Training Planning and Working Memory in Third Graders

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ABSTRACT— Working memory and planning are fundamental cognitive skills supporting fluid reasoning. We show that 2 games that train working memory and planning skills in school-aged children promote transfer to 2 different tasks: an attentional test and a fluid reasoning test. We also show long-term improvement of planning and memory capacities in 8-year-old children after playing adaptive computer games specifically tailored to entrain these cognitive functions. Working memory capacity expanded from 5 to 7 items by using our games. Furthermore, steady progression in the task indicates that this capacity can be trained rapidly. Planning abilities persisted in a nonmarkovian form of play, where a move is highly influenced by previous moves, avoiding back-ups. Here, we introduce a public and growing platform (http://www.matemarote.com.ar/) developed for this research which has the potential for wide use in educational research.

Working memory and planning are basic cognitive skills supporting fluid reasoning affecting performance on a wide range of cognitive tasks (Buschkuehl & Jaeggi, 2010; Conway, Kane, & Engle, 2003; Ferrer, O'Hare, & Bunge, 2009). Working memory refers to the capacity to store and manipulate information for very brief periods of time (Baddeley & Hitch, 1974). Its capacity is limited to a few items both in adults (Cowan, 2001) and infants (Feigenson & Carey, 2005) and has been directly related to children's performance at school (St. Clair-Thompson & Gathercole, 2006; Gathercole, Brown, & Pickering, 2003). An efficient way to expand working memory load is by intelligently grouping items in chunks of interrelated units (Miller, 1956). Chunking cues can be of different origins, including perceptual, conceptual, linguistic, or spatial (Feigenson & Halberda, 2008). Working memory is necessary for planning and interacts with other executive functions.

Contemplating the potential costs and benefits of future actions, imagining goals, and planning sequences of actions to attain a goal is an important part of our everyday control of actions (Simon & Newell, 1971; Unterrainer & Owen, 2006). This is broadly referred as *problem solving*, the process of developing a sequence of actions to achieve a goal. *Planning* is one problem-solving technique, which involves deciding on a course of action before acting (Cohen, 1986, Chapter XV). Failure to plan can result in less than optimal problem solving. Moreover, plans can be used to monitor progress during problem solving and to detect errors sooner. Feedback about the state of the world is compared with what is predicted by the plan, which can then be modified in the event of discrepancies (Cohen, 1986, Chapter XV).

Planning ability relates to other cognitive faculties. For instance, children with reading disabilities are less efficient in conducting a plan (Condor, Anderson, & Saling, 1995) and good planners have better metacognition, exercising more conscious control over the whole planning process (Hayes-Roth, 1980). Planning in infants share many features with adult planning, with important parametric differences (Klahr & Robinson, 1981). Children as young as 3 years old are able to construct simple plans and planning skills develop faster between the ages of 5 and 8, while improvements in performance still continue well into early adulthood (Jurado & Rosselli, 2007).

In this article we present two computerized games specifically tailored to train working memory and planning skills in school age children. There has been controversy on the efficacy and specificity of interventions to improve fluent reasoning and other executive functions (Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Mackey, Hill, Stone, & Bunge, 2011; Morrison & Chein, 2011; Owen et al., 2010; Shipstead, Redick, & Engle, 2012; Sternberg, 2008). Our goal was to investigate whether 8-year-old children can improve planning and memory with practice and, if so, how transferable is that

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learning. For that purpose we deployed a playful training intervention at the school the children attended.

Play is a motivating and engaging way of learning things (Ackerman, 2000). Playing has been shown to foster academic, cognitive and social abilities in children (recently reviewed in Fisher, Hirsh-pasek, Golinkoff, Singer, & Berk, 2011) and several authors have suggested that playing might produce a qualitative change in learning and education (e.g., Prensky, 2002). Computer games in particular are typically fast and more responsive and, while the computer sets the rules of the game, players can immerse themselves more deeply in the experience, sustaining interest in the game (Prensky, 2001, Chapter 5). Games can be seen as means of encouraging learners who may lack interest or confidence and of enhancing their self-esteem (Din & Calao, 2001). Computer games have many advantages that are crucial for learning: they can provide instant feedback (Prensky, 2001, Chapter 5), they can deal with infinite amounts of content and afford adaptable levels of challenge, and they can be instantly updated and modified for research purposes.

Beyond the specific results shown in this article, our aim is also to present a public platform which is available at http://www.matemarote.com.ar/. It consists of a growing set of games designed to entrain and evaluate executive functions and mechanisms related to specific reasoning and problem strategies used by children throughout the course of learning. School experience has revealed that these games are entertaining and that children are eager to play, indicating that they may constitute a useful tool to promote educational research.

MATERIALS AND METHODS

Participants

A total of 23 eight-year-old children (12 males), participated in the study. All participants were recruited from one school in the metropolitan area of Buenos Aires. Children's caregivers gave written consent to participate in the study, which was previously authorized by the institutional Ethical Committee (CEMIC-CONICET).

Description of the Games

Two games were designed with the aim of training working memory and planning skills.

Working Memory Game

This game is based on a nonspatial, pattern recognition working memory task, a paradigm that measures recognition memory for visual patterns, but not spatial locations (Luciana & Nelson, 1998; Petrides & Milner, 1982). Each trial consists of a constant number of items that appear randomly located in a 4×3 squared grid (12 possible locations, Figure 2a).[1] When the trial starts all the items are presented, each in a different random location of the grid. The child has to select one of the items with a mouse click in its specific location. A new screen appears after 2,000 milliseconds with the same list of items in a newly randomized spatial distribution. Now the child has to select an item different from the one s/he chose before and the process repeats. In each step of the sequence (referred as "an event") the child has to choose one item which was not chosen in the previous events of that trial. The process continues until the child has chosen, without repetition, all the items of the list (correct trial) or when s/he makes a repetition (error). The game starts with a predefined low number of items (three for this study; see section Training and Testing Procedures for further details) and this number can increase or decrease depending on the child's performance (i.e., after a number of consecutive correct three-item trials, the following trials have four items to be remembered, and the game can continue up to 12 items; if, on the other hand, children make errors in a number of consecutive trials, in the following trial one less item will have to be remembered). Note that for a small number of items children have to remember all the chosen/not yet chosen cards (to avoid repetition). When the number of items exceeds the working memory limit, kids have to adopt a chunking or ordering strategy to solve the problem. Analyses were made considering the quantity of remembered items per trial per child.

Each item is an image (a card) defined by a list of features. Features can be present or absent (for instance an item may or may not have an umbrella). When present, they can assume a wide range of values. Features include card shape (eight different shapes), background (can be a color or an image of a beach), character (a boy or a girl in three different situations, or none), umbrella (of different colors or absent), number of buckets, and number of stars. In each trial, any variable can be defined to be binary, assuming only two values across all the items. For instance, in Figure 2a a stimulus in which a character takes only value "girl" or "none" is shown. This variable is binary and can potentially be used by children to chunk and categorize the items.

Planning Game

This game is based on the Dog-Cat-Mouse puzzle designed by Klahr (Klahr, 1985) and consists of three characters (a boy, a girl, and a cat) and three places ("homes") that belong to each character. The characters and the places are arranged on a square board, which has four paths ("bridges"), each one parallel to each side of the board, and one diagonal path between the upper left and lower right corners of the board (Figure 2a). The characters can only be moved along the paths one at a time. The goal of a trial is to move every character to its corresponding place. To move a character, children click on it and drag it and drop it to the new position. If the drop is made outside of a house or if the child comes back to the original position, the action is not counted as a move. These actions are recorded but were not considered for analysis in this manuscript. All the children in this study were already familiar with computers and could do the task almost perfectly. Nevertheless, the first phase of the game was a practice period in which children familiarized themselves with the game (see below for more details). Children were instructed to move each character to its home according to three rules: the characters have to be moved one at a time and to an empty place (this is called “a movement”), they can only be moved through the bridges, and they cannot share a house. They were also told not to rush since speed was not necessary to win. After very few trials all children understood these rules perfectly.

In this planning problem there is no obvious order in which the characters have to reach their places. Children have to plan the whole path in order to win the trial. This contrasts with subgoaling problems, where partitioning a large planning problem into easier second-level subproblems, each with its own subgoal, helps to succeed (i.e., Tower of Hanoi, where the bottom-most object must reach the goal peg before the second one, and this effective strategy nearly always results in an optimal solution path; see Simon, 1975). Each trial can be characterized in terms of its path length (i.e., how many moves have to be done to attain the trial): the total number of possible problems varies from one to seven moves (Klahr, 1985; see Figure 3b). For this study, minimum-move trials imply two movements and after three consecutive correct trials the number of movements increases by one. Number of moves made and number of correct trials for each distance and each child were considered for the analyses. As we show, with this study we gained considerable knowledge of the difficulty of the different states of the game.

Experimental Design

The original idea of this pilot study was not only to test the training and transfer of working memory and planning games but also to test how children react to Mate Marote’s games and interface: if they like the games, how they learn to play them, what kind of strategies they use to solve the different levels, if they find them fun. Hence, we needed more children to play Mate Marote’s games. Our eight-year-olds were randomly divided into trained ($n = 15$) and control ($n = 8$) groups.

Each experiment consisted of a total of 7 nonconsecutive days of training on two different computer games. All children played computer games in experimental sessions which lasted between 10 and 15 min (time difference was due to school issues and was random for each child in all sessions). Children played only one game in each session and performed at least two sessions per week. Children in the trained group played the working memory game for the first four sessions

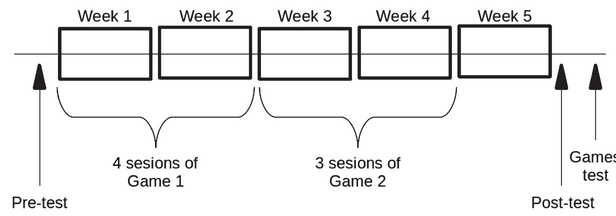

Fig. 1. Time line of the experiment. A diagram of the whole experimental procedure is shown. Children played only one game in each session and performed at least two sessions per week (boxes). Children in the trained groups played Mate Marotes’ games. Trained group game 1: Working Memory game; trained group game 2: Planning game. Children in the control group played two different games (1 and 2) which were selected to minimize cognitive demands with comparable engaging and motor action than Mate Marote’s games. Evaluation for transfer was assessed one week before (pre-test) and after (post-test) the intervention sessions, and a final test session was conducted to assess the long-term memory triggered by the games. All evaluations are shown by arrows.

and immediately after that played the planning game for the last three sessions (see timeline in Figure). Children in the control group played four and three sessions of two different games which were selected to minimize cognitive demands with comparable engaging and motor action (control Game 1: One character had to jump in order to win color balls, and keyboard arrows were needed; control Game 2: It was a rally race, not restricted by time, and mouse usage was necessary).

The sample size of this pilot experiment was too small to provide robust conclusions of the effect of this intervention on cognitive batteries. However, for the purpose of piloting this intervention and to provide an initial estimate of its efficacy, 1 week before the beginning of the training and 1 week after the last game session (Figure 1) all children took a battery of standard tests.

A final session was conducted to test for the long-term memory achieved by playing the games. That session took place 7 days after the last planning training session and 21 days after the last working memory training session (Figure 1). All the training and testing procedures were assessed by the investigators inside the school, in appropriate rooms for these purposes.

Software Design and Requirements

Games were programmed in javascript and designed to run on any browser. They were specifically designed to work on conventional Pentium II PC-compatible computers, not using heavy computing power, to assure that they will be broadly usable in future school interventions. This experiment involves two different games specifically aimed to train working memory (*memomarote*) and planning (*casitas*) skills (http://www.matemarote.com.ar/). Note that this platform is constantly being developed and updated, so current games may not be identical to the ones used in this specific experiment.

Games progress using an algorithm that continuously adapts the difficulty level based on participant's performance (see section Training and Testing Procedures for further details). The adaptive nature of the game is determined by a structure of predefined levels (for instance, in this article a small number of items in the working memory game constitutes a lower level than one with a higher number of items). Each level determines the parameters of a trial and for each experimental design the experimenter can flexibly set a precise pattern of features and levels and the policy to advance between the levels (for instance, how many successive correct/erred trials to advance/decrease one level).

All the programs have interfaces which give feedback for correct performance. The graphics were depicted by image designers to make the esthetics of the game enjoyable to children. The graphics design process had several iterations informed by feedback from children in the 4–8-year-old age range. The software registers all participant's responses including response times and specific mouse trajectories which can then be used for quantitative analysis.

Training and Testing Procedures

In all the experimental and training sessions, every child played accompanied by an adult who was there to explain the rules (the first time) or remind them (whenever necessary) and to support the child if needed (for instance, some children need somebody to tell them that they play well and that it is part of the game if they lose). All experimenters gave the same instructions every time they explained the rules. All the children understood the rules perfectly after less than three trials on all games.

Children never knew they were been evaluated. The experimenters' discourse was always playful, both in the training and in the testing phase. Experimenters had to make sure that the children enjoyed the experience as much as possible. Children were told that if they did not want to stay in the experimental room they could go back to their classroom as soon as they wished to. No children left any experimental session and all children had fun while playing.

Working Memory Game Training Phase

In the training phase of the working memory game, all children started playing three items' trials. When a child performed five correct consecutive trials, the number of items increased by one. When s/he made three consecutive errors, the number of items decreased by one. Each experimental session started with the level of difficulty that the child had attained in the previous session. During 2 weeks (weeks 1 and 2, Figure 1), four training sessions (nonconsecutive days) were conducted as long as the child went to school that day.

Working Memory Game Testing Phase

To assess the long-lasting memory of the working memory game, a testing session with the same game was run 3 weeks after the last working memory game training session. The evolution policy during this session was set in the following manner. A fixed sequence of six items was chosen for all participants with the following sequence of number of items (levels): 5, 8, 8, 10, 10, 10. A trial was repeated until (a) the child performed it correctly, in which case s/he moved to the next level, or (b) the end of the six-trials test session. The number of items for each level was chosen considering the difficulty seen during the training session (see Figure 2b): five-item trials were completed at the end of the first session, whereas almost no children had accomplished eight-item trials at the end of the fourth session.

Planning Game Training Phase

Training sessions were organized in two different phases: a first *free-exploration* phase and a following *restricted-movements* phase. During 2 weeks (weeks 3 and 4, Figure 1), three training sessions (on nonconsecutive days) were conducted as long as the children went to school that day.

Free-exploration phase: In this phase a trial was considered correct when the children moved all the characters to their corresponding houses regardless of the number of moves they used to attain the goal. Children were told to solve the trial in the minimum number of moves, but it was emphasized that they would not lose if they solved the problem using more moves. This phase finished when children completed all the sequence of trials (three consecutive trials in which the number of moves between the initial configuration and the goal was, respectively 2, 3, 4, 5, 6, and 7). All children completed this phase by the end of the second session.

Restricted-movements phase: In this phase a trial was considered correct only if the goal was attained in the minimal number of moves. Children were told how many moves were enough to solve each trial and were told that they would lose if they made more moves to reach the goal. All the children understood perfectly well this new rule.

Planning Game Testing Phase

To assess the long lasting memory of the planning game, after 2 weeks from the last training session all children played five trials of the planning game. Each trial involved a path of three, five,or six moves. As in the *free-exploration phase*, children were told to solve the trials in the minimum number of moves but they did not lose if they made more moves. For the analysis, a trial was considered correct only if it was solved in the minimal number of moves. There was no restricted phase in the testing session.

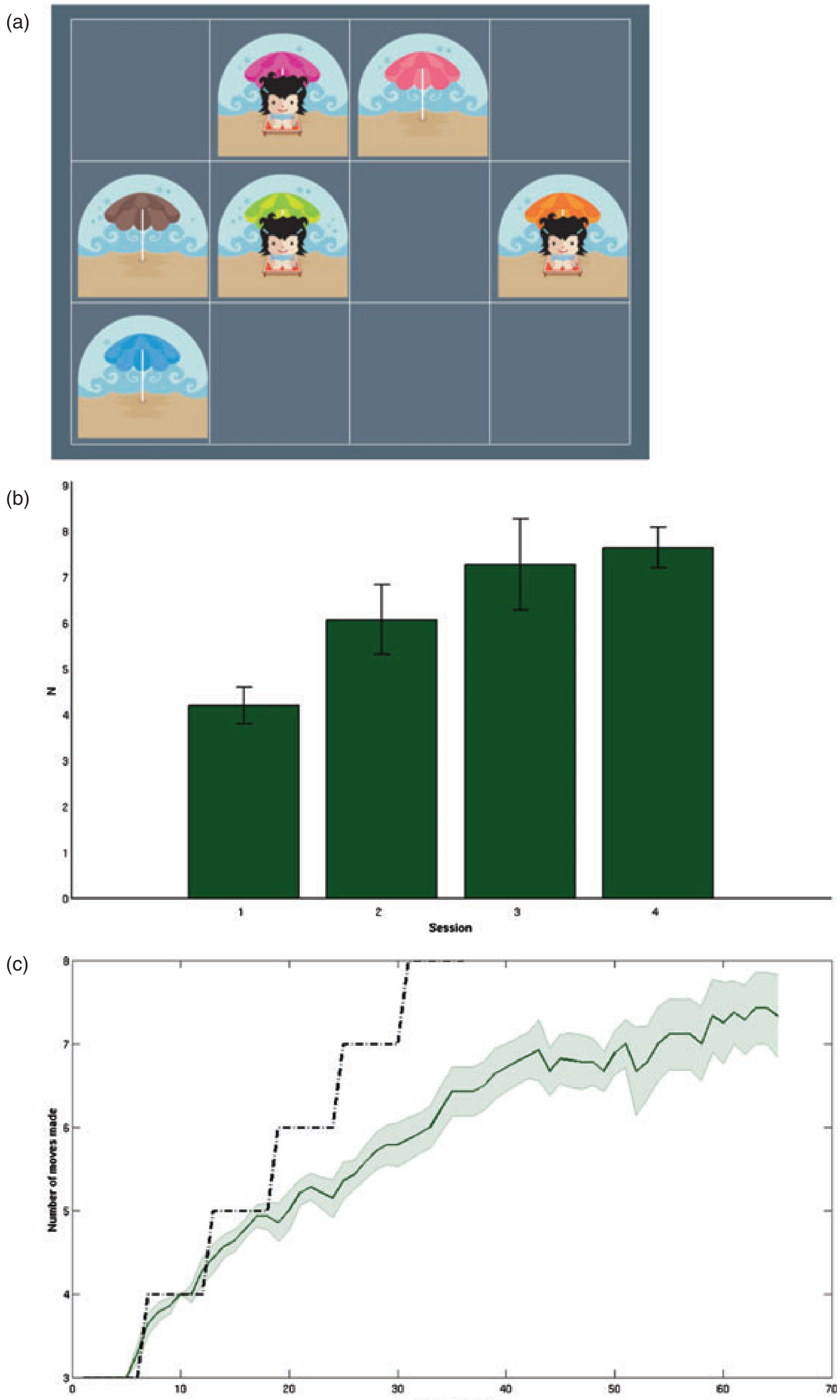

Fig. 2. Mate Marote's working memory game. (a) The screen of a six-item trial. All the cards have the same background and shape and an umbrella that differs in color. All cards have different number of stars. Half of the items have the girl character sit on a chair. There are no buckets in this trials (buckets can differ in number and appear on the sand, surrounding the girl). (b) Mean number of items achieved by children in the trained group in each session (day) played (Bars: mean ± SEM). (c) Working memory game dynamics: mean number of items achieved in each trial played, regardless the session when it occurred. Only trials played by at least six children are plotted. The dotted line is the "perfect play" curve (Points: mean ± SEM).

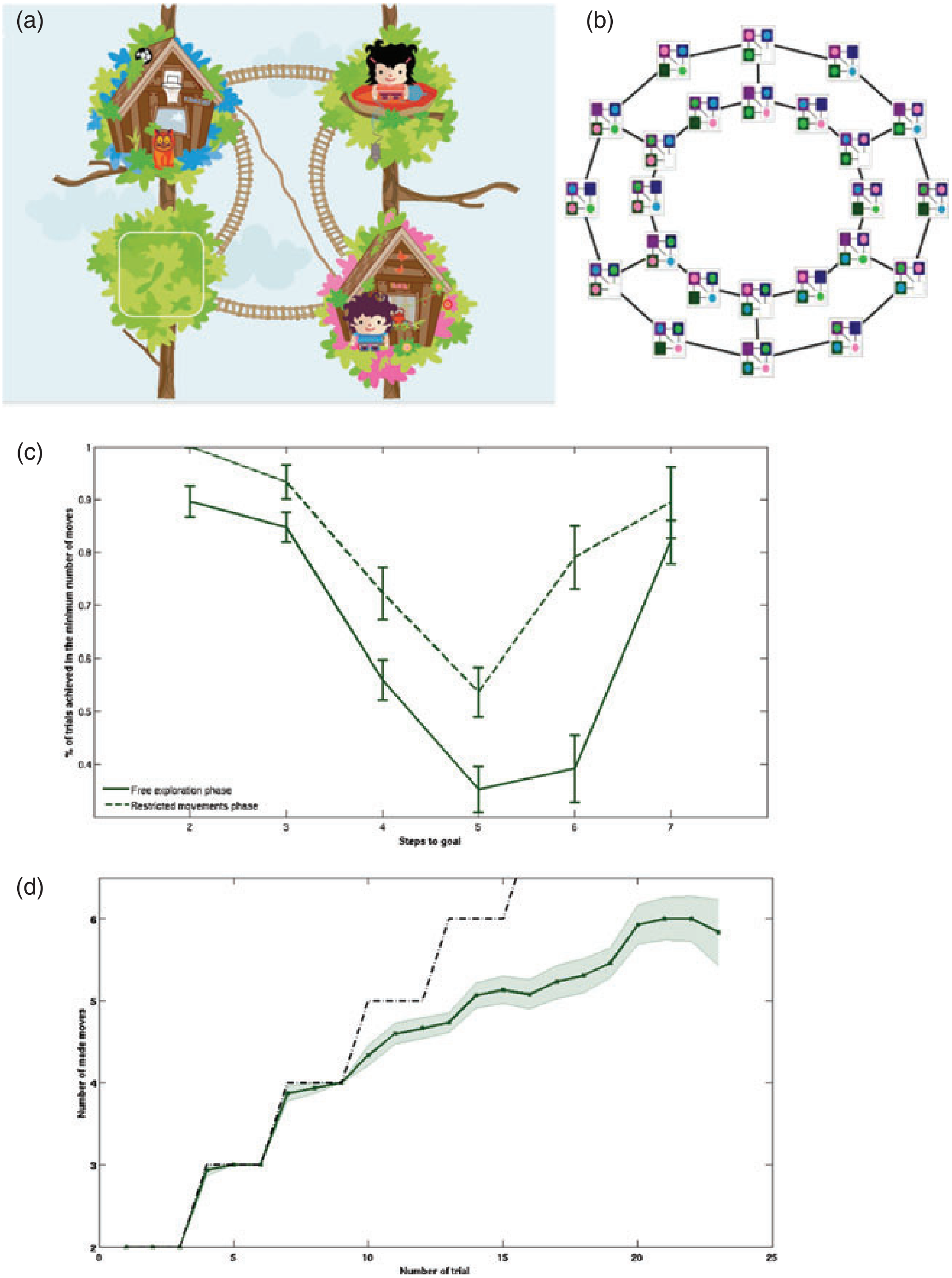

Fig. 3. Mate Marote's planning game. (a) The screen of one 4-moves trial. The three characters (Pancho on the lower right corner, Ana on the upper right corner, and Nubis the cat on the upper left corner) have to reach their homes (Pancho's upper left, Ana's lower right, and Nubis's upper right; the lower left corner is an empty place to temporarily occupy). (b) The state space for the planning problem. Each node represents a unique configuration of the three characters/homes. The longest distance between two nodes is seven moves. (c) Percentage of correct trials as a function of the number of moves required to go from the initial to the final configuration for children in the trained group. Line: Free exploration phase; dotted line: Restricted movements phase (Points: mean ± SEM). (d) Planning game dynamics: mean number of movements made in each trial played in the restricted movements phase. Only trials played by at least six children are plotted. The dotted line is the "perfect play" curve (Points: mean ± SEM).

Pre- and Postmeasures for Transfer

To evaluate the transference of the working memory and planning skills improved, 1 week before the beginning of the training and 1 week after the last playing session all children's took a battery of standard tests. Tests included the children version of attentional test *ANT* (Attention Network Test, Rueda et al., 2004), the abstract reasoning skills (Matrices) of general intelligence *K-BIT* test (Kaufman Brief Intelligence Test, Naugle, Chelune, & Tucker, 1993), the Tower of London planning test (TOL, Shallice, 1982), and a spatial working memory task (Corsi Blocks, Corsi, 1973).

RESULTS

Training Process

As mentioned before, one of the aims of this study was to evaluate how children played the games and if they were properly designed to train working memory and planning skills. In the working memory game children showed a steady improvement in the number of items per trial (Figure 2b). This progression became slower as the game advanced. The number of trials to reach the four-item level was 7.00 ± 0.60 (Figure 2c), showing considerably slower progression than expected by perfect play (five trials). When the number of items increased, children progressed at a slower pace, revealing a greater number of errors and a slow speed of progress compared to perfect play (black line Figure 2c. Number of trials to pass from the four- to the five-item level: 8.64 ± 1.79. Number of trials to pass from the five- to the six-item level: 12.36 ± 1.88). This suggests that the levels played in this experiment were already challenging, at least for this age group, and the improvement suggests some effect on the ability to develop working memory strategies.

The planning game is conveniently described by a graph in which each node is a state and all links are legal moves between two states (Figure 3b). We assumed that the difficulty of the game would increase monotonically with the distance between the initial and end-state, and we therefore designed a structure of levels in which this distance increased as the children performed the game correctly. As we show below, this assumption was erroneous, because the difficulty of the game is a nonmonotonic function of distance.

Analysis of the planning game was slightly different for the different phases of training. In the free-exploration phase children progressed to different levels regardless of the number of moves they made. However, for analysis, we measured the fraction of trials which were completed in the minimal number of moves. This analysis revealed a nonmonotonic pattern of performance (Figure 3c, line). The fraction of trials performed in the minimal number of moves decreased as the distance between the initial and final states (d) increased from 2 to 5, reaching a very low minimum proportion of correct trials ($35.16 \pm 4.38\%$). Performance then increased, reaching more accurate performance for the longer distances (for $d = 7$: $81.97 \pm 4.06\%$). An analysis of variance (ANOVA) with distance (2–7 moves) as main factor showed a significant effect ($F_5 = 28.63; p < .0001$). Post hoc Bonferroni comparisons showed $p < .0001$ for distances 4, 5 and 6 vs. 2, 3 and 7.

Table 1

Probability of Wining a Planning Game Trial if Passing or if Starting in One Same Distance, for Both Phases

	Free exploration	*Restricted movements*
Passing	0.8978 ± 0.0599	0.9506 ± 0.0826
Starting	0.5980 ± 0.0886	0.7967 ± 0.0941
t-value	17.111	29.635
df	1310	932
$p_{t\text{-test}} <$	1.25×10^{-5}	8.20×10^{-7}

The evolution in performance in the restricted phase was different (Figure 3c dotted line and *d*). Children showed an evolution expected by perfect performance for initial states at distances below 4. For trials in which the distance between the initial configuration and the goal is greater than 4, 8-year-olds diminish the rate of progress indicating a greater number of errors. To quantify these observations we submitted the data to an ANOVA with distance as main factor, which was significant: $F_5 = 13.65$; $p < .0001$. Post hoc Bonferroni comparisons showed $p < .001$ for distances 2 and 3 vs. 5, $p < .01$ for distances 6 and 7 vs. 5, and $p < .01$ for distance 2 vs. 4.

The nonmonotonic dependence of performance suggests a form of play without back-ups, as described in Klahr's original study (Klahr, 1985). In initial configurations in the antipode of the graph relative to the objective (at the maximal distance $d = 7$, see Figure 3b) the first move is always correct. If children's tendency is to persist without back-ups then they would pass through the next state (at $d = 6$) with a correct direction of movement, revealing some form of inertia. A prediction of this behavior is that performance in a given state should be much better when it is a point of passage following a sequence of correct moves than when it is the initial configuration. This prediction was clearly verified as children performed at higher levels of accuracy when they passed by certain distance than when they started in that same distance (Table 1; for instance, when $d = 5$ it was more likely for a child to win if s/he children passed through that position while playing a trial that had started at $d = 7$ than if the child had started at $d = 5$).

Testing Process

Twenty-one (working memory) of seven (planning) days after the last training session, trained children were tested for long-term memory of the Mate Marote's game and compared with the control group, which had never played.

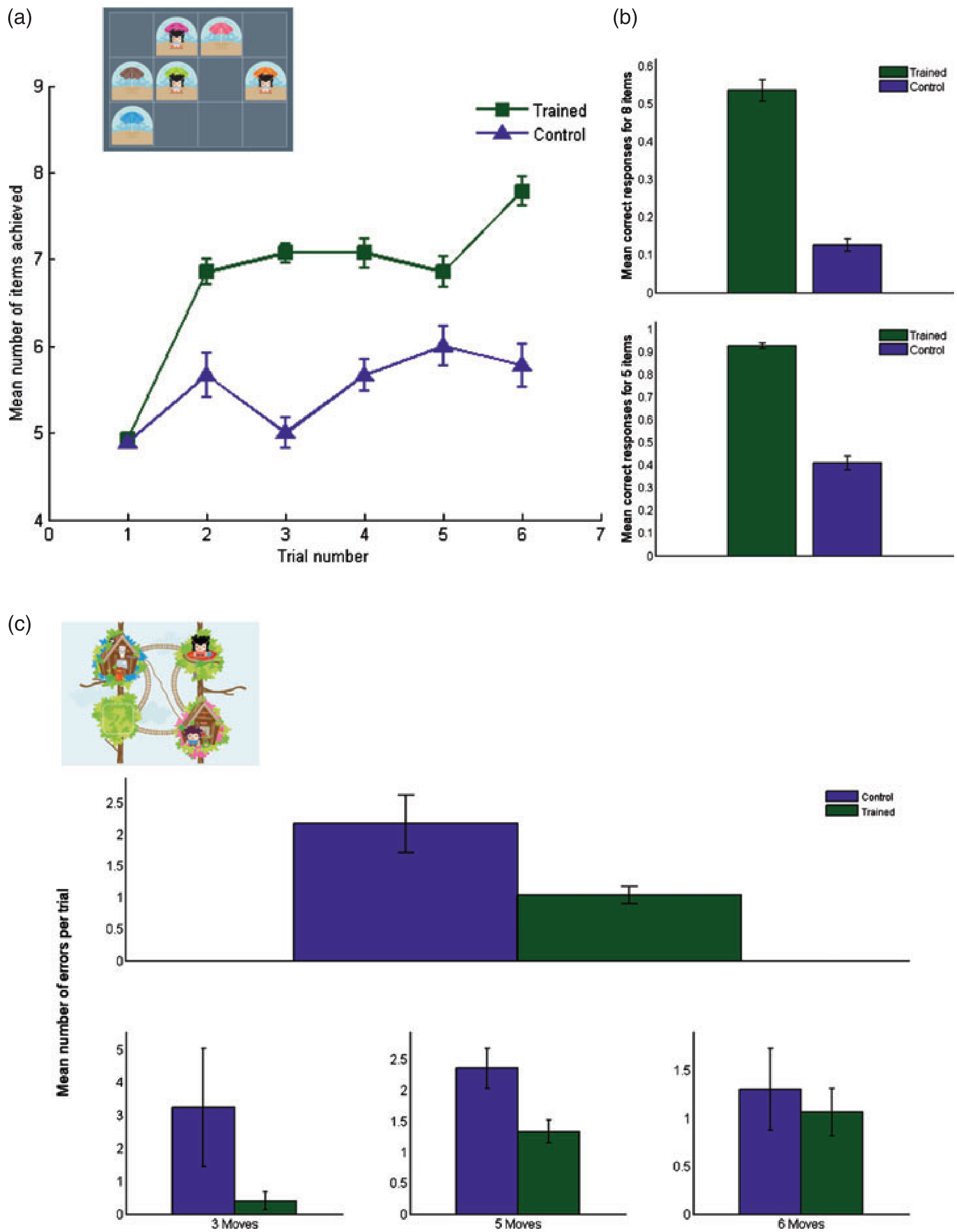

Fig. 4. Both games promote long-lasting memory. (a) Number of remembered items as a function of trial number for the trained group (green squares) and control group (who played a game without as much cognitive demand, purple triangles). The test session was performed 21 days after the end of training and it started with a 5-item trial followed, if correctly done, by two 8-item trials and, always if correct, three 10-item trials (Points: mean ± SEM). (b) Percentage of correct trials only for 8-(top) or 5-item (bottom) trials during the test session (trained: green, control: purple) (Bars: mean ± SEM). (c) Mean number of errors per test trial for trained (green) and control (purple) groups. Bottom: mean number of errors separated by number of movements to achieve the goal. The planning game test session was performed 7 days after the end of training (Bars: mean ± SEM).

Working Memory Game

Children in the trained group performed significantly better than children in the control group (Figure 4a: a significant difference is found in the third trial, from where most of the controls could not progress; $t_{21} = 3.18$; $p < .05$, Figure 4b. Five-item trials: $t_{26} = 4.21$; $p < .0003$. Eight-item trials: $t_{26} = 3.37$; $p < .0023$, a *t*-test for the 10-item trials could not be performed because children of the control group did not reach this stage).

As pointed before, in this work we are presenting a new educational research tool. While this result shows that children in the trained group perform significantly better than children in the control group, it does not inform on whether learning is fully retained or if instead it deteriorates during the three weeks of no exposure. To perform this analysis, we compared performance of children while they were playing the game with their own performance during the test session (data not shown). Children in the trained group performed 3 weeks after training nearly perfectly in the five-item trials, almost doubling their own performance during training ($t_{26} = 4.57$; $p < .0001$). For the eight-item trials they performed on average at 53.57% during the test session compared to 50.50% during the training sessions ($t_{26} = 0.27$; $p > .788$), revealing that even for the hardest levels the learning is long-lasting.

Planning Game

We compared the mean number of errors (moves that move the goal away) performed in each test trial for the control versus the trained group (Figure 4c). An ANOVA with group ("control" or "trained") and distance ("three," "five," or "six") as factors revealed a significant group effect ($F_1 = 13.22$; $p < .0004$) and a significant interaction ($F_2 = 3.6$; $p < .03$). No effect was seen for the factor distance ($F_2 = 1.51$; $p > .22$). Taken altogether, this analysis suggests that the control children made more mistakes and, hence, that the training long-lastingly improves performance.

Transfer Measures

We calculated several scores related to each task in the battery administered in the pre- and post-training stages. The K-BIT test provides two scale scores, but we used only the total score related to abstract reasoning skills (Matrices). For the child ANT, we computed the standard measure of conflict: median reaction time (RT) for incongruent trials minus median RT for congruent trials. For TOL and the Corsi Block tasks, we used an overall score computed as the total amount of correct trials by the level of difficulty corresponding to the minimum number of moves to reach the final model, or to remember a sequence of stimuli, respectively. Table 2 shows pre- and post-training scores of control and trained groups.

First, we conducted one ANOVA for each task to compare performance of groups in the pretraining stage. This ANOVA revealed that, as expected, there were no differences between control and intervention groups prior to the intervention (*K-BIT*: $F(1, 22) = 0{,}23$; $p > .636$; *ANT* Conflict: $F(1, 22) = 0{,}71$; $p > .408$; *Corsi Blocks* Overall Score: $F(1, 22) = 0{,}00$; $p > .998$; *TOL* Overall Score: $F(1, 22) = 2{,}21$; $p > .163$).

To test possible differences in the pattern of results we conducted one *t*-test for related samples for each task and group (control, intervention). Table 3 shows the results of each task. Pre- versus post-training differences in *K-BIT Matrices*

Table 2

Pre- and Post-Transfer Scores for Children in Control and Trained Groups

		Control					*Trained*				
		Pre		*Post*			*Pre*		*Post*		
Task	*Variable*	*Mean*	*SEM*	*Mean*	*SEM*	Post-Pre	*Mean*	*SEM*	*Mean*	*SEM*	Post-Pre
K-BIT	Matrices	27.28	2.3	29	2.68	1.62	26.33	1.12	28.61	1.41	2.28
ANT	Conflict	109.47	27.55	98.17	31.56	−11.30	133.92	15.35	80.15	11.1	−53.77
Corsi	Overall score	2.27	0.05	2.31	0.11	−0.04	2.27	0.08	2.21	0.11	−0.07
TOL	Overall score	1.91	0.13	2.18	0.12	0.27	2.15	0.05	2.46	0.07	0.31

Table 3

t-Test Transfer Results for Related Samples in Control and Trained Groups

		Control			*Trained*		
Task	*Variable*	*t*	*CI 95%*	*p*	*t*	*CI 95%*	*p*
K-BIT	Matrices	−1.08	−5.19/1.94	.32	−2.17	−4.50/−0.03	.05
ANT	Conflict	0.21	−112.89/135.49	.84	3.18	17.59/89.94	.01
Corsi	Overall score	−0.4	−0.27/0.19	.69	0.56	−1.19/−0.32	.58
TOL	Overall score	−3.8	−0.43/−0.10	.01	−4.07	−0.47/−0.14	.01

and in *ANT Conflict* were marginally significant ($t = -2.17$; CI 95% $-4.50/-0.03$; $p = .05$), and significant ($t = 3.18$; CI 95% 17.59/89.94; $p < .01$) for the trained group, respectively. No differences were verified in *Corsi Blocks*, and both groups (control and trained) improved their performances in *TOL* (control: $t = -3.80$; CI 95% $-0.43/-0.10$; $p < .01$; trained: $t = -4.07$; CI 95% $-0.47/-0.14$; $p < .01$).

DISCUSSION

In this article we present two games which form part of a broad educational project known as *Mate Marote*. The results indicate that playing these games leads to significant learning which is retained even after a hiatus of 1 (in planning) or 3 (in working memory) weeks. Sessions are relatively short (less than 15 min) indicating that performance in the games can improve without a major intervention.

In the working memory game, the fact that the five-item trials were solved significantly better during testing than during training (Figure 4b bottom) shows that the strategies learned during the training sessions lasted long enough to allow an almost perfect performance three weeks later.

Of course, all the previous results only demonstrate a specific form of learning. Transfer was investigated by comparing performance in a battery of cognitive tasks before and after the interventions, compared to a control group playing games which were equally or even more engaging but did not directly involve working memory or planning abilities. Pre- versus post-training differences in K-BIT matrices were marginally significant, and significant in ANT Conflict for the trained group. This pattern of behavioral results is consistent with previous studies by Rueda and colleagues (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005) after running a computerized attentional training program for five days with 4- and 6-year-olds. We emphasize that the sample size of this experiment was too small to provide robust conclusions, and hence these results should be taken with caution and as a motivation to conduct interventions on a larger sample in the near future.

These games were designed for educational purposes, and hence the most important challenges for future research are to progressively determine whether: (1) working memory and planning do transfer to other measures in different games or domains, (2) this training has an impact on broader measures of cognitive performance such as fluid and abstract reasoning (Ferrer et al., 2009) and spatial thinking (Newcombe & Frick, 2010), (3) a different spacing and/or play timing impacts in the transfer to other tests, and (4) this form of training impacts school performance.

The conclusions of this work are encouraging in that the games developed here are challenging and motivating, engage children in active play, yield long-lasting improvements within the specific game context, and show significant transfer of skills. Taken all together, the results presented here indicate that Mate Marote's games may constitute a useful tool to promote educational research.

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NOTE

1 The current version of the software does not have a grid and can exceed the limit of 12 items.

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