities in spatial thinking can be associated with success in occupations and tasks related to engineering, science, and fields of mathematics. Gardner [17] suggests "it is skill in spatial ability which determines how far one will progress in the sciences" (192). As a result there have been recommendations to include spatial reasoning into the curriculum in elementary schools. However, the mechanism that underlie the relationship between spatial ability and STEM achievement, particularly mathematics is unclear; therefore the type of spatial tasks that are most beneficial is unknown.

2. Mathematics and Spatial Processing

There is evidence to suggest a strong relationship between spatial ability and mathematics ([23,29,31,43,50]). Studies have found that

performance on spatial tasks like mental rotation is correlated with mathematics achievement in school age children [1,30,36] and that visuospatial working memory is related to number and mathematics problem-solving [18,37]. There is also evidence to suggest that number is represented spatially ([11,60]). Multiple studies have reported an association of small numbers with the left visual field and large numbers with the right visual field (see Fias & Fischer 60 for review). Additionally, mathematics writing conventions rely on spatial relations. Landy and Goldstone [27], for example, found that when the spatial distances between terms in an algebraic equation were manipulated it impacted adults' performance.

Neuroimaging studies have confirmed the behavioral findings and have shown that arithmetic calculation processes overlap with regions associated with spatial processing, including the cerebellum and parietal regions [14]. One of the most prominent theories of the neuroscience of mathematics is Dehaene's triple code theory [10,12]. This theory places number processing, including calculation, within four regions of the parietal lobe – angular gyrus for verbal coding related to retrieval; intraparietal sulcus (IPS) related to abstract, amodal representations of number; the horizontal intraparietal cortex related to calculation and procedural processes; and the superior parietal cortex related to visuospatial processing. For example, Danker and Anderson [61] linked the superior parietal cortex to transformation processes—the movement of variables around the equal sign—during algebraic problem-solving.

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Additionally, the intraparietal sulcus has also been linked to spatial processing ([51]). For example, Dehaene, Spelke, Pinel, Stanescu and Tsivkin [13] concluded that approximate arithmetic, which showed increased activation of bilateral intraparietal sulcus, was based on visuospatial processing. In a meta-analysis study Hawes et al. [22] synthesized results from 83 neuroimaging papers and reported shared use of bilateral IPS across symbolic number processing, arithmetic, and mental rotation, in addition to more specific overlap between numerical and arithmetic processing on the left IPS and common activation of the middle frontal gyri only for mental rotation and arithmetic processing. In sum, both behavioral and neuroimaging studies appear to indicate a strong relationship between both number and mathematics and spatial processing.

3. Spatial Training

There is evidence that spatial ability can be improved through training ([33,58,59]), including play ([25,28]; Newman et al., 2016). Play is an important way that young children learn [41]. Playing with spatial toys and engaging in spatial activities may prove to be an essential part of the development of spatial thinking. There are a number of studies that have related spatial play with spatial skill [25,28] and number processing [8,9,47]. Block play, in particular, has garnered a great deal of attention in terms of its potential link to spatial thinking [7]. There are at least two key types of spatial skills closely related to block building. The first is spatial visualization. This involves mentally combining objects to produce designs. As an individual is working with blocks, they are mentally visualizing how blocks will fit and interact with one another. Another spatial skill related to block building is mental rotation. This involves mentally visualizing what an object will look like after it is rotated [7].

Although many preschool and elementary programs as well as homes have block toys, how these toys are played with may have an impact on whether and how spatial skills are developed. Two types of block play have been considered; free play where children are provided blocks and they create designs, and structured block play in which children copy a model of a structure [47]. Structured block play is analogous to block copying tasks that have been studied extensively [2]. It is structured block play that requires the analysis of a spatial representation and that may result in more significant improvements in spatial ability. Again, while classrooms may have block building activities, there is not enough structured play for children to greatly enhance spatial learning [8]. Casey [8] suggests that “if this skill were taught in a more systematic way in the early childhood classroom, it might have the potential to further develop spatial reasoning” (p. 271).

Previous studies that included spatial training together with mathematical instruction reported improvements both in spatial and mathematical skills ([20]; Lowrie, Logan & Ramful, 2017). However, randomized controlled studies that investigated the transfer of gains from spatial training to mathematical skills, in the absence of mathematical training, reported mixed results. Cheng and Mix [9] reported gains in performance during calculation problems (particularly missing term problems, e.g., $3 + _ = 12$) as a result of mental rotation training with 6- to 8-year-olds. The authors argued the spatial training may have helped the participants to transform the missing term problems to a more familiar format (e.g., $_ = 12 - 3$). In a similar mental rotation training study, again with 6- to 8-year-olds, Hawes et al. [21] did not report any transfer of gains to mathematics performance. However, analysis of the pre-test data showed that the two mental rotation scores shared 25 % (mental rotation with animal pictures) and 40 % (mental rotation with letter stimuli) of the variance on missing term problems, implying sharing of cognitive mechanisms between mental rotation and calculation of missing term problems. Cheung, Sung, and Lourenco [56] reported far transfer of mental rotation training to performance during canonical arithmetic problems with a group of 6- and 7-year-olds. Because the spatial training gains did not transfer to non-symbolic

quantity processing, the authors argued that the gains in arithmetic performance is due to improvements in visualization ability or access to mental number line. Further, unlike Cheng and Mix's [9] study, the results did not show any improvements in missing term problems. The authors suggested that the different results on the transfer to missing term problems might be due to the mode of training (physical manipulatives were used by Cheng and Mix and a virtual medium by Cheung, Sung, and Lourenco). Future research is needed to compare how and why training with physical manipulatives compared to virtual ones may lead to different transfer outcomes across different mathematical skills. It is possible that the tactile, motor, and visuospatial nature of interaction with physical manipulatives lead to differential outcomes in spatial gains and transfer, compared to virtual. In addition to mental rotation, block play has also garnered attention in previous studies.

3.1. Structured vs. Free Block Play

Block play has been thought to improve visuo-spatial processing ability in children [8]. However, the specific aspects of visuo-spatial processing impacted is unclear. Visuo-spatial processing is complex with there being distinctions between object imagery (construction of detailed vivid images of objects including shape) and spatial imagery (construction of images with details about spatial relations). It can be argued that structured and free block play rely differentially on these two types of imagery. Structured block play requires the ability to analyze a spatial representation – comparing a model structure to one that is being built in order to understand the relationship between parts. This analysis of the spatial representation required in structured block play is thought to develop skills in estimation, measurement, patterning, part-whole relations, visualization, symmetry, transformation and balance [6,46,47]. As a result, structured block play may differentially train spatial imagery processes more so than object imagery processes. Conversely, free block play requires the ability to create a mental representation of a structure and then recreate it with blocks; it is more analogous to the work of visual artists in that it requires a somewhat vivid representation of the object to be created. Interestingly, in a study by Blajenkova and colleagues [4], they found that visual artists had above average object imagery skills and below average spatial ability demonstrating that these two forms of imagery rely on different neurocognitive systems.

In an extensive review, Hawes & Ansari [23] provide four different, but not mutually exclusive, mechanistic accounts for how spatial and mathematical skills are related. The first one explains how numbers are represented in a visuospatial form, most noticeably in the form of a mental number line, among others (e.g., Cartesian coordinate system). The second focuses on the neural overlap between visuospatial and mathematical processing. The third one, the spatial modeling account, describes how spatial visualization acts as a “mental blackboard,” allowing visualization of numerical relations and operations. Finally, the fourth one, accounts for how visuospatial working memory can act as a proxy linking domain-general cognitive skills, such as working memory, and numerical skills. Given the wide range of visuospatial and numerical skills, it is quite possible that all four accounts play a role with different weights in how specific spatial and mathematical skills are related. So far there has been a strong emphasis on the relation between arithmetic and visuospatial skills, both because arithmetic learning is crucial for elementary mathematics education, and the cognitive and neural processes involved across different mathematical operations are divergent, meaning that they may differ in how they relate to visuospatial skills. In early elementary education (6- to 8-year-olds) addition and subtraction, and how they relate to visuospatial skills are particularly important.

3.2. Addition vs. Subtraction

Different arithmetic operations are supported by different cognitive

processes. In adults, there is converging evidence that suggests that single digit addition and multiplication are much more likely to be solved by fact retrieval (e.g., from the rote-learned multiplication tables) than subtraction and division problems [5,14,35,45]. For example, Lee (2000) presented participants with single-digit multiplication and subtraction problems and observed larger activation in the intraparietal sulcus bilaterally during subtraction but stronger involvement of the left angular and supramarginal gyri during multiplication. This dissociation between arithmetic operation and brain activation, which is thought to be linked to solution strategy, has been found to increase developmentally ([57]), which likely coincides with the rote learning of addition facts. In sum, this difference in strategy used to solve addition and subtraction problems as well as neural network recruitment differences demonstrate differential reliance on spatial processing. Therefore, we predicted that spatial training would show a differential impact on arithmetic processing; subtraction performance improving after spatial training but not addition.

3.3. The current study

The goal of the current study was to examine the impact of spatial play on mathematics skill. The effect of a 5 day, 30 min per day training was examined using both behavioral and functional magnetic resonance imaging (fMRI). This study was designed to extend previous findings to explore the differential impact of two types of block play, free and structured block play, on arithmetic performance. Play was used here as it is an activity that children engage in regularly.

Participants in both groups played with the same set of blocks and a researcher played the game with participants in both groups. During structured block play training participants played Blocks Rock! in which two players are provided a set of colored blocks and there is a deck of cards with images of block configurations. The goal of the game is to create an accurate copy of the structure displayed on the card as fast as possible; the player who builds the structure first wins the round. The researcher playing the game with the participant adjusted their game play to keep the game challenging enough, but not overwhelmingly competitive. As with structured block play, Blocks Rock! involves the inspection of spatial relations, the re-creation of a specified structure, and hand-eye coordination to build the structure. The free play group had the same set of blocks and also played with a researcher. The participant was encouraged to build structures and played interactively with the researcher as in the structured play training. Free play training also involves hand-eye coordination during building and creative thinking as well as spatial processing. However, as suggested by Casey et al. [8], the spatial analysis required during structured block play is qualitatively different than that required during free block play. In addition to differences in spatial processing, the two game conditions differed in terms of the nature of the social interaction with the other player (competition for structured play vs. loose cooperation for free play), in addition to more nuanced differences like the use of cards showing the target design in structured play. These might have an impact on the outcomes. While we assume that these social factors only have an indirect impact on visuospatial skill development (e.g., competition might be more motivating for some participants, modulating attention and therefore improving performance outcomes), we need future research to help us explore how social factors like competition vs. cooperation can impact development of spatial skills in training studies.

The hypothesis tested was that structured block play with the game Blocks Rock! would result in greater improvements in arithmetic performance due to its impact on spatial processing. Additionally, both addition and subtraction performance was examined. It was predicted that even in the young population examined, spatial training would have a greater impact on subtraction due to its more extensive reliance on spatial processes compared to addition [14,35].

4. Methods

4.1. Participants

Forty-three (female = 21) children participated (age 8.3 ± 0.8 years) (see Table 1 for demographic information). The age group was similar to the ones participated in previous spatial training studies ([9]; Cheung, Sung, and Lourenco, 2020; [21]). Nine additional participants were recruited, but did not complete the protocol due to inability to complete the first MRI scan. Participants were recruited from the local community. Parents completed a short survey regarding their child's play behavior and parental education level. Participants had a variety of block building experience prior to this study, (e.g., playing with Legos); as such the two groups were equated on spatial play, gender, age, mathematics test score, and parental education. Parental consent and child assent were both obtained prior to the experimental sessions, in accordance with the University Institutional Review Board.

4.2. Experimental Design

The participants completed seven sessions, all on separate days. The first and last sessions were pre- and post-training evaluations. The middle five sessions were the training sessions. The length of time between the first and last session ranged from twelve days to thirty-nine days ($M = 26.1 \pm 9.6$ days), the mean number of days between the first and final session was similar for both groups (see Table 1). MRI scanning was performed during the pre- and post-training sessions. All sessions took place in the first author's lab.

4.3. Procedure

Participants completed a subset of questions from the Grade 2 Mathematics California Standards Tests from 2003-2007 as well as the Naglieri Nonverbal ability test prior to training to equate for ability across groups. The scanner task was a single-digit arithmetic task that included separate blocks of addition and subtraction. The presentation design is shown in Fig. 1. As shown, the participant was presented with the problem with the answer and then pressed a button to indicate whether the answer was correct or incorrect. Each block contained 4 problems, and the blocks were separated by 12 second fixation periods. If the participant did not answer a trial within 10 seconds, the program moved to the next trial. The task consisted of 48 single-digit addition and subtraction problems (24 addition, 24 subtraction). Accuracy and reaction time data were acquired for each trial.

Participants were separated into one of two groups – structured and free block play groups. During each of the 5 training sessions, participants played for 30 minutes with a research assistant. The Blocks Rock! game, a commercially available game, was used for both groups. The structured block play group played the game as designed. The game has a set of cards, two identical sets of blocks of varying shape, size and color

Table 1
Demographic information

	Structured Block play $M \pm \text{stdev}$	Free Block play $M \pm \text{stdev}$	2-tailed t-test p-value
Age (years)	$8.38 \pm .75$	$8.29 \pm .89$	0.70
n/# Female	22/11	21/10	n.a
Mathematics pre-test	11.5 ± 3.4	9.9 ± 3.6	0.76
Non-verbal ability pre-test	4.5 ± 2	4.3 ± 2	0.76
Time between scans (days)	26.7 ± 10.7	25.3 ± 8.4	0.62
Parent education*	Bachelor's Degree	Bachelor's Degree	0.9

* Note: the categories of parental education included: high school/GED, some college/associates degree; bachelor's degree; advanced degree.

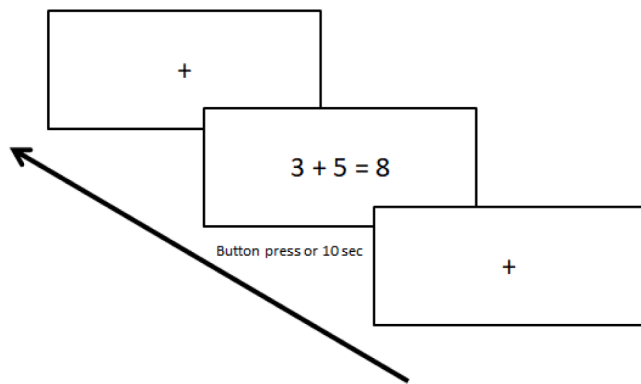


Fig. 1. Description of the order and timing of each trial.

and a bell. Each player has a set of blocks and one player turns over a card during play, which shows a particular structure, a point value and how to build the structure (e.g., up or flat on the table). The complexity of the structure increases during play. Each player attempts to build the structure as fast as possible with the player who does so correctly first and rings the bell being awarded the points displayed on the card. The score is kept and once all cards have been played the winner is the player with the most points. During each training session, participants played for 30 minutes with a research assistant who adjusted their play to match the subject. For the free block play group the same set of colored blocks were used but there were no cards and no competition. Participants were encouraged to create structures using the blocks and played with them and a trained research assistant who encouraged play/building for the 30 min period. In sum both groups played with the same colored blocks and both groups built structures with them with a partner. However, the structured block play required copying a structure and included a competitive component while the free block play required creating a structure from imagination and there was no competitive component. The research assistant ensured participants in both groups were engaged as they were involved in both training paradigms. The MRI protocol for the post-training session was identical to that of the pre-training session.

4.4. Imaging Parameters

Participants underwent MRI scanning using a 64-channel head coil and a Siemens 3T Prisma MRI scanner. The first scan was an anatomical T1-weighted scan used to co-register functional images. An MPRAGE sequence (176 sagittal slices; FOV=256 mm, matrix=256 × 256, TR=1800 ms, TE=2.7 ms, TI=900 ms, flip angle=9°, slice thickness=1mm, resulting in 1-mm x 1-mm x 1-mm voxels) was used. The experimental functional scan was a multiband EPI scan (40 axial slices using the following protocol: field of view=220 mm, multi-band acceleration factor=4, TR=750 ms, TE=30 ms, flip angle=50°, slice thickness=3.4mm, 0 gap resulting in 3.4 × 3.4 × 3.4 -mm voxels).

4.5. Data Analysis

fMRI data were analyzed with SPM12 (Wellcome Trust Centre for Neuroimaging; <http://www.fil.ion.ucl.ac.uk/spm>). fMRI data were preprocessed in several steps including motion correction by realignment, co-registration between functional and anatomical scans, spatial normalization and smoothing. All functional data were resampled to 2mm³ isomorphic voxels normalized to the Montreal Neurological Institute (MNI) template. For spatial smoothing an 8mm FWHM Gaussian kernel was applied. On the preprocessed fMRI data of individual subjects, a canonical statistical analysis based on the general linear model (GLM) and Gaussian random field theory was performed [16]. The hemodynamic response for each trial was modeled with a

canonical HRF built on the onsets of each block and the time to complete each block entered as the duration. For each individual data analysis, the 6 regressors from the realignment step were included in the model to remove unexpected effects from motion. First, a full factorial analysis was performed that included group, operation, and training as factors. Second, contrast images comparing pre- and post-training for subtraction and addition were computed using a paired t-test for each group separately.

For the contrasts examined we applied a Monte Carlo simulation of the brain volume to establish an appropriate voxel contiguity threshold. The threshold obtained from the simulation has the advantage of higher sensitivity to smaller effect sizes [42]. The result of the Monte Carlo simulation indicated that a cluster size of 40 contiguous resampled voxels using an uncorrected threshold of $p < 0.005$ would be appropriate to control type I error, at a $p < 0.05$ corrected for the multiple comparisons in the whole brain volume analysis.

5. Results

5.1. Behavioral

A repeated measures ANOVA with group (structured vs. free play) × operation (addition vs. subtraction) × training (pre- vs. post-training) was first computed on reaction time data (RT). The results showed a significant effect of training [$F(1,40)=28.55, p<0.001$] and operation [$F(1,39)=17.05, p=0.0002$]. There was no significant effect of group and none of the interactions were significant. Because there was an a priori hypothesis that structured block play has a larger impact on arithmetic performance than free block play paired t-tests were also used to examine the change in arithmetic performance after block play training. To correct for multiple comparisons a Bonferroni correction was applied such that the p-threshold for significance was set to 0.05/4 (0.0125; 2 groups 2 conditions). Both groups showed improvements in reaction time (RT) after training. However, using a 2-tailed t-test, the structured block play group showed a significant difference for both addition [$t(20)=2.91; p=0.0087$; Cohen's $d = 0.29$] and subtraction [$t(20)=2.96; p=0.0077$; Cohen's $d = 0.37$] while the free block play group only showed a marginally significant effect for subtraction [$t(20)=2.74; p=0.0127$; Cohen's $d = 0.38$] and a non-significant difference for addition [$t(20)=2.02; p=0.0567$; Cohen's $d = 0.21$], see Fig. 2. There were no effects of training on accuracy (all p-values>0.2). Additionally, no the groups showed differences in RT or accuracy for pre-training addition and subtraction conditions.

5.2. fMRI

5.2.1. fMRI analyses

First, a full factorial analysis was performed. As shown in Fig. 3A, the typical network was found for the average effect of condition. Additionally, the main effect of operation reveals differential activation for addition and subtraction (Fig. 3B). The interaction between group and training was of most interest. For the group by training interaction, revealed activation in the left putamen (x,y,z coordinates=-26, -6, 12; $k=117$; $z=3.08$) and the left precentral gyrus (x,y,z coordinates=-36, -10, 38; $k=40$; $z=3.38$).

5.2.2. Structured Block Play

Paired t-tests were then performed for each group and operation separately. The structured block play group showed increased activation after training in a number of regions (see Fig. 4, Table 2). The pattern of change was different for addition and subtraction. For addition, increased activation was observed in the right temporo-parietal cortex, left putamen, left inferior frontal cortex and left parietal cortex. Training related activation differences for subtraction were found in the right putamen, right inferior frontal gyrus and left precentral cortex.

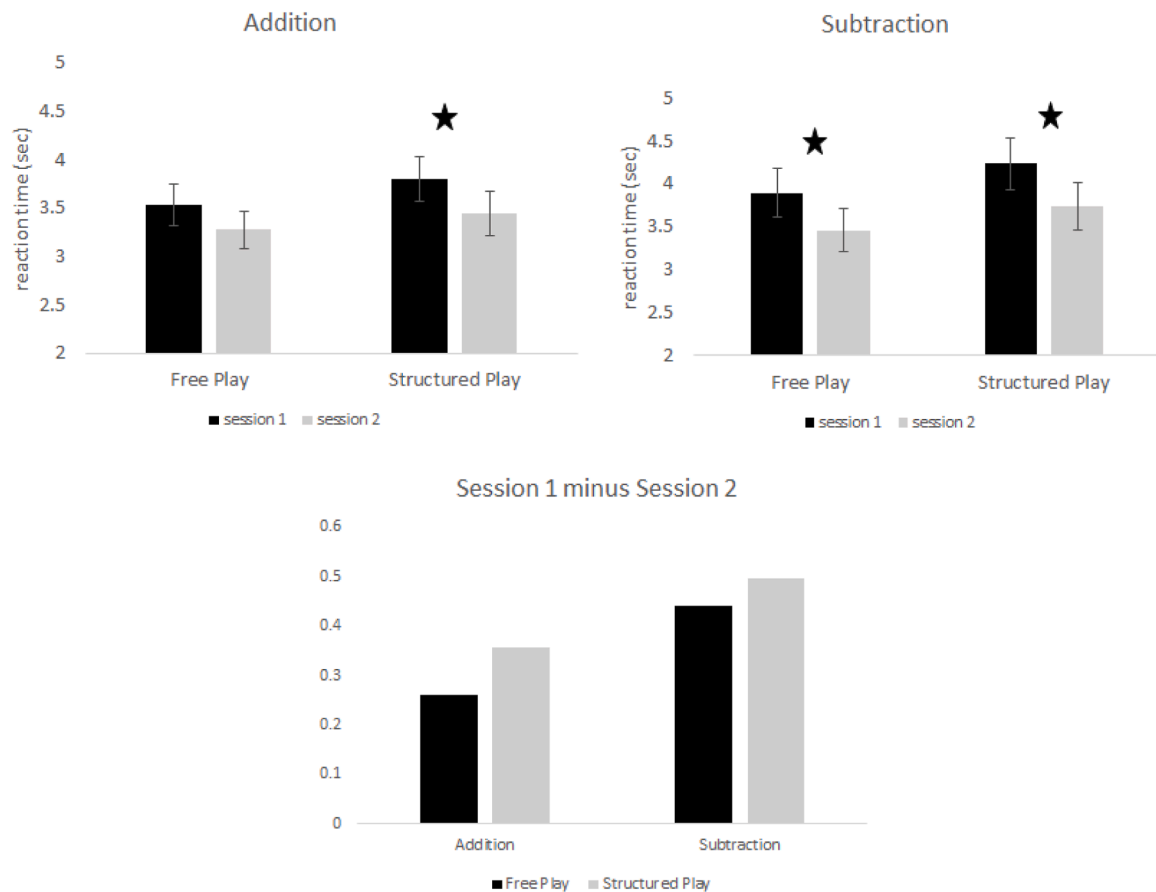


Fig. 2. Reaction time differences after training. As shown reaction times were faster after training for both groups for addition and subtraction; however, only the structured block play group showed a significant speed increase after training for addition, both groups showed improvements for subtraction.

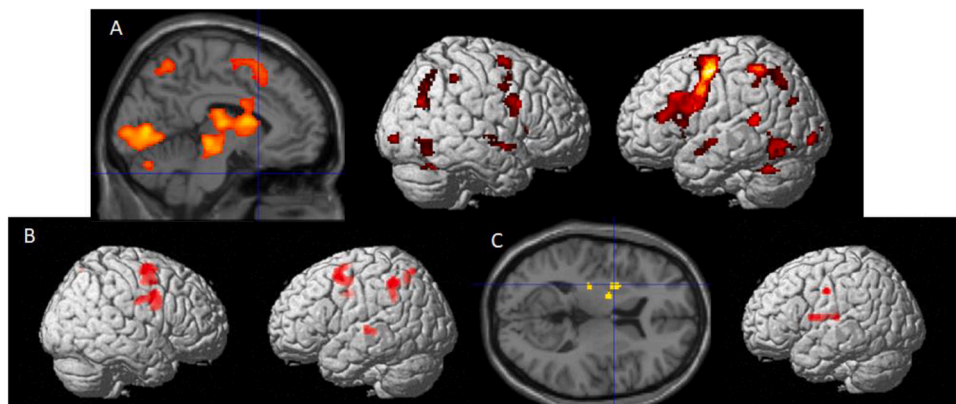


Fig. 3. Results from the full factorial analysis. (A) Depicts the average effect of condition; (B) main effect of operation; and (C) the interaction between group and training session.

5.2.3. Free Block Play

The free block play group showed no significant training-related activation differences for addition. For subtraction, the group showed decreases in activation after training in left inferior parietal cortex, temporal-parietal lobe and precuneus (see Fig. 5, Table 2).

6. Discussion

The primary goal of this study was to examine the impact of block play on arithmetic processing. After 5 days of either free block play or structured block play the current study showed that both forms of block

play resulted in improvements in performance; however, the improvements were different. Children who played a structured block building game was faster at answering both addition and subtraction problems and they showed training-related brain activation changes in regions linked to spatial processing. Unlike structured block play, free block play training resulted in improvements in subtraction performance but had a smaller effect on addition. These findings have implications for the usefulness of block play in the development of mathematical competency and suggest that structured block play and free block play engage different neurocognitive systems.

In the current study, when examining the brain regions impacted by

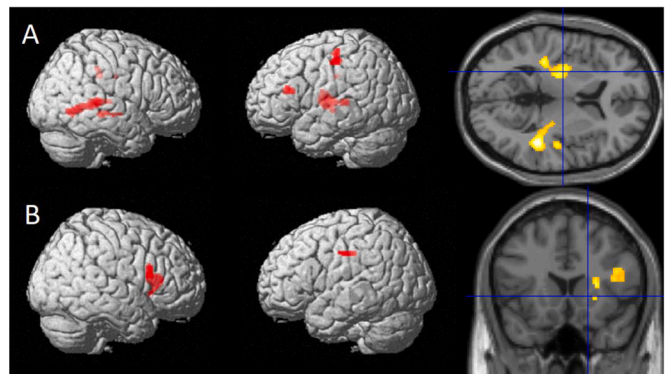


Fig. 4. Structured Block Play: (A) Depicts activation increases after structured block play for addition. (B) Depicts activation increases after structured block play for subtraction.

Table 2
Activation foci

Region	BA	k	t	x	y	z
Structured Block Play (addition)						
Right Temporal-Parietal Lobe	37/39	324	4.57	44	-36	6
Right Posterior Insula/S. Temporal	13/22	58	3.93	38	-30	-6
Left Superior temporal gyrus	41	360	3.91	-36	-30	6
Left Putamen			3.81	-22	-16	6
Right Cingulate Gyrus	31	54	3.46	6	-32	34
Right Cingulate Gyrus	23	56	3.34	2	-18	32
Left Inferior Frontal gyrus	45	49	3.32	-46	28	20
Left Parietal Cortex	3/40/7	119	3.29	-42	-22	60
Structured Block Play (subtraction)						
Right Putamen/Caudate		140	4.65	26	24	10
Right Inferior Frontal Gyrus	44	86	3.53	44	16	22
Left Precentral Cortex	4	95	3.33	-42	-18	36
Left Parietal Cortex	2/3		3.31	-32	-22	36
Free Block Play (addition)						
No activated voxels						
Free Block Play (subtraction)						
Left Temporal-Occipital Lobe	37	180	3.98	-52	-52	-2
Left Inferior Parietal Lobe	40	88	3.5	-60	-34	26
Left Precuneus	7	64	3.4	-10	-52	50

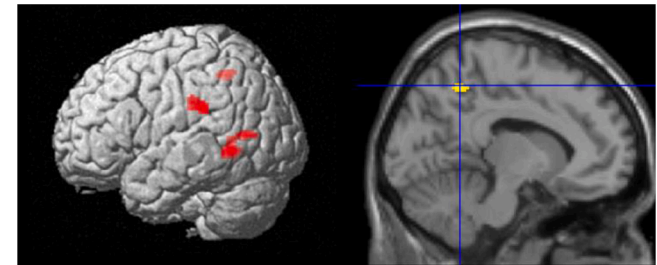


Fig. 5. Depicts activation decreases after free block play training for subtraction. There were no training-related activation differences for addition.

block training for subtraction we find very different regions for structured and free block play. Free block training elicited a differential response in the precuneus and the temporal-occipital cortex. The precuneus participates in a range of multimodal tasks involving visuospatial processing (see Cavanna & Trimble [55] for a review), including visuospatial imagery, and encoding and retrieval of spatial locations ([54]). The temporal-occipital regions have been linked to object shape processing [24]. Structured block training, on the other hand elicited a differential response for subtraction in the striatum (putamen/caudate) and right inferior frontal cortex, both of which have been implicated in

spatial working memory [32,34]. These results support the hypothesis that free and structured block play training impact different aspects of visuospatial processing.

Individual differences in object and spatial imagery skills have been linked to mathematics competency with spatial imagers performing better on math tests than object imagers [19]. For example, Haclomeroglu [19] found that spatial imaging ability positively correlated with performance on a calculus exam while object imaging ability negatively correlated with performance. This suggests that although both forms of block play may result in improvements in visuo-spatial processing, structured block play may have a greater impact on processes that overlap with mathematics.

6.1. Addition vs. Subtraction

Previous studies have shown a strong relationship between spatial processing ability and mathematical competency [1,23,30,36]. The results presented here show that spatial training with block play impacted arithmetic processing. As predicted, block play training, whether free or structured, had a stronger effect on the arithmetic operation that is thought to rely more heavily on spatial reasoning – subtraction. The current study showed a main effect of operation with subtraction eliciting more activation than addition in the left parietal cortex and bilateral frontal eye fields. Previous studies have suggested that unlike addition, few subtraction facts are stored in memory and as such calculation processes are required for subtraction [40]. These calculation processes likely rely on spatial processing including spatial attention, transformation processes and even magnitude processing.

A second, related, difference between the two operations may be their reliance on finger use. Given the age of the participants it is very likely that many were using finger counting strategies (see [44] for a review). Unfortunately, finger counting use was not recorded. However, studies have shown that finger use varies with arithmetic operation ([3, 53]). For example, Berteletti and Booth [3] found that children recruited finger based motor areas more for subtraction than for multiplication suggesting that finger use supported subtraction but not multiplication. It should be noted that finger processing is related to visuospatial processing [15,38]. Therefore, while speculative, improvements in spatial processing may also improve the efficiency of finger use.

In support of the differential reliance of addition and subtraction on spatial processes, a number of studies have shown brain activation differences for addition and subtraction, even in adults [14,26,39]. These previous results show significant overlap between the subtraction-related activation and regions linked to spatial processing, particularly bilateral parietal cortex and the cerebellum (Stoodley, Valera & Schmahmann, 2010; [48,49,52]).

6.2. Limitations

The results reported here are very promising and suggest that structured block play may be an important tool to help improve mathematical performance. However, the results are preliminary in that the number of subjects is somewhat small. The lack of a control group makes it difficult to generalize the results. While the comparison of two interventions inform the differential impact of the two forms of block play, this study does not inform the impact of block play in general compared to business-as-usual. Additionally, the two forms of play, free and structured play, differ not only in terms of the visuospatial processes involved, but also in terms of the nature of social interaction (i.e., competitive vs. loosely collaborative). This difference might have impacted each participants motivation differently (e.g., competition or collaboration being more motivating than the other) and affected the level of engagement during game play, which could have an indirect impact on visuospatial skill development. Finally, the training period was rather short. A longitudinal study in which cognitive ability, including spatial ability, is thoroughly assessed to determine the

developmental consequences of both free and structured block play is necessary to fully characterize the impact of block play on mathematics.

7. Conclusions

The results presented here suggest that spatial training can transfer to other tasks that have overlapping processes, in this case mathematics. It also suggests that not all block play is equal and that free and structured block play may impact different neurocognitive systems. Here training on a speeded, structured block building game, Blocks Rock!, resulted in improvements in both addition and subtraction. This was not the case for free block play that also has visuo-spatial attributes, with it showing improvements only for subtraction, suggesting that these two games possibly train different aspects of visuo-spatial processing with Blocks Rock! having an impact on spatial working memory. The findings reported here have important implications on child play activities. Given the importance of spatial thinking to success in science, technology, engineering and mathematics, using games like structured block building may prove to be important for helping to set a solid foundation.

Ethics statement

All protocols in the study were approved by a university ethics review committee. All participants provided written, informed consent or assent.

Financial disclosure

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Declaration of Competing Interest

There are no conflicts of interest related to this research.

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