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Integration of Skill Application and Attention Regulation Training to Improve Goal-Directed Cognitive Functioning

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Integration of Skill Application and Attention Regulation Training to Improve Goal-Directed Cognitive Functioning

By

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A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

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in the

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of the

University of California, Berkeley

Committee in charge:

Professor Michael A. Silver, Chair
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Professor David E. Presti

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Abstract

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Improvement of cognitive function is of great value to many aspects of society. However, identifying robust procedures for training cognitive processes with generalizable benefits remains elusive. Here we present a novel attention regulation training paradigm that incorporates skill application in multiple learning environments. We hypothesized that our training procedure would enhance goal-oriented cognitive function and cognitive control mechanisms. We evaluated training effects using both computerized assessments and self-report questionnaires designed to probe cognitive control in everyday life. We tested for specificity of training effects by employing multiple active control conditions and for generalizability by using assessments that were significantly different from the training tasks as well as a set of secondary self-report questionnaires to explore the extent of far transfer. Training substantially improved performance on multiple tasks that involve goal-oriented cognitive functioning and cognitive control, and these gains were often specific to the group that received attention regulation training and also applied learned skills in varied environments.

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Integration of guided experiential skill application into attention regulation training yields generalized improvements in cognitive functioning

Acknowledgments

Dedicated to my grandmother, Nezhat Al Sadat Shadbahr. who was never allowed to pursue an education. You taught me that education is a privilege and the pursuit of knowledge is the most important mountain to climb. I found the biggest mountain I could find and I climbed it in your honor.

I would like to first thank my husband, János Botyánszki. Your undying support is the foundation that I rise from each and every day. I strive to deserve the purity with which you love and live.

I am indebted to my parents Sousan Eftekharzadeh and Mahmood Mohammad Yousef for raising me to be brave enough to break things, question the status quo, and fight for what I believe in.

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1.1 INTRODUCTION

Goal-oriented cognitive functioning, which includes the ability to sustain and regulate attention while maintaining relevant information in working memory during goal pursuit, is crucial for success in academic and work environments as well as personal life (Chen et al., 2011). This cognitive functioning continues to develop into adulthood and can be affected by a number of pathologic conditions during development, by injury, and by aging. Reliable procedures for effectively improving goal-oriented cognitive functioning in a generalizable manner would provide significant practical benefits to both clinical and healthy populations.

Successful goal achievement is a complex process that begins with recognizing and selectively attending to goal-relevant information, which is then processed in working memory, organized and maintained over time, and used to guide behavior (Chen, A. J. W., & Novakovic-Agopian, 2012). The protection of goal-relevant information during this process is critical for success, since goal-pursuit is typically marked by disruptions, distractions, and other challenges. Self-regulatory mechanisms are key for successful goal achievement; these mechanisms include the ability to recognize, attend to, and maintain information and actions that are goal-relevant, to manage distractions and emotions, and to regulate attention back to the goal when distracted. Training and rehabilitative programs that focus on self-regulatory mechanisms may therefore lead to improvements in goal-oriented cognitive functioning that contributes to the individual's overall success.

In recent years, there has been substantial interest in both the scientific community and the general public in enhancing cognitive and neural plasticity through "brain training" and cognitive training. However, applicability of a cognitive training paradigm outside the training environment requires improvements in tasks that are not trained directly. Many of the reported training gains in the literature have been limited to the training tasks themselves, and methodological issues have limited the interpretability of many previous studies. In this dissertation, I will describe our investigation of a novel attention regulation training paradigm that explicitly promotes and trains skill application in multiple learning environments. We found that this training paradigm produces generalized improvements in goal-oriented cognitive functioning in both task-based measurements and neuropsychological surveys in healthy adults.

Previous studies have reported performance gains following various forms of training such as computerized cognitive training (CCT; (Anguera et al., 2013; Mahncke et al., 2006), gamified working memory training (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Klingberg, 2010), and action video games (Green & Bavelier, 2003). These studies have typically used digital, game-based learning environments that focus on intensive practice on tasks isolated from other functions or contexts. These tools are easily scalable, engaging, and allow task difficulty to be adjusted based on the performance of each user. However, other studies have failed to replicate some of these findings (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Redick et al., 2013). Moreover, improvements using these digital, game-based learning environments often do not generalize to non-trained tasks (Oei & Patterson, 2014; Owen et al., 2010; Simons et al., 2016).

Experiential learning and skill application, which involve practicing learned skills in variable, challenging environments, may improve training outcomes and generalizability. There is evidence to suggest that the limited generalizability of cognitive benefits of many digital game-based training paradigms is due to a lack of varied learning environments. In particular, it is well established that "varied training leads to greater generalization" (Lustig, Shah, Seidler & Reuter-Lorenz, 2013) when compared to more limited practice environments (Deveau, Jaeggi, Zordan, Phung, & Seitz, 2015; Green & Bavelier, 2008; Slagter et al., 2007). Although some investigators have claimed that training on specific tasks can produce transfer of learning to other tasks that share cognitive mechanisms and the same underlying neural circuitry (Kolb, 1984; Thompson et al., 2013), most current digital game-based training approaches vary only the sensory stimuli and/or cognitive task and not the environments in which training occurs. In addition, current training paradigms typically do not incorporate explicit skills training in the cognitive domains they aim to improve (Owen et al., 2010; Simons et al., 2016), which could potentially limit an individual's ability to realize the benefits of training outside of the training environment. To address this, we integrated guided experiential skill application into the training program to encourage generalization to real-life scenarios outside of the training.

Apparent gains following cognitive training can occur due to multiple confounding factors, including participants' expectation of benefit, placebo effects, differences in general activity, time spent training, and social contact with experimenters and instructors (the Hawthorne Effect (Benson, 2001; Foroughi, Monfort, Paczynski, McKnight, & Greenwood, 2016; Green & Bavelier, 2012; Simons et al., 2016). To address these issues, we sought to assess the distinct effects of the integrated training program and its isolated components by employing multiple active control groups.

Another methodological issue in cognitive training studies is varying levels of previous experience with the subject matter across participants (Simons et al., 2016). To address this, we included subjects that had no prior background in video game play, state regulation, meditation, or any other self-reported cognitive training. In our study design, we recruited widely from a population of university students, using a broad set of recruitment questions that were designed to avoid creating specific expectations with respect to the outcomes being tested (Foroughi et al., 2016).

Assessing generalizability of training gains requires measurement of functioning using tasks dissimilar to the tasks used in training. Our primary objective was to measure the effects of the integrated training on goal-oriented cognitive functioning. We assessed this by measuring transfer to tasks affected by goal-oriented cognitive functioning using both computerized, cognitive tasks and self-report questionnaires to assess real-life, applied generalizability distinct from the training procedures. Secondarily, we sought to explore the limits of generalization by assessing the effects of the training on functions further removed from goal-oriented cognitive functioning, such as emotional regulation, mental resilience, and metacognitive awareness.

In this dissertation, I will present results from a cognitive training paradigm that explicitly promotes skill training and guided skill application to real-life situations in the form of coaching, individualized feedback, and intensive skill practice in three different learning environments. Specifically, healthy adults were taught attention regulation skills and then applied them in three learning environments: small-group classroom interactions (didactic training), digital scenario-based environment (game play), and real-life applications.

We found substantial improvements in untrained tasks of cognitive control that were specific to the group that received Fully-Integrated training. Our results indicate that integrated attention regulation training with guided experiential skill application in multiple environments can produce substantial transfer to basic cognitive processes of cognitive control such as attention and working memory. This training paradigm has wide applicability for cognitive enhancement in both healthy and clinical populations.

1.2 METHODS

Participants. 459 students from the University of California, Berkeley, were screened to take part in the cognitive training study and were screened using the following inclusion criteria:

- no prior instruction in meditation and no self-meditation practice
- not more than two hours/week video game experience within the past three years and no current video game play
- No history of psychological or neurological abnormalities (including attention deficit disorder, depression, anxiety disorders, and serious concussion or TBI)
- Currently taking a full course load at UC Berkeley

We assigned 276 students who fit the above criteria to one of four experimental groups (see below). This ensured that all participants had equivalent motivation and reasons for wanting to participate in the study. 73 students declined due to scheduling conflicts with the class times, leaving 203 students who accepted admission to the study. Our sample size was based on the number of students we were able to train in the classroom environment and the number of students who volunteered to participate in the study.

Cognitive and Attention Regulation Training

Content and Format

The primary training we employed focuses on self-regulation skills to improve goal-oriented executive functioning in the face of distraction. These self-regulatory skills aim to aid in an individual's ability to selectively attend to goal-relevant information, suppress distraction, maintain goal-relevant information in working memory, and redirect attention when distracted or disrupted. Training explicitly focused on increasing the salience of individuals' goals in order to facilitate recognition of non-optimal states, with the resulting increased self-awareness benefiting skill application in the moment. The training included coaching and discussion about establishing clear goals, subgoals, and plans of action for accomplishing goals. The goal management techniques were not included as the principle aim of the training but served as a foundation and framework for strategically applying the other skills and techniques.

Subjects participated in seven weekly 1.5-hour small group classroom sessions with an instructor that included approximately 45 minutes of a PowerPoint lecture in which attention regulation skills and principles were presented, followed by approximately 45 minutes of group discussion and skill application. Subjects were also instructed to practice skill application for a total of 15-20 hours outside of the classroom across 7 weeks.

Participants were first instructed in *focused breathing exercises* which involved maintaining a relaxed focus on the breath, observing instances of mind wandering, and redirecting attention back to the breath when distracted. This technique was integrated into the *Stop-Regulate* (*S-R*) skills that were also included in the training. S-R skill application involves stopping activity, relaxing via deep breathing, and refocusing attention on the present goal. Participants were coached to use the S-R skills to either manage difficulties in goal-directed functioning and attention or sustain goal-directed attention when committing new information to memory

(Baumeister, Heatherton, Baumeister, & Heatherton, 2010; Hofmann, Schmeichel, & Baddeley, 2012). A complete description of training skills is in the Supplement.

Training Content Overview

Week	Content
1	Attention Regulation, Goal and Distraction Management, and 'The Optimal State' **Attention Regulation Techniques:** Focused Breathing and Creating Clear Goals and Sub-goals
2	The Self-Regulatory Strength Model, Procrastination, and Emotional Misregulation **Attention Regulation Techniques:** STOP and Stop-Relax-Refocus Introduction to the **Startup-to-CEO game** and the STOP button.
3	Having a 'Standard of Self' for Behavioral Goals **Working Memory Techniques:** Stop-Lock-it in, Chunking, and Repeat-Repeat-Repeat
4	Strategic Automaticity, Planning for Overcoming Goal-Related Obstacles, and Planning for Goal-Related Opportunities **Attention Regulation Techniques:** Goal Implementation Intentions (If/Then Plans) and 'When and Where' (specific plans)
5	Updating Plans and Goals, Mental Flexibility **Attention Regulation Technique:** Mental Contrasting
6	Markers of Progress, Self-Efficacy, and Positive Reinforcement **Attention Regulation Techniques:** Mastery Experiences and Rewarding Yourself
7	Depletion of Self-Regulatory Strength and Review of Course Content

Table 1. Syllabus for Classroom-based Attention Regulation Training

Focused Breathing Exercise

Students were instructed to conduct 5-10 minutes per day of a focused breathing exercise. These are the instructions they were given:

1. Focus all of your attention on your breath. Do not try to change anything about your breath, just maintain your attention on your breath
2. Notice when your mind wanders
3. Then gently redirect your attention back to your breath

Learning Environments and Skill Application. Our training program included three varied learning environments for subjects to practice skill application:

(a) Computerized virtual environment: subjects were assigned skill application during gameplay for 20-30 minutes/day, ~5 days/week for 5 weeks (see next section for game details).

(b) Classroom interactions: during the weekly small group sessions, subjects practiced self- and attention-regulation skills taught during training to ensure both an understanding of the skills being taught and to provide an additional learning environment in which they could ask questions of the instructor. During the classroom session, subjects were also asked to consider their personal lives, identify opportunities for skill application, and make explicit plans to apply learned skills outside the classroom.

(c) Personal and professional environments: each week, subjects were assigned 5-10 minutes of daily practice of the focused breathing exercise (see Supplement for instructions).

Subjects were also explicitly encouraged to practice the skills they learned each week in their personal lives in a wide variety of environments, including classroom settings, while studying and working, and during social interaction. They were encouraged to record occurrences of skill application and their associated experiences.

Game Description

We used the 'Startup-to-CEO' computer game as a training tool. The game was developed by the Program for Rehabilitative Neuroscience for research purposes and is not a commercial product. Game scenarios were utilized to help illustrate training concepts and to provide low-risk opportunities for intensive and repetitive skill practice in a fun and engaging format to facilitate generalized learning and transfer to everyday life (Chen, Loya, Binder, in press). The game also allows direct tracking of performance and skill application to provide personalized feedback to each subject and engagement and skill application metrics throughout training to the researchers. The aim of the game was to support *learning and application* of S-R skills through instruction, skill practice, and personalized guidance (Kirschner, Sweller, & Clark, 2006).

Design of the Training Game

The Startup-to-CEO game employs a story arc of starting, maintaining, and growing a food truck business. Participants are tasked with encoding and then fulfilling customers' orders following a brief on-screen presentation. The customers' orders are adaptively adjusted in complexity and load based upon performance in the game (Figure 1). New business challenges are introduced as the training progresses, allowing subjects more opportunities to practice skills in a wide-variety of scenarios requiring goal prioritization, self-monitoring, and task-switching.

Figure 1. Game display of filling a customer order

The ability to deal with distractions is a primary focus of the training. In the game, passersby appear without warning and ask for information or items that are not goal-relevant.

This requires the subject to stop the current goal-relevant activity, shift his/her attention to complete the distracter's request, and then re-direct attention back to the original task. Distractions took place at pseudo-randomly selected times and increased in quantity and complexity over the course of training. Training focused on coaching subjects to apply skills to regulate their internal states in pursuing the goals in the game while overcoming challenges.

In addition to basic feedback regarding accuracy and efficiency (speed of response) of customer service, feedback was provided in terms of game money earned for accurate service and customer loyalty for specific goal-congruent actions.

Specific examples of subject game play were presented in class discussions in which each individual could share his or her experience practicing the training skills in the game. Each participant also received a weekly personalized email based on game play data that contained (a) their compliance with the expected amount of game play for the week, (b) a summary of their performance data, and (c) suggested tips for the upcoming week, based on their previous performance.

Integrated Skill Application in the Game

During initial phases of gameplay, subjects were instructed to use the *Stop* button whenever applying S-R skills. Thus, the *Stop* button served as both a training and assessment tool; it was used to cue skill use and to measure compliance with the cue. *Stop* button usage (i.e., quantity of use and the conditions in which it was used) as well as the relationship between *Stop* button use and multiple game performance metrics were reviewed at the beginning of each training session to reinforce skill use. Gameplay experiences and lessons were integrated in the discussion of skill application extending to real life and the pursuit of personal goals.

Control Groups

We utilized three control conditions containing isolated components of our training procedures. The Fully-Integrated training included both classroom-based didactic training and skill application in the context of customized digital game scenarios. The control groups were: (1) Game-Only, matched for gameplay experiences but lacking didactics and guided skill application; (2) Conceptual-Learning Only, involving didactic instruction on concepts related to attention regulation skills but without game play, skill practice, or guided skill application; and (3) Assessment-Only, in which subjects received no training but completed the pre- and post-assessments according to the same schedule as the training groups.

These control groups were similar to the training group in the following ways a) overall time commitment, b) level of engagement, and c) expectation of benefit and motivation. The Conceptual-Learning Only group and the Fully-Integrated training group spent the same amount of time in classroom interactions and in work outside of the classroom. For the Conceptual-Learning Only group, this work included reading, writing, and thinking critically about the training materials, and for the Fully-Integrated training group, it included skill practice in the game and in personal life situations. The Game-Only group and the Fully-Integrated training group spent the same amount of time playing the game. To achieve similar expectations of benefit across groups, we assigned subjects in a pseudo-random procedure in which subjects were typically not aware of the existence of other experimental groups in the study.

1. Conceptual-Learning Only control

A classroom-based control group was used to quantify the effects of training without explicit coaching and promotion of skill application in either personal life or the virtual environment of the training game. Participants completed a training course that had the same length, instructor, course title, structure, and level of engagement as the Fully-Integrated training group. Both the Fully-Integrated and Conceptual-Learning Only groups involved didactic instruction on the same skills and techniques, but participants in the Conceptual-Learning Only group were not actively coached or instructed to apply the techniques to their personal lives. For this group, the skills and principles were introduced and discussed at a theoretical level without practical application.

2. Game-Only control

A Game-Only group served to quantify the effects of game play of Startup-to-CEO. Subjects in the Game-Only control group did not receive any classroom instruction in cognitive or attention regulation techniques to practice while playing the game. Subjects in this group played Startup-to-CEO for five weeks on the same schedule as the Fully-Integrated training group. We attempted to minimize differences in expectation of benefit across groups by describing the Startup-to-CEO game as a "brain-training game designed by researchers that may lead to cognitive enhancement." As in the Fully-Integrated training group, the Game-Only control subjects turned in their gameplay homework once a week and received personalized feedback on their performance via emails from an instructor.

3. Assessment-Only control

We quantified test-retest effects of cognitive assessments in a population-matched control group without expectation of benefit. Participants in this group came from the waitlist for the training course. Cognitive assessments were identical to those performed for the other groups, but the Assessment-Only control participants received no training and did not have any game play.

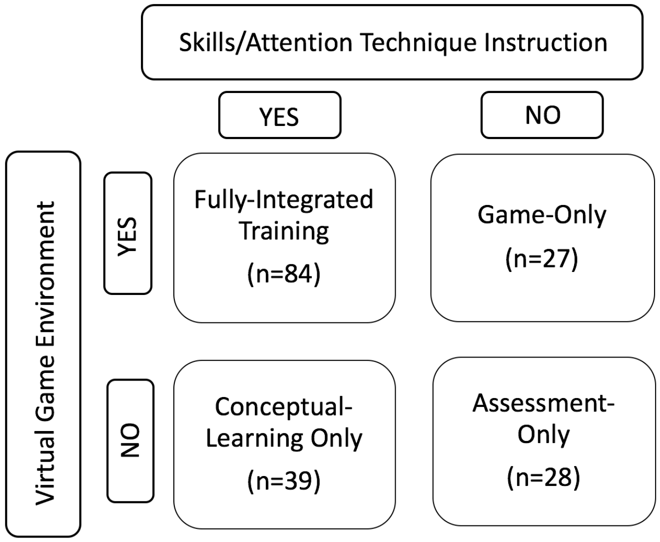

Figure 2. Design matrix of Fully-Integrated training group and three control groups

	Training Group	Conceptual-Learning Group	Game-Only	Assessment-Only
Accepted Admission	107	44	39	30
Completed study through post-assessment	84	39	27	28
Did not complete study through post-assessment	17	5	12	2
Skipped 1-2 assessments due to fatigue or scheduling issues	3	1	0	1
Removed on one or more tasks for score of 0	6	1	0	1

Table 2. Number of subjects in each group

	Training	Game-Only	Conceptual Learning	Assessment-Only
Operation Span	78	26	36	27
SART	84	26	37	27
Forward Digit Span	83	25	36	25
Reverse Digit Span	81	25	36	26
Spanboard	83	26	37	27
BRIEF-Mod	64	24	35	26
ERQ	63	7	33	15
DERS	65	25	35	26
Metacognitive Awareness	65	25	35	26
Resilience	51	25	35	26
Cause of Fatigue	63	6	33	15
Modified Fatigue Impact Scale	63	7	33	14

Table 3. Total number of participants that generated a complete data set for each measure.

Cognitive Assessments

All students completed cognitive assessments both before and after training. Subjects were asked to adequately prepare for the assessments (having recently eaten, had a full night's sleep, not unusually stressed due to academic or personal life circumstances, and to bring glasses/wear contact lenses if they had corrected vision). Students were given the opportunity to reschedule their assessments at any time if conditions were not optimal. All tasks were presented using an LCD monitor in a lab testing room with 1680x1050 screen resolution and a refresh rate of 60 Hz.

Primary Tasks

Sustained Attention

The **Sustained Attention to Response Test** (SART) assesses sustained attention and mind wandering. SART is a go/no-go paradigm in which a stream of digits is displayed at a rate of 4 Hz, and subjects must respond with a button press to each digit that is not the target. A stream of 250 single digits (25 of each of the 10 digits) was presented over a 4.3-minute period. Each digit was presented for 250 ms, followed by a 900 ms mask. The mask consists of a ring with a diagonal cross in the middle presented centrally, the total diameter is 29mm. Subjects responded with a mouse click to each digit, except for the 25 occasions when the target digit (randomly assigned across subjects) appeared, in which case they had to withhold their response. The target digits were distributed throughout the 250 trials in a pseudo-random order using the random class in Python. Subjects were instructed to give equal importance to accuracy and speed and to use their preferred hand. The digits were presented in one of five font sizes (48, 72, 94, 100, and 120 pt Symbol font; randomly assigned for each trial) to discourage subjects from detecting the target based on single features. Accuracy was defined as the percentage of target trials for which the response was inhibited. SART has been shown to be predictive of everyday attentional failures and action slips in brain-injured patients and neurotypical control participants (Robertson, Manly, Andrade, Baddeley, & Yiend, 1996).

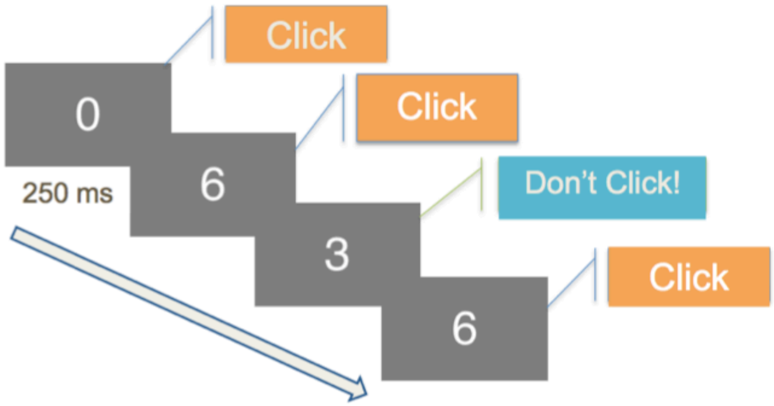

Fig 3.

Complex Working Memory

The **Operation Span task** is a complex working memory task in which letters to be memorized are presented to the subject. Following each letter presentation, the subject completes a simple arithmetic problem. At the end of the trial, subjects attempt to report all of the letters they saw in the order that they appeared. We implemented a computerized version of this task in which each letter is displayed for 800 ms, replicating the methods of Unsworth et al (Unsworth, Heitz, & Engle, 2005) (Figure X). The first trial in a block consists of three letters and arithmetic problem, and an additional letter/problem is added following each trial for which the letters were correctly remembered. For the arithmetic portion, operations were presented on the screen (e.g., (3*2) + 3 =?) and participants were instructed to calculate the answer as quickly as possible and then click the mouse to advance to the next screen. A digit (e.g., 9) was then presented, and the participants were clicked either "true" or "false". After each response, participants were given feedback. Prior to administration of the Operation Span, 15 arithmetic practice problems were presented, and the mean response time plus 2.5 standard deviations from these trials was then used as a limit for the arithmetic portion of the Operation Span task for that participant. The first trial in the first block contained three letters in the sequence with three arithmetic operations in between each letter presentation. At recall, a 4X3 matrix of letters (F, H, J, K, L, N, P, Q, R, S, T, and Y) was presented, and subjects clicked a box next to the appropriate letters in the correct sequence. The recall phase was untimed. After recall, the participant received feedback about the number of letters correctly recalled as well as the percent correct for the arithmetic portion of the task in the current set. If the arithmetic portion of the task was less than 85% correct, the trial did not count towards the memory span score. With each correct response on the letter memory task, the subsequent trial was incremented by one letter. Incorrect responses resulted in the subsequent trial having the same sequence length as the previous trial. Three incorrect responses in a row on the letter sequence recall terminated the block, and memory span for that block was defined as the number of letters in the sequence of the last correct trial. For blocks 2 and 3, the sequence length of the first trial was three fewer than the memory span attained during the previous block.

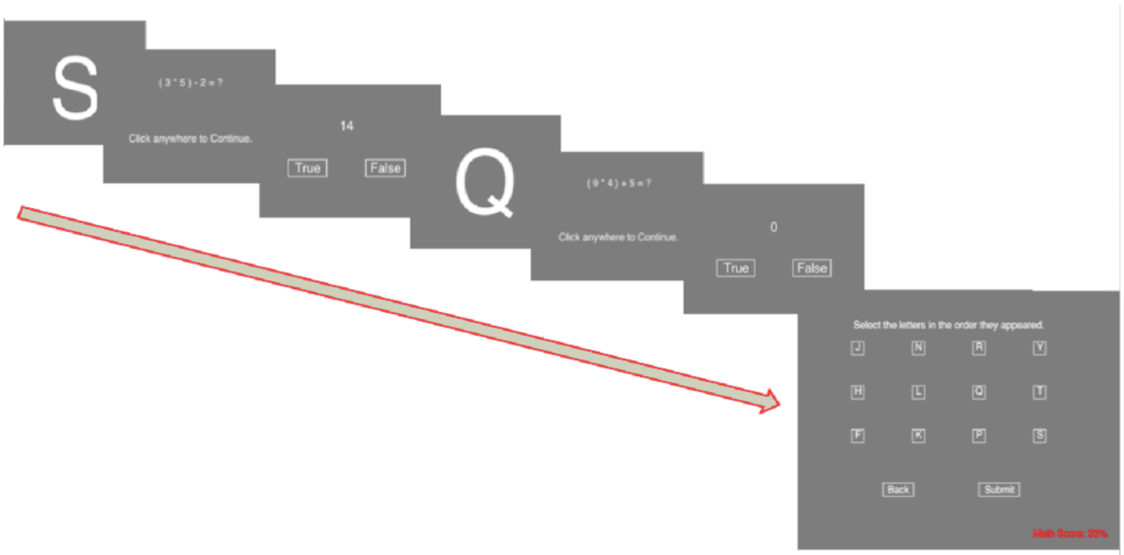

Figure 4. Operation Span Task

Verbal Working Task

The **Digit Span** task is a measure of verbal working memory for sequences of digits. In the face-to-face version of this task, the evaluator reads a pre-determined sequence of numbers (0-9) aloud in a steady rhythm, and the participant then attempts to repeat the numbers back in the order that they were presented. We used a computerized version of the task in which each digit was presented at a rate of once per second with a voice recording. Subjects used a keypad to recreate the presented sequence of digits (FIGURE X). The first trial contains three digits in the sequence. With each correct response, the subsequent trial contains one additional digit in the sequence. Incorrect responses result in the subsequent trial having the same sequence length as the previous trial. Two incorrect responses in a row terminates the task and memory span is defined as the number of digits in the sequence at the end of the task. Following the termination of the forward digit span task the reverse digit span task begins. The reverse digit span task has participants reporting the digits in the reverse order from which they are presented in the sequence. Verbal Memory Span was defined as the number of digits in the sequence at the end of the task for both Forward and Reverse Digit Span where a higher score indicates improved verbal working memory span.

Fig 5.

Visuospatial Working Memory

The **Span-board task** assesses visuospatial working memory and was originally used in face-to-face neuropsychological testing (Wechsler, 1981). We implemented a computerized version of this task in which twelve squares are arranged on the screen in a random pattern (Fig X). A subset of the squares is highlighted in a fixed sequence for each subject for 800 ms each. After the termination of the sequence, the subject attempts to recreate the sequence by clicking on each square in the order they were highlighted. The first trial in the first block contains only the initial three squares in the sequence. With each correct response, the subsequent trial contains one additional square in the sequence. Incorrect responses result in the subsequent trial having the same sequence length as the previous trial. Three incorrect responses in a row terminates the block, and memory span for that block is defined as the number of squares in the sequence of the last correct trial. For blocks 2 and 3, the sequence length of the first trial is three fewer than the memory span attained during the previous block. Visuospatial working memory was defined as the number of squares of the last correct trial, averaged across three blocks, where a higher score indicates improved visuospatial working memory.

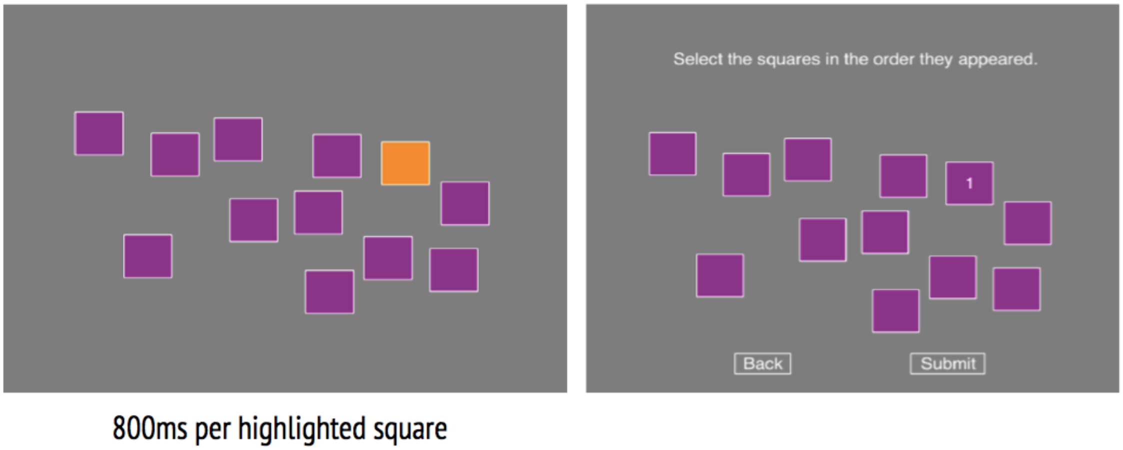

Fig 6.

Details of Neuropsychological Assessments

Behavior Rating Inventory of Executive Function

The Behavior Rating Inventory of Executive Function (BRIEF) is a 30-item questionnaire that assesses executive function and self-regulation (Roth, R. M., & Gioia, 2005). The BRIEF is frequently used for evaluating a variety of disorders and disabilities in clinical settings in addition to day-to-day executive function for healthy individuals. The BRIEF has four subscales: Planning and Organizing, Task-Monitoring, Shifting, and Working Memory. A total composite score for executive function can also be calculated by combining the four subscale totals.

Metacognitive Awareness Inventory

Metacognition is defined as the activity of monitoring and controlling cognition or cognitive functions that are used in learning and memory (Schraw & Moshman, 1995). The Metacognitive Awareness Inventory (MAI) is frequently used for assessing metacognition in education or performance in metacognitive training (Schraw, Gregory; Dennison, 1994). We used the 35-item MAI questionnaire, which has five subscales (Information Management Strategies, Debugging Strategies, Planning, Comprehension Monitoring, and Evaluation), in addition to calculating a total composite score of all the subscales.

Resilience Survey

The Resilience Survey is a 25-item questionnaire that assesses cognitive resilience in four subscales of functioning in addition to generating a total composite score (Connor & Davidson, 2003). The four subscales include Personal Confidence, Tolerance to Negative Affect, Acceptance of Change, and Personal Control.

Difficulties in Emotional Regulation Survey

The Difficulties in Emotional Regulation Survey (DERS) is a self-report questionnaire designed to assess multiple aspects of emotional deregulation along the following dimensions: Awareness and Understanding of Emotions, Acceptance of Emotions, Ability to Engage in Goal-Directed Behavior during Negative Emotions, and Access to Strategies Perceived as Effective (Gratz & Roemer, 2004). The final dimension is designed to measure the flexible use of strategies to modulate emotional states. We utilized a 17-item version of the questionnaire that provided three subscales of Goal-directedness, Awareness, and Impulsivity.

Emotional Regulation Questionnaire

The Emotional Regulation Questionnaire is a 10-item questionnaire that assesses emotional regulation along the subscales of Suppression and Reappraisal (Gross & John, 2003).

Modified Fatigue Impact Scale

The Modified Fatigue Impact Scale (MFIS) is a 21-item questionnaire that provides an assessment of the effects of fatigue in three categories: physical, cognitive, and psychosocial (Fisk et al., 1994).

Causes of Fatigue Scale

The Causes of Fatigue (COF) scale is a 12-item questionnaire that includes both Mental Effort and Physical Effort dimensions (Ziino & Ponsford, 2005).

Excluded Measurements

The full cognitive assessment also included a task of selective attention, the Response Competition Paradigm (Lavie, 1995), the results of which will be presented elsewhere. Missing data and excluded subjects are discussed in detail in the Supplement. These include outliers who had a score of zero on one or more tasks (n=8 across all groups), subjects who withdrew or failed to complete the study to the post- assessments (n=36 across all groups), and subjects who didn't complete their assessments due to fatigue or scheduling (n=5 across all groups).

Statistical Analyses

Our primary research question was whether the Fully-Integrated attention regulation training program would produce generalizable transfer of benefits of training. In order to answer this question, planned ANOVAs (using R) were conducted for each task, with time (pre and post) as a factor and task performance as the dependent variable.

Our secondary research question was whether a subset of the components of the Attention Regulation Training program (the control groups) produced similar changes. To test this, planned ANOVAs were conducted for each task, with group (Fully-Integrated training, Conceptual-Learning Only, Game-Only, and Assessment-Only) and time (pre and post) as factors, and task performance as the dependent variable. When a time by group interaction was detected, we conducted planned independent t-tests on the performance change scores (post-pre) of the Fully-Integrated training group compared to each of the three control groups separately. In order to correct for multiple comparisons, we utilized the False Discovery Rate (FDR) method for t-tests (Benajmini & Hochberg, 1995). We used 95% confidence intervals and effect size to quantify effects on performance change scores (Cumming, 2013). The magnitude of the effect (the effect size) was calculated using Cohen's D.

1.3 RESULTS

We tested performance on variety of task-based measures and self-report measures related to both our primary and secondary research objectives related to generalizability of training effects at two time points in four groups: Fully-Integrated training group, Conceptual-Learning Only, Game-Only, and Assessment-Only. The combination of classroom training and experiential skill application significantly improved individuals' performance on both the cognitive and applied/real-life domains of cognitive control. In addition, these benefits of training effects were specific to the Fully-Integrated training group and were not observed in any of the control groups.

Primary Results

Sustained Attention

Sustained Attention performance was defined as the percentage of targets for which the subject successfully inhibited his or her response. There was a significant time X group interaction ($F= 10.67$, $p<.001$; Figure 7), indicating group differences in the effects of training. The Fully-Integrated training group showed significant improvements in SART accuracy ($n=84$, FDR-corrected $p<0.001$, $d=1.07$), and this improvement was significantly larger for this group compared to the three control groups ($p<.001$ for all three comparisons).

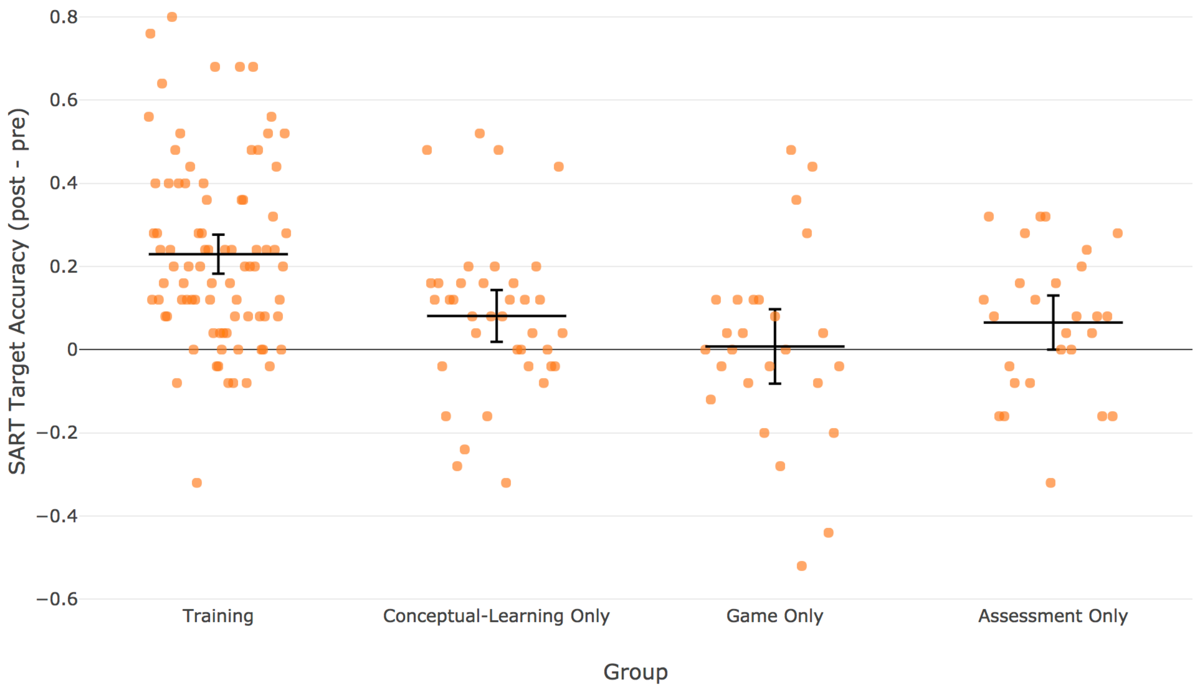

Figure 7. Fully-Integrated training resulted in significant and selective improvements in SART accuracy. Individual post-pre differences in SART accuracy are plotted for each subject, along with group means and SEM.

Complex Working Memory

Performance on the Operation Span task showed a significant time X group interaction ($F=5.44$, $p=0.001$) with significant improvement only for the Fully-Integrated training group ($n=78$, FDR-corrected $p<0.001$, $d=0.58$) (Figure 8). The magnitude of the training effect was significantly greater for this group compared to all other groups: Conceptual-Learning Only ($p=0.002$), Game-Only ($p=0.008$), and Assessments-Only ($p=0.007$).

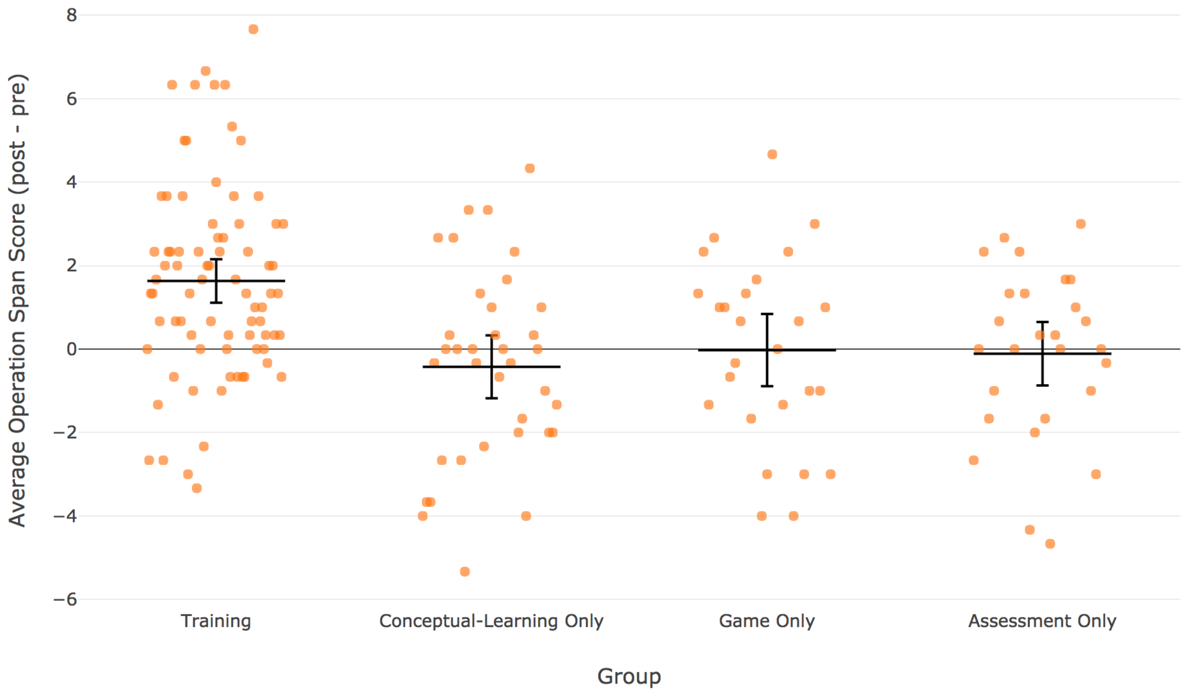

Figure 8. Fully-Integrated training resulted in significant and selective improvements in performance on the Operation Span task.

Verbal Working Memory

Analysis of Forward Digit Span task performance revealed a significant main effect of time ($F=23.9$, $p<0.001$) but no time X group interaction ($F=0.86$, $p=0.46$) (Figure 9A). Similarly, the Reverse Digit Span task revealed a significant main effect of time ($F=6.73$, $p=0.01$) but no time X group interaction ($F=0.24$, $p=0.87$) (Figure 9B). These results indicate that for verbal working memory, there was general improvement for the four groups with no selectivity of improvement for the Fully-Integrated training group.

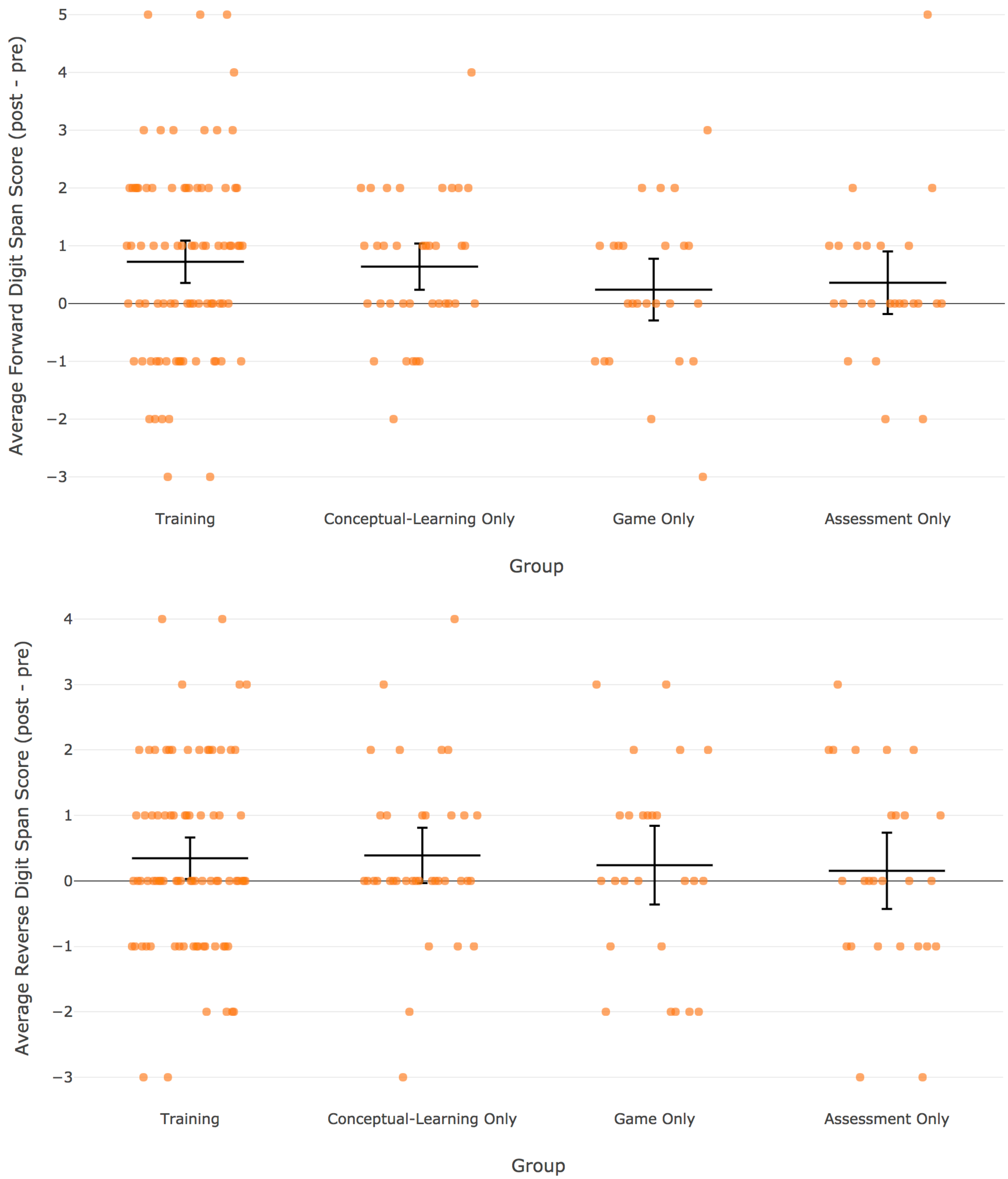

Figure 9. General improvement in task performance for Forward and Reverse Digit Span did not differentiate the four experimental groups.

Visuospatial Working Memory

There was a significant main effect of time (F=9.52, p=0.002) but no time X group interaction (F=0.36, p=0.78) for the Spanboard Task. As for verbal working memory, the improvement was not significantly different across the four groups.

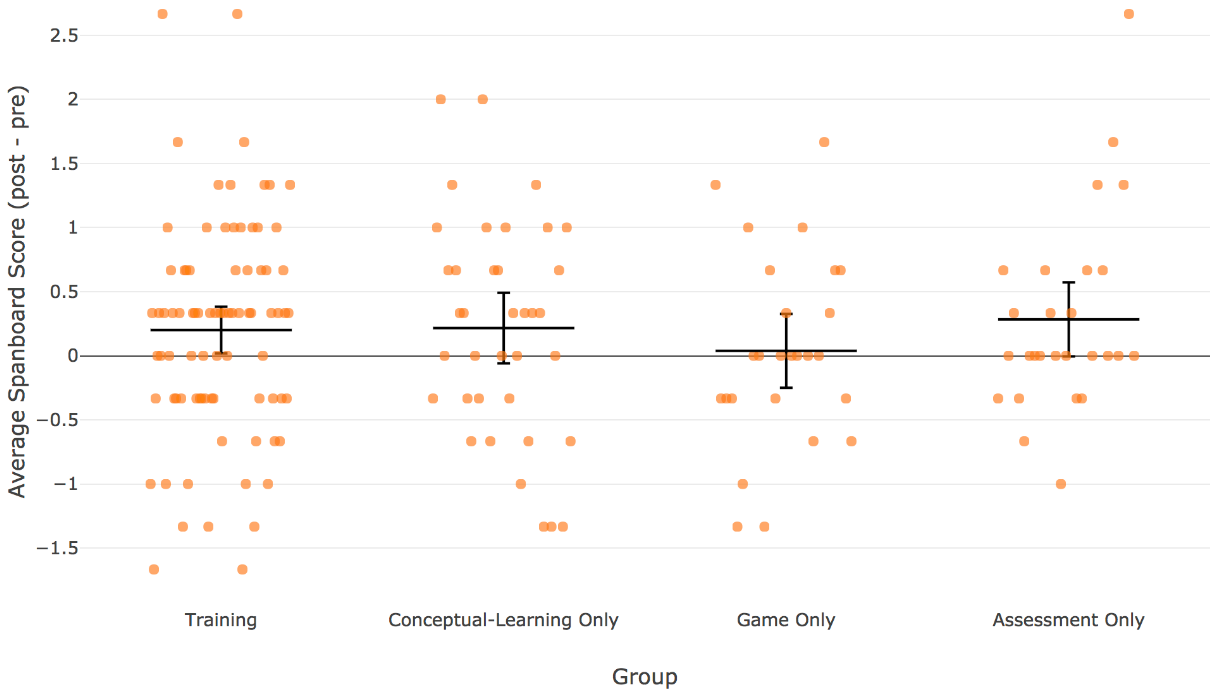

Figure 10. General improvement in task performance for Spanboard did not differentiate the four experimental groups.

Behavior Rating Inventory of Executive Function – Modified

Lower scores indicate better functioning on the Behavior Rating Inventory of Executive Function. We found a significant time X group interaction on the total composite BRIEF-Mod score (Table 2, Figure 10). Significant time X group interactions were also observed for all four components assessed by BRIEF-Mod: shifting, working memory, planning/organization, and task monitoring. The improvement in the composite score was significantly greater for the Fully-Integrated training group compared to any other group: Conceptual-Learning Only (p<0.001), Game-Only (p=0.02), and Assessments-Only (p<0.001).

	ANOVA Time X Group Interaction	**FDR corrected T-test for Fully-Integrated training group**	**Cohen's D**
BRIEF-Mod Total	F=9.6 p<0.001	p< 0.001	d= 0.58
Shifting	F=3.09 p= 0.03	p= 0.008	d= 0.4
Working Memory	F=8.90 p<0.001	p< 0.001	d= 0.51
Plan/Organization	F=8.42	p< 0.001	d= 0.55

	p<0.001		
Task Monitoring	F=2.72 p= 0.05	p= 0.04	d= 0.26

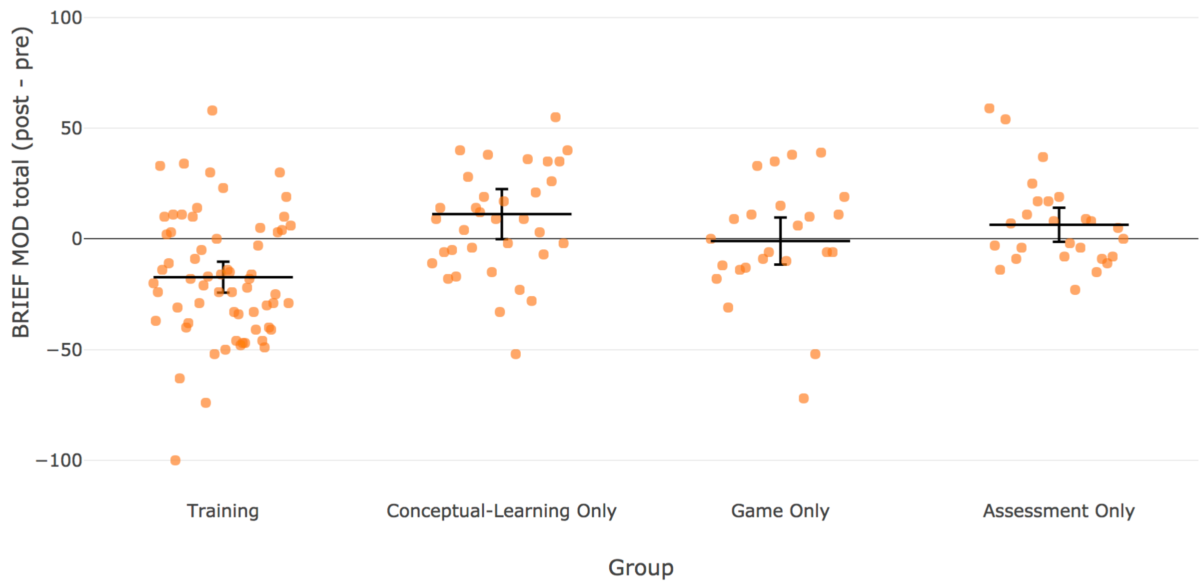

Figure 11. Fully-integrated training resulted in significant and selective improvements in BRIEF-Mod composite assessment of executive function.

Secondary Results

Resilience Survey

For the Resilience Survey, there was a significant time X group interaction on the total score and two of the four components: Acceptance of Change and Personal Control (Figure 11; Table 3). A significant time X group interaction was not found for the subscales of either Personal Confidence or Tolerance of Negative Affect. The Fully-Integrated training group exhibited significant improvement on the total score and two of the four components (Table 3). The magnitude of the Fully-Integrated training group's improvement on the total score was significantly greater than that of any of the other groups: Conceptual-Learning Only (p=0.006), Game-Only (p=0.05), and Assessments-Only (p=0.004).

	ANOVA Time X Group Interaction	FDR-corrected T-test for Fully-Integrated training group	Cohen's D
Resilience Total	F= 4.56 p= 0.004	p= 0.003	d= 0.33
Personal Confidence	F= 1.92 p= 0.13	p= 0.10	d= 0.18

Tolerance of Negative Affect	F= 1.31 p= 0.27	p= 0.02	d= 0.28
Acceptance of Change	F= 6.05 p<0.001	p= 0.02	d= 0.35
Personal Control	F= 3.11 p= 0.03	p= 0.004	d= 0.25

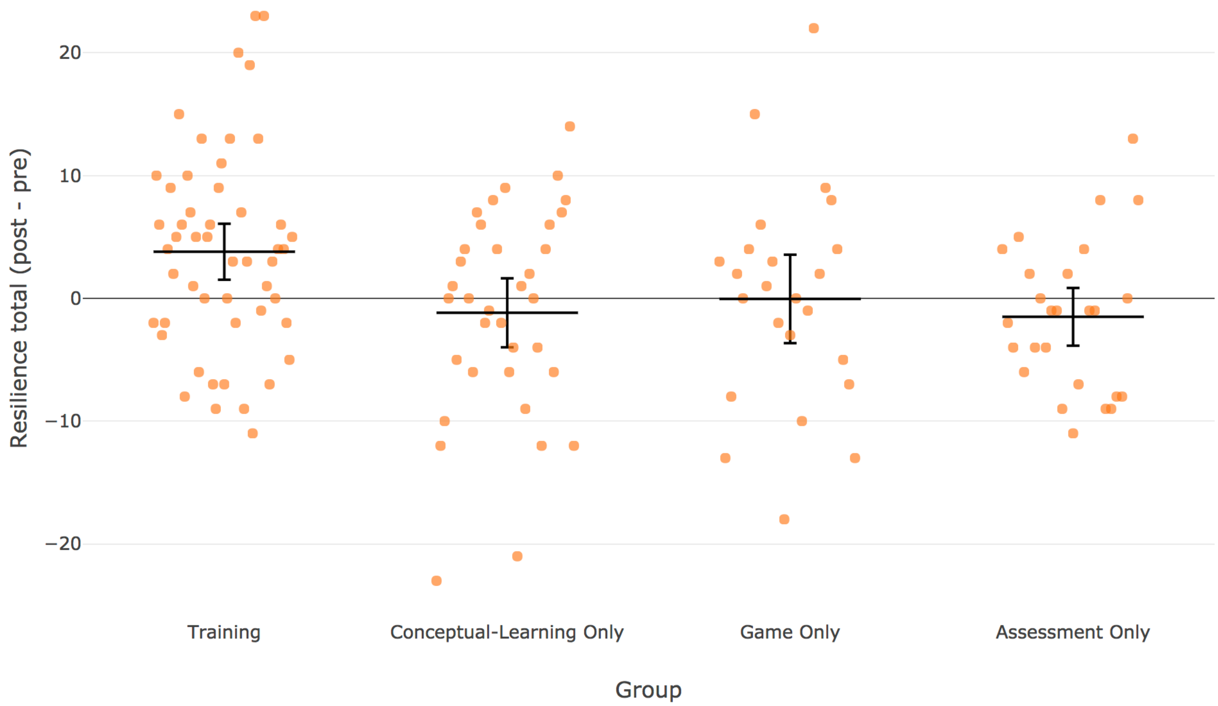

Figure 12. Fully-Integrated training resulted in significant and selective improvements in resilience.

Metacognitive Awareness Inventory

There was a significant time X group interaction on the total composite score for the Metacognitive Awareness Inventory and for four of the five individual components: Information Management Strategies, Planning, Comprehension Monitoring, and Evaluation (Figure 12; Table 4). The Fully-Integrated training group exhibited significant improvements in the total score as well as each of the four of five components (Table 4). The magnitude of improvement in this group's total score (post-pre) was significantly greater than that of the other three groups: Conceptual-Learning Only (p<0.001), Game-Only (p=0.01), and Assessments-Only (p=0.01).

	ANOVA Time X Group Interaction	**FDR-corrected T-test for Fully-Integrated training group**	**Cohen's D**
Metacognitive Total	F= 7.5 p< 0.001	p< 0.001	d= 0.56
Information Management Strategies	F= 6.89 p< 0.001	p< 0.001	d= 0.52

Debugging Strategies	F= 1.66 p=0.18	p= 0.04	d= 0.30
Planning	F= 6.93 p< 0.001	p< 0.001	d= 0.65
Comprehension Monitoring	F= 7.28 p< 0.001	p= 0.002	d= 0.46
Evaluation	F= 4.77 p=0.003	p= 0.002	d= 0.49

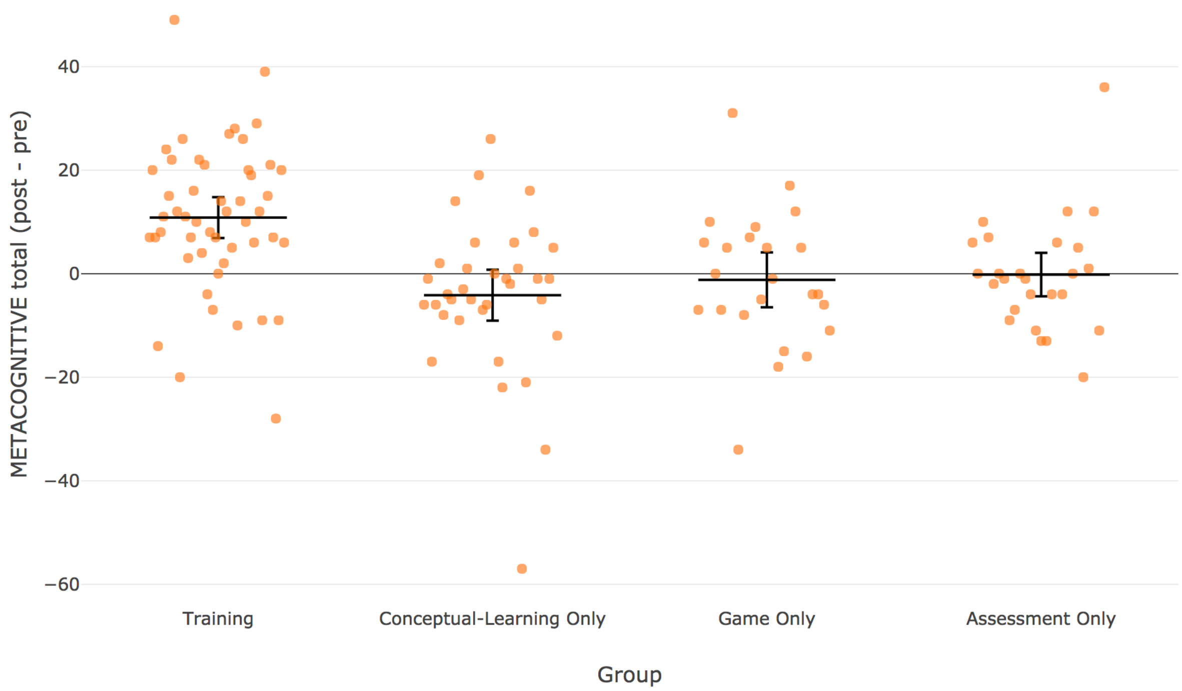

Figure 13. Fully-Integrated training resulted in significant and selective improvements in metacognitive awareness.

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Difficulties in Emotional Regulation

There was a significant time X group interaction for the total composite score of the Difficulties in Emotional Regulation questionnaire and for the Impulsivity subcomponent (Figure 13; Table 5). Significant time X group interactions were not observed for the Goals or Awareness subcomponents. The Fully-Integrated training group showed significant improvement for the total score and the Impulsivity subcomponent (Table 5), and this group's improvement on the total score significantly differed from the Conceptual-Learning Only (p=0.01) and Assessments-Only (p=0.01) groups but not from the Game-Only group (p=0.09).

	ANOVA Time X Group Interaction	**FDR-corrected T-test for Fully-Integrated training group**	**Cohen's D**

Difficulties in Emotional Regulation Total	F= 5.63 p= 0.001	p= 0.002	d= 0.44
Goals	F= 1.56 p= 0.20	p= 0.02	d= 0.30
Impulsivity	F= 4.69 p= 0.004	p= 0.002	d= 0.30
Awareness	F= 0.97 p= 0.06	p= 0.04	d= 0.26

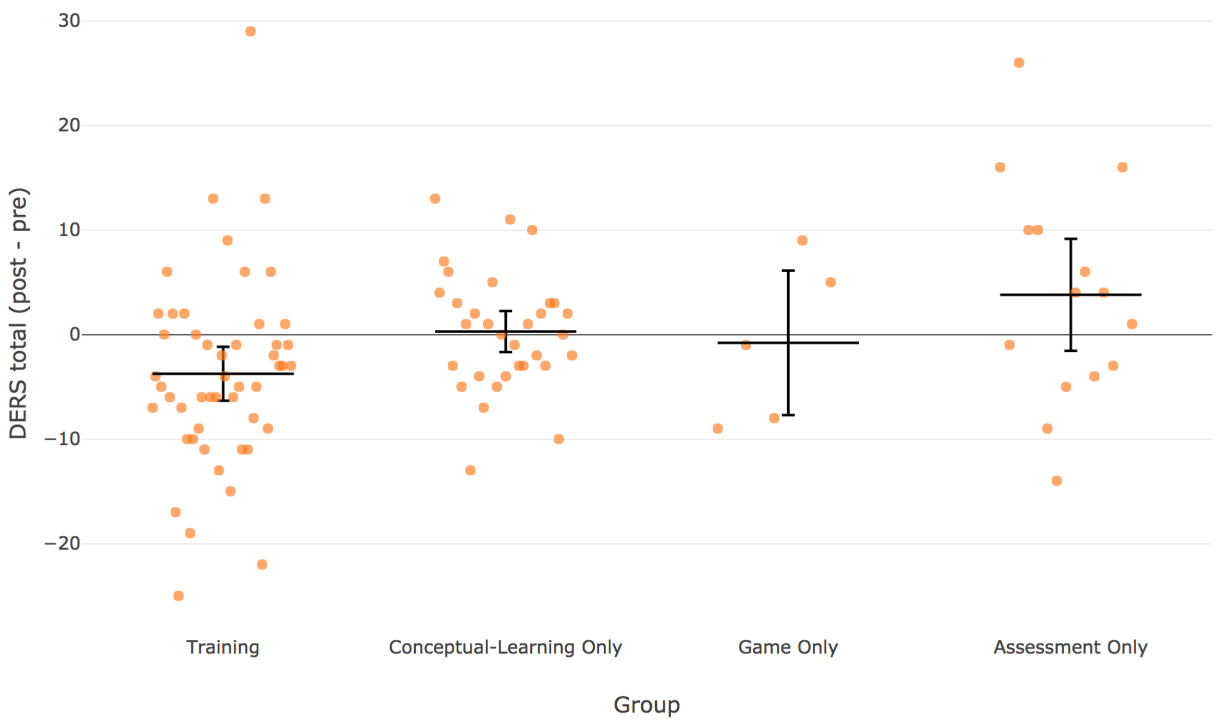

Figure 14. Fully-integrated training resulted in significant and selective improvements in emotional regulation. Lower values indicate greater emotional regulation.

Emotional Regulation Questionnaire

There was a significant main effect of time only for the Reappraisal subcomponent (F=9.72, p=0.002) of the Emotional Regulation Questionnaire and not the total composite score (F=1.68, p=0.20). No significant time X group interactions were observed for the total composite score (F=.33, p=0.80).

Modified Fatigue Impact Scale

There was a significant time X group interaction for the total composite score for the Modified Fatigue Impact Scale as well as for the Cognitive subcomponent but not for the Physical or

Psychosocial subcomponents (Figure 14; Table 6). The Fully-Integrated training group showed significant improvement for the total score as well as the Cognitive subcomponent. The change in this group's total score significantly differed from that in the Conceptual-Learning Only (p=0.02) and Assessments-Only (p=0.03) groups, but not from the Game-Only group (p=0.82).

	ANOVA Time X Group Interaction	**FDR-corrected T-test for Fully-Integrated training group**	**Cohen's D**
Modified Fatigue Impact Scale: Total	F= 3.11 p= 0.03	p= 0.003	d= 0.42
Physical	F= 0.97 p= 0.41	p=0.14	d= 0.20
Cognitive	F= 5.20 p= 0.002	p< 0.001	d= 0.55
Psychosocial	F= 0.57 p= 0.63	p=0.13	d= 0.24

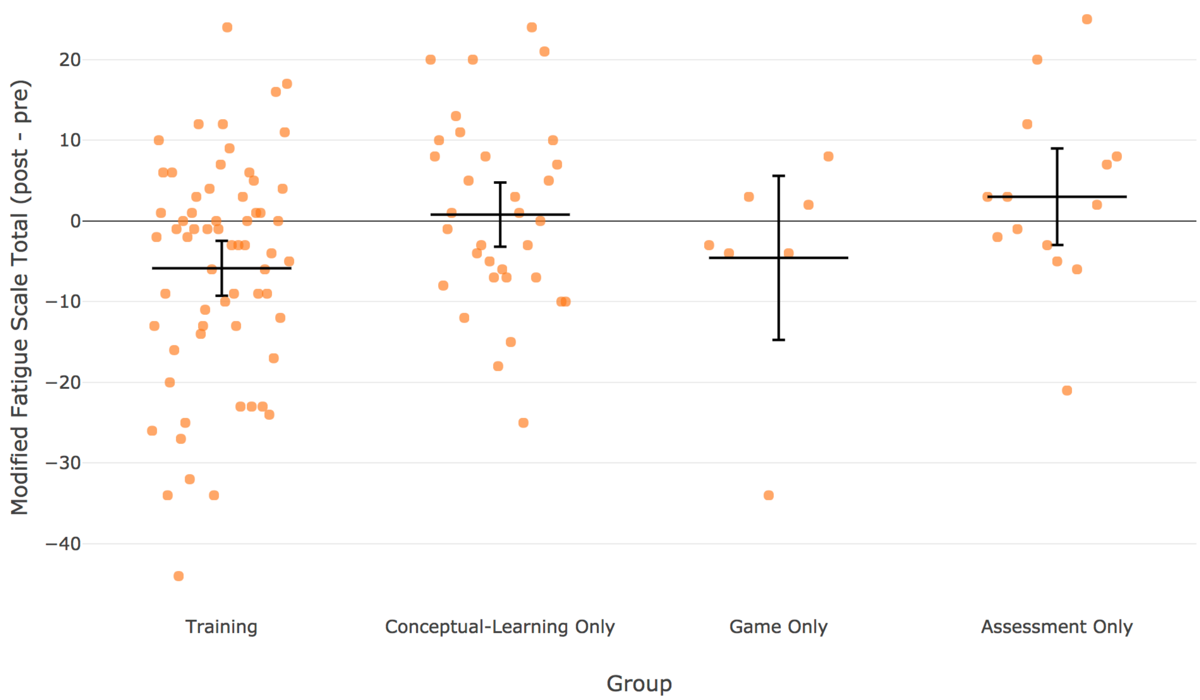

Figure 15. Fully-Integrated training resulted in significant and selective improvements in the Modified Fatigue Impact Scale. Lower values indicate less fatigue.

Causes of Fatigue

There was no significant main effect of time (F=0.69, p=0.41) and no time X group interaction (F=2.51, p=0.06) on the total composite score for the Causes of Fatigue questionnaire.

Testing for generalizable transfer

In order to test whether each of our primary tasks is measuring a distinct aspect of cognitive function we calculated a Pearson's coefficient correlation matrix. This analysis indicated that performance on any given task was not highly correlated with any other task in the group (Table 7).

	SART	Ospan	REV Digit Span	FWD Digit Span	Spanboard	BRIEF-Mod
SART	-					
Ospan	-0.02	-				
REV Digit Span	0.12	0.20	-			
FWD Digit Span	0.08	0.09	0.29	-		
Spanboard	0.16	0.11	0.17	0.22	-	
BRIEF-Mod	-0.17	-0.17	-0.10	0.04	-0.10	-

Game Details

The purpose of the game within the training program was to allow subjects to practice learned techniques in a challenging yet low-risk environment. There was no significant difference in mean duration of game play between the Fully-Integrated training and Game-Only groups (Supplement). Linear regression analysis revealed that the amount of gameplay was not correlated with the magnitude of training effects on task performance for any task in either group (Supplement).

Gameplay Analyses.

Gameplay also provided data regarding the ways in which different groups employed the training techniques. We hypothesized that participants in the Fully-Integrated training group would differ from those in the Game-Only group in their usage of the *Stop* button. This button corresponded to stop-regulation (S-R) techniques introduced in the didactic training for the Fully-Integrated training group, but the Game-Only subjects received no explicit encouragement to use the SR skills in association with the *Stop* button (although they were informed that they could use it to pause the game at any time). In our analysis, we removed outliers defined by pauses that were shorter than two seconds (to exclude accidental clicking) or longer than eight minutes (to exclude long-term task switching). The Fully-Integrated training group utilized the *Stop* button more frequently than the Game-Only group (Figure 15).

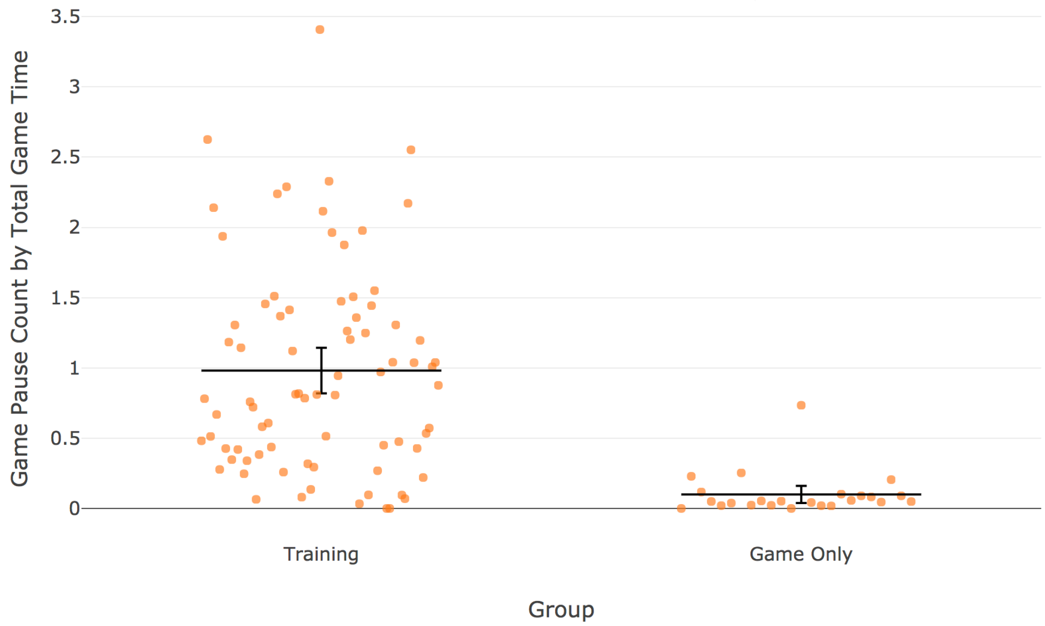

Figure 16. Pause button frequency (Number of Pause button presses divided by the total number of gameplay minutes) for each subject for the Fully-Integrated training and Game-Only groups

Working Memory Load performance in the context of the game was defined as the highest memory load reached during each game chapter. The Fully-Integrated training group and Game-Only control group performed similarly for all chapters combined.

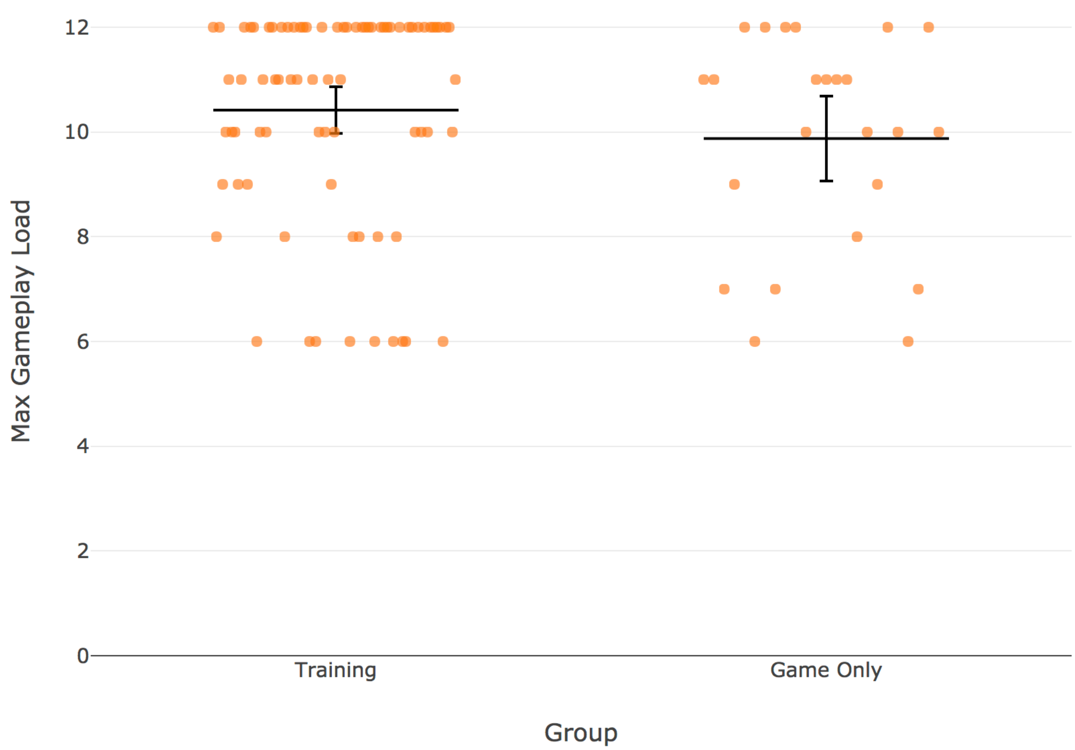

Figure 17. Participants in the Training group and the Game-only group performed similarly in the game.

1.4 DISCUSSION AND CONCLUSION

We found that attention regulation training involving guided experiential skill application produces substantial and generalizable improvements in goal-oriented cognitive functioning, as assessed with cognitive task-based measurements and self-report questionnaires. Overall, these gains were selective to fully integrated training group, demonstrating specificity of the training effects and the importance of the combination of didactic training and experiential skill application for cognitive improvements.

Our results indicate that the fully-integrated attention regulation/guided skill application training paradigm had the greatest impact on domains that rely most strongly on cognitive control and goal-oriented cognitive functioning. The primary tasks included tests of sustained attention, complex working memory, verbal working memory, visuospatial working memory, and a separate self-report measure of executive function. Basic memory tasks such as visuospatial working memory (Spanboard) and verbal working memory (Forward and Reverse Digit Span) require the least amount of cognitive control, as they are rote memory tasks. These tasks also showed the least amount of improvement post-training (Figure 16). The sustained attention task (SART) requires relatively more cognitive control, as the subject is instructed to sustain prioritization of goal-relevant information while engaging in the go/no-go task. This task also showed substantially more improvement after training (Figure 16). The complex working memory task (Operation Span) requires the most cognitive control due to the need for subjects to maintain memory representations while switching back and forth to a secondary arithmetic task that also includes manipulation of information. This task showed the greatest magnitude of improvement with training (Figure 16). The separate self-report measure of executive function (BRIEF-Mod) also showed significant improvement with an effect size equal to that of the complex working memory task (Ospan).

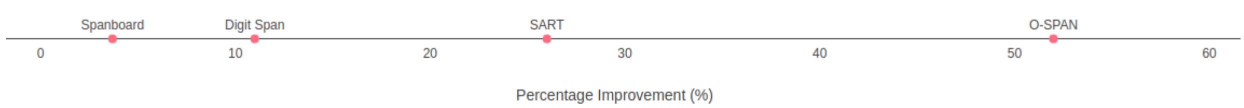

Fig 18. Percentage improvement following training in the Fully-Integrated training group for the four cognitive assessments

The secondary objective was to test the limits of generalizability. Here, the results are expectedly variable with some of the self-report questionnaires showing selective improvement in the Fully-Integrated training group and some not. Further research is needed to elucidate the spread of generalizable transfer that is possible with this type of integrated training.

1.5 LIMITATIONS AND FUTURE DIRECTIONS

Most of the training gains in our study required the combination of didactic instruction and guided skill application. Given the complexity and breadth of the didactic instruction (Supplement), as well as the varied ways in which individual subjects applied learned skills in their everyday life, it remains unclear exactly which aspects of the integrated training are most critical to realize the significant improvements in cognition that we report. This is an important practical point, as the integrated training was time-intensive for both the instructor and the participant. More research is needed with simplified versions of our integrated training paradigm to determine which components (or combinations of components) are the most impactful. In addition, it will be important to elucidate which baseline measures are most predictive of a given individual realizing the benefits of this type of cognitive training.

Meaningful generalizability in any field of training aims to produce benefits in everyday life outside the training environment. Many cognitive training studies have defined generalizability only in terms of other laboratory-based computerized tasks of cognitive functions. While a truly broad generalization of cognitive gains to everyday life is challenging to measure, given substantial individual differences in the cognitive processes employed in everyday activities, we used validated neuropsychological assessments to probe changes in a wide variety of cognitive processes following training. The Fully-Integrated training group reported improvements in diverse processes such as executive function, emotional regulation, resilience, and metacognitive awareness, suggesting that the training-induced enhancements on performance of cognitive tasks in the laboratory extended to improved cognition and cognitive control in everyday life.

Overall, this study supports the importance of integrated guided experiential learning that involves skill application in multiple environments in achieving improvements in goal-oriented cognitive functioning. These outcomes were observed not only in computerized tasks of cognitive function but were also evident in the self-report questionnaires of cognitive abilities applied to real-life.

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