A test of the efficacy of the MC Square device for improving verbal memory, learning and attention

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Abstract: Cognitive enhancement devices have been supported by positive anecdotal reports, but generally have not undergone rigorous testing. In the following report we tested one such device, the MC Square, which uses Audio-Visual Stimulation (AVS) (synchronised pulsed tones and flickering lights set at an alpha or theta frequency) to entrain neural activity. Its effect on three key cognitive functions (verbal learning, memory, and attention) was tested following a regimen of training with the device. A double blind, placebo controlled (sham device), and crossover design was utilised with pre- and post-testing on the cognitive measures occurring during each phase of the crossover. The primary hypothesis was that after training with the MC Square there would be improvement in verbal memory, associative learning, working memory and attention/concentration. Results showed a statistically reliable improvement on the measure of attention/concentration, the Digit Span Forwards test, following MC Square training. The data suggest the MC Square device provides modest enhancement in the ability to focus, attend, and report information over the short term.

Keywords: cognitive enhancement; neural training; memory; learning; attention; Audio-Visual Stimulation; AVS; learning technology; MC square device.

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1 Introduction

In modern society there is an increased focus on academic achievement. This competitive environment has lead to a growing demand for learning tools that will aid and enhance performance on standardised achievement or ability tests, employment/civil service tests, or for those seeking admission to advanced schooling such as undergraduate or graduate school. In addition, cognitive enhancement tools are also sought for rehabilitation after brain injury following stroke, head trauma, or other brain insults. Many of these cognitive enhancement devices have positive anecdotal reports behind them, but have not undergone rigorous testing to determine if they yield any actual cognitive benefit. In the following report we provide the results for one such cognitive enhancement device, called the MC Square device. We specifically evaluated the MC Square, for its ability to improve key cognitive functions (verbal learning, memory, and attention) following substantive training and practice with the device.

The MC Square was developed by Daeyang E&C, Inc. of Seoul, Korea. This utilises synchronised sound and light to entrain brain waves to alpha and theta neural rhythms. The device has gone through testing in laboratories in China, Korea, and Japan, but none of the reports have been subject to peer review and thus will not be summarised or presented here. The device purports to improve learning, memory, and attention and has sold over one million units in Korea, largely to students. The device uses a series of flashing red lights in conjunction with pulsed tones and background relaxing sounds (river gurgling, birds chirping) to achieve its effects. The lights are presented through an eye goggle device that resembles a thick pair of eyeglasses. Light emitting diodes present red light that appear as flickering dots which occur synchronously with pulsed tones at a rate and pattern that is thought to induce alpha and theta brain wave activity. The technology differs from most available tools which appear to focus on computer assisted learning or external memory aid devices such as the palm pilot, calendars, and computer programmed memory reminders.

This technique of inducing alpha and theta waves of brain by Audio-visual Stimulation (AVS) is known as brain wave entrainment or Audio-visual Entrainment (AVE). AVE has been demonstrated to cause significant changes in EEG patterns and cerebral synchronisation. Scientific research examining the effects of light and sound started in mid-1930s when scientists discovered that the electrical rhythm of brain tended to adopt the frequency of light when this is used as external stimulation. In one of the earliest reports, Adrian and Matthews (1934) confirmed that alpha rhythm can be driven above and below the natural frequency by photic stimulation. Flickering light appears to share some similarity in terms of frequency with brain waves in the alpha and theta range. Manufacturers of light and sound devices have almost exclusively used red light-emitting diodes because they are bright, inexpensive, and blood vessels in the eyelids pass red/orange light most efficiently. Komatsu (1987) examined college students and found that red light produces optimal EEG driving it in the 17–18 Hz band. Green increases brain wave activity to 15 Hz, blue light enhances 10–13 Hz activity, and white light peaks at 18–19 Hz. AVE has been associated with increases in cerebral blood flow (Fox and Raichle, 1985; Sappey-Marinier *et al*., 1992) and this is thought to be one of the mechanism by which it entrains brain waves to the alpha and theta state as measured by EEG. Fox and Raichle (1985) showed that photic stimulation at alpha and low beta frequencies increased cerebral blood flow 20%–30% over baseline in the striate cortex. Moreover, certain parameters of the EEG tend to correlate with cerebral perfusion at least in the neocortex (Fried, 1993). Hypoperfusion will tend to be mirrored by the increase of theta band (4–8 Hz) power in the EEG on the scalp surface in that location. Reductions in cerebral perfusion has been shown to decrease with age and in elderly individuals generally, with some signs that the effect may be more pronounced in the elderly who show cognitive deficits (Schreiter-Gasser *et al*., 1993). One well-demonstrated effect of AVS is relaxation. This effect may arise from high sympathetic activation that occurs during alpha state. EMG correlates of relaxation have been observed in individuals undergoing AVS (Manns *et al*., 1981).

Alpha and theta brain waves are considered optimal for learning and attention and there have been attempts to induce these states to reduce memory problems and regain cognitive function. Several studies have shown that there is a strong relationship between peak alpha rhythm and mental performance (Jausovec, 1996). Klimesch *et al*. (1997) presented evidence that EEG oscillations in the alpha and theta band reflect cognitive and memory performance in particular. A peak alpha rhythm of less than 10 Hz is associated with poorer academic performance and an alpha rhythm frequency of more than 10 Hz is associated with better performance (Jausovec, 1996). Budzynski and Tang (1998) collected EEG in a sample of college students and subdivided alpha rhythms (9–13 Hz) into three categories (A1, 7–9; A2, 9–11; A3, 11–13) and examined whether the ratio between A3/A1 predicted academic performance. A ratio value above 1.0 was associated with above average academic performance. They also found that after 34 sessions of 14 Hz light stimulation the high-to-low alpha frequency ratio was increased along with an increase in peak alpha frequency. In a later study by Budzynski *et al*. (1999) again with college students, they found that following 30 sessions of repeated cycles of AVE at 22 Hz and 14 Hz in an alternating pattern, there was a significant increase in the mean A3/A1 ratio, alpha rhythm, and academic performance. This positive ratio was also related to improved cognitive performance as measured by a digit span task. Budzynski *et al*. (2002) used AVE (a Digital Audio-Visual Integration Device, Paradise XL) to aid 31 elderly individuals who were experiencing cognitive problems. The AVE session utilised random frequency stimulation from 9–22 Hz and an average of 33 treatment sessions took place. The treatment was considered very cost effective because ten individuals could be treated at one time. A computer-based Continuous Performance Test and the Microcog Test Battery were utilised to assess cognitive change. The Microcog measures several domains of cognitive function including attention, reasoning ability, memory, spatial ability, processing speed and accuracy, and cognitive proficiency. Over 60% of participants showed improvement in at least some of the cognitive measures. This AVE procedure has also been shown to improve cognitive functioning in certain clinical populations such as dementia (Tan *et al*., 1997) and dyslexia (Magnan *et al*., 2004). Other studies with AVE devices have suggested beneficial effects may be observed in behaviour and psychiatric symptoms such as depression (Kumano *et al*., 1996; Rosenfeld, 1997), premenstrual syndrome (David, 1997) and attention deficit disorder (Cohen and Douglas, 1972; Zentall and Zentall, 1976).

The current study investigated the cognitive efficacy of the MC Square device, to examine its affect on major domains of cognitive functioning. Verbal material was chosen, since informal reports from users of the device suggested that it produces gains in the acquisition and retention of verbal material such as might be required when studying for an academic exam. As practice with the device was also reported to be superior to single instance use, we implemented week long device use in testing it. A Sham device was constructed to create a placebo arm of the study whereby participants were run through the identical procedure without the key element of the MC Square device; that is the sham device used randomised not synchronised light and sound.

Our hypotheses were as follows:

- After training with the MC Square Device there would be improvement in verbal memory, associative learning, working memory and attention/concentration. The sham device will produce no such training effect.
- On individual performance measures, pre- or post-training, the MC Square Device would be associated with better performance than the sham device.

The above cognitive tasks involve novel material that requires effort, cognitive resources, and cognitive skill to complete successfully. In contrast, Vocabulary items involving over-learned, highly familiar material that require no new learning and fewer cognitive resources to complete successfully were used as a control task. These multiple-choice vocabulary items called upon existing, readily available knowledge. Therefore, hypothesis three was that neither training on the MC Square nor the Sham would produce improvement in Vocabulary.

2 Methods

Participants were recruited by advertisements at Thomas Jefferson University. All participants for this study were screened for good general health and the absence of any neurological, psychiatric or medical disorder. A questionnaire was constructed to eliminate individuals with photosensitive seizures, *i.e.*, seizures in response to light stimulation. A total of 120 normal, healthy adult subjects within the 18–45 age range were screened to enrol 40 subjects. All subjects were native English speakers with at least an Average IQ (90 or greater) based on the Shipley Hartford Institute for Living Scale. All participants were medical students, physical therapy or PhD students, residents and nurses from Thomas Jefferson University. Ineligibility arose from having IQ below 90, abnormal state or trait anxiety scores on the Spielberger Inventories, and prior medical or psychiatric history with potential central nervous system impact (*e.g.*, neurological or medical condition with central nervous system impact, depression, anxiety, substance abuse, obsessive-compulsive disorder, and migraines; 70 individuals). Six individuals were dropped because of time and scheduling constraints. Three individuals were dropped because of IQ less than 89, and one because of risk of photosensitive seizures. This produced a final enrolment sample of 40 subjects. One subject dropped out in the middle of the study due to scheduling conflicts. This yielded a final analytic sample of 39.

Sample demographics can be seen in Table 1. The sample primarily was Caucasian though some mixed ethnicity was present. The sample was well educated and of above average IQ. As the MC Square device might induce relaxation, we sought to reduce the differential and beneficial effect this might have across individuals by limiting our sample to individuals who showed clearly average range (*i.e.*, low) levels of state and trait anxiety as measured by the Spielberger Inventory (Spielberger *et al.*, 1970).

Table 1 Demographic baseline screening data

Mean age	25.60 (S.D of 5.21)
Males	22
Females	18
Mean education	16.90 (S.D of 2.37)
Ethnicity	Black (8), Caucasian (26), Asian (6)
Mean IQ (Shipley Hartford Scale estimate)	112.30 (S.D of 7.19)
Spielberger Anxiety Scales	
State	–0.4 Z score (S.D of .516) – Normal range
Trait	0.11 Z score (S.D of .785) – Normal range

2.1 Research design

The study utilised a double blind, placebo controlled, and crossover design. Within each element of the crossover (MC Square device, Sham) participants underwent pre-testing on the cognitive measures, training with the device, then post-testing on the same cognitive measures. Participants undertook baseline testing (3 h) of the neurocognitive skills under investigation without the MC Square device. The baseline testing included screening materials such as the The Shipley Hartford Institute of Living Scale for assessment of IQ (Robert, 2001), and the Spielberger State and Trait Anxiety Scales for determining baseline levels of anxiety. Other measures in this first session included the initial assessments of Memory (Hopkins Verbal Learning Test) (Jason, 2001), Verbal Learning (Paired Associate subtests from the Wechsler Memory Scale, WMS, with versions III, R, and the original WMS were used in order to obtain five versions), Working Memory (Letter Number Sequencing subtest from the WMS-III with additional versions constructed), (Wechsler, 1997) Attention (Digit Span subtest from the WMS-III with additional versions constructed), and Vocabulary (multiple choice practice PSAT and SAT items, with the five versions equated for difficulty by pre-testing with a separate sample of ten individuals. All five versions were completed with the mean scores within two points of each other).

Participants underwent cognitive testing with initial use of the MC Square Device or Sham on Day 1. Post-testing with the cognitive tests took place on Day 8. During the intervening period participants practiced for 15–20 min each day at home with the MC Square device or Sham depending on the experimental condition. A log book and sworn statement was used to attest to their practice with the device. A second identical testing session was held on Day 15 (pre-test) and Day 22 (post-test) with the device not utilised during the first session. Participants were randomly assigned in a counterbalanced fashion to one of two experimental session orders, *e.g.*, Sham (day 1 pre-test, day eight post-test) then the active MC Square device (day 15 pre-test, day 22 post-test), or the opposite order – active MC Square then the Sham device. During days nine though 14 participants were given a break and did not utilise the MC Square device or Sham. All pre- and post-test sessions utilised the device and followed the sequence of events depicted in Table 2. A post-doctoral research fellow administered the cognitive tests and remained blind to participant assignment. In total, participants attended five sessions: baseline (3 h), session one pre-test and post-test, and session two pre-test and post-test. The pre- and post-test sessions took approximately two and a half hours. The blind was broken at the end of the last session for the last subject after scoring and final entry of all data.

2.2 MC Square device characteristics

The MC Square device has different modes of operation, but only two modes were used in this study. The P-1 mode is for concentration enhancement and set at an alpha frequency (8–12 Hz) throughout the study. The P-2 mode is for inducing relaxation and is set at a combination of alpha and theta frequencies (4–12 Hz range), beginning with alpha, then theta (4–8 Hz), and then ending in alpha. The device works much like a small hand held radio. The choice of modes was easily set by a dial on the surface of the device. The device generated pulsed tones in the frequency range of 4–12 Hz (the range of theta and alpha waves), which was always synchronised at the same frequency as the flickering light. In the background, nature sounds were presented. The brightness of the flickering light, the volume of the tone pulses, and the volume of the background nature sounds was adjustable. The rate of flickering of the light and the rate of pulsing for the tones was not adjustable and determined by the P-1 and P-2 modes. There were four light diodes per eye set at a flickering rate of 4–12 Hz with a wavelength of 70 to 370 nm and brightness of 400 to 1000 millicandels. The diodes emitted red light, and as noted earlier this is because blood vessels in the eyelids pass red/orange light most efficiently. The volume of the pulsed tones was allowed to be adjustable and customised to the subject so as to avoid aversive loudness. The frequency set to alpha and theta, and the synchronisation of flickering lights and tones were considered the major though not the sole ingredient of effective brain wave entrainment through the MC Square device.

So that any observed effect could be reliably attributed to one variable, it was decided that the Sham would be identical to the MC Square device with the exception of the frequency. The rate (frequency) of the flickering light and the synchronised pulsed tone was randomised and never settled into an alpha, theta or other range reliably for more than one second. Also, so as not to potentially eliminate a characteristic that may contribute to the MC Square's effectiveness, all other aspects associated with typical use of the device were maintained (*e.g.*, background audio track for relaxation).

Thus, the Sham device looked, felt, and operated identically to the active MC Square device with the exception that the light and tone pulses were presented in a random, though synchronised, fashion and did not utilise a wavelength entrainment algorithm.

During each pre- and post-test session the MC Square or Sham device was administered four times. The order of events in the pre- and post-test sessions is depicted in Table 3. The device was kept in P-2 mode for the first or initial use at each session then changed to P-1 mode for all subsequent uses. Subjects utilised the P-1 mode during practice sessions at home.

Table 2 Experimental design and sequence of events

		Experimental Session 1				*Experimental Session 2*		
Order	*Baseline assessment*	*Day 1*	*Day 2–7*	*Day 8*	*6 Days interval*	*Day 15*	*Day 16–21*	*Day 22*
MC Sq./ Sham	• Health History, Photosen. Epilepsy Qnaire. • Shipley • Spielberger • HVLT • Digit Span • VPA • LNS • Vocabulary	• MC Square p2,p1 mode • HVLT Learning Trials • Digit Span • HVLT-DR • MC Sq. p-1 • VPA • LNS • VPA-DR • MC Sq. p-1 • Vocabulary	MC Square at home or work (two times per day)	• MC Square p2,p1 mode • HVLT,123 Learning Trials • Digit Span • HVLT-DR • MC Sq. p-1 • VPA • LNS • VPA-DR • MC Sq. p-1 • Vocabulary	Break	• Sham device p2,p1 mode • HVLT,123 Learning Trials • Digit Span • HVLT-DR • MC Sq. p-1 • VPA • LNS • VPA-DR • MC Sq. p-1 • Vocabulary	Sham device at home or work (two times per day)	• Sham device p2,p1 mode • HVLT,123 Learning Trials • Digit Span • HVLT-DR • MC Sq p-1 • VPA • LNS • VPA-DR • MC Sq. p-1 • Vocabulary
Sham/ MC Sq.	• Qnaire. • Shipley • Spielberger • HVLT • Digit Span • VPA • LNS • Vocabulary	• Sham device p2,p1 mode • HVLT,123 Learning Trials • Digit Span • HVLT-DR • MC Sq. p-1 • VPA • LNS • VPA-DR • MC Sq. p-1 • Vocabulary	Sham device at home or work (two times per day)	• Sham device p2,p1 mode • HVLT,123 Learning Trials • Digit Span • HVLT-DR • MC Sq. p-1 • VPA • LNS • VPA-DR • MC Sq. p-1 • Vocabulary	Break	• MC Square p2,p1 mode • HVLT,123 Learning Trials • Digit Span • HVLT-DR • MC Sq. p-1 • VPA • LNS • VPA-DR • MC Sq. p-1 • Vocabulary	MC Square at home or work (two times per day)	• MC Square p2,p1 mode • HVLT,123 Learning Trials • Digit Span • HVLT-DR • MC Sq. p-1 • VPA • LNS • VPA-DR • MC Sq. p-1 • Vocabulary

Table 3 Pre- and post-training means and standard deviations of cognitive measures during MC Square and Sham conditions

	Condition			
	MC Sq.		*Sham*	
Cognitive measures	*Mean*	*sd*	*Mean*	*sd*
HVLT-TR				
Pre	50.3	9.6	50.7	8
Post	52.8	7.6	51.7	10.2
HVLT-DR				
Pre	50.5	11.6	49.4	10.7
Post	53.8	8.1	50.4	10
HVLT-PR				
Pre	48.8	10.9	47.3	10.4
Post	50.5	8.7	49.2	8.9
HVLT-RDI				
Pre	50.9	9.4	51.5	8.4
Post	54.4	6.8	51.9	8
VPA-TL				
Pre	23.8	6.7	24.1	6
Post	25.5	5.4	24.4	5.8
VPA-TDR				
Pre	7.1	1.5	7.3	1.2
Post	7.5	1.2	7.3	1.4
VPA-LS				
Pre	3.7	1.9	3.8	2
Post	3.1	1.8	4	1.8
VPA-PR				
Pre	96.7	17.3	99.5	9
Post	97.3	7.7	99.5	10.05
VPA-DRecog.				
Pre	24	0	24	0
Post	24	0	24	0
LN-Sequencing				
Pre	13.3	3	12.9	2.6
Post	14.8	2.7	13.3	2.8
Digit Forward*				
Pre	12.1	2	12.3	1.9
Post	13.05	1.6	11.9	2.3

Table 3 Pre- and post-training means and standard deviations of cognitive measures during MC Square and Sham conditions (continued)

	Condition			
	MC Sq.		*Sham*	
Cognitive measures	*Mean*	*sd*	*Mean*	*sd*
Digit Backward				
Pre	9.4	2.9	9.6	2.2
Post	10.5	2.7	9.5	2.7
Total Digit Span*				
Pre	21.5	4.1	22.1	3.7
Post	23.7	4.1	21.4	4.6
Vocabulary				
Pre	34.2	5.7	34.05	6.1
Post	34	5.6	34.5	5.8

Notes: Hopkins Verbal Learning Test-Total Recall (HVLT-TR).
Hopkins Verbal Learning Test-Delayed Recall (HVLT-DR).
Hopkins Verbal Learning Test-Percent Retention Score (HVLT-PR).
Hopkins Verbal Learning Test-Recognition Discrimination Index (HVLT-RDI).
Verbal paired Associates-Total Learning (VPA-TL).
Verbal paired Associates-Total Delayed Recall (VPA-TDR).
Verbal paired Associates-Learning Slope (VPA-LS).
Verbal paired Associates-Percent Retention (VPA-PR).
Verbal paired Associates-Delayed Recognition (VPA-DRecog.).
Letter Number Sequencing-(LN-Sequencing).
* Statistically significant pre/post difference after Bonferroni Correction.

The technical merits of the MC Square device are its portability, ease and comfort of use, relatively inexpensive cost, safety, and potentially rapid effect on brain state.

2.3 Pre- and post-test measures

Four areas of neurocognitive functioning was assessed: Verbal Episodic Memory, Verbal Associative Learning, Verbal Working Memory, and Attention/Concentration. Two of the tests utilised to assess these domains had five versions available (Hopkins Verbal Learning Test, Paired Associates Learning Test). Additional versions were constructed for the remaining tests (Vocabulary, Digit Span Forwards and Backwards, and Letter Number Sequencing). A control task was developed, assessing vocabulary skills through a multiple choice format. Pre-test and post-test sessions were identical with the exception of the particular test version utilised. All tests with the exception of the Vocabulary test were well-established, well-normed neuropsychological instruments. Administration and scoring procedures followed the standardised procedure described in the test manuals.

2.3.1 Verbal episodic memory

The Hopkins Verbal Learning Test (Jason, 2001) was used as a measure of verbal episodic memory. This test consists of three learning trials composed of 12 individual words. A Delayed Recall of the words was taken 20–25 after the third learning trial. A Delayed Recognition trial was then administered composed of the 12 target words plus 12 non-target (non-heard) distracters. A Total Learning score (HVLT-TR) based on the three learning trials, a Delayed Recall score (HVLT-DR) score, Delayed Recognition Index (HVLT-RDI), and a Percent Retention score (HVLT-PR) were computed according to the manual and utilised in the analyses.

2.3.2 Verbal associative learning

The Verbal Paired Associates subtest of the Wechsler Memory Scale-III (Wechsler, 1997) was used as a measure of verbal learning. In this test there were a total of eight word pairs. After the word pairs were read aloud, participants were given the first word in the pair and required to provide the second. The set of eight word pairs was given and tested four times in each session. After 25–30 min a delayed recall test was given where again only the first word of the pair was given and participants had to provide the second word in the pair. A final delayed recognition phase was administered at each session. Here, participants read the eight word pairs randomly interspersed among 16 non-target (non-heard) pairs and participants had to identify the correct pair. Note, only non-semantically related word pairs were utilised. By utilising past versions of the Wechsler Memory Scale (version III, Revised, and original, five versions of this tests were created). A Total Learning score (VPA-TL) based on the four learning trials was computed in addition to a Learning Slope score (VPA-LS), Total Delayed Recall score (VPA-TDR), a Percent Retention score (VPA-PR), and a Total Delayed Recognition score (VPA-DRecog).

2.3.3 Verbal working memory

The Letter Number Sequencing subtest of the Wechsler Memory Scale-III (Wechsler, 1997) was utilised as the measure of verbal working memory. Participants were given series of random letters and numbers. The subject was required to repeat back the numbers in their cardinal (ascending) order and the letters in alphabetical order. The string of letters and numbers became increasingly longer with each trial. The subjects proceeded until they failed three times at a given letter/number span. A total of 21 trials were administered, two at each span with a maximum span of eight items (four letters, four numbers). Additional versions of this test were developed simply by utilising strings of random numbers and letters with no repetition of any string. The Total Score (LN-Sequencing) reflecting the number of correct trials was utilised in the analyses.

The Digit Span Backwards subtest of the Wechsler Memory Scale-III was used as a second measure of verbal working memory. The task is identical to the Digit Span Forward subtest described above with the exception that the participant had to recite the digits backwards, opposite the heard order. Additional versions of this test were developed simply by utilising strings of random numbers. The Total Digits Backward score was in used in the analyses.

2.3.4 Attention/Concentration

The Digit Span (Forward) subtest of the Wechsler Memory Scale-III (Wechsler, 1997) was used as a measure of auditory attention. The subject is required to repeat back a given string of digits, with each series of digits becoming increasingly longer. The subjects proceed until they fail twice at a given digit span. There were 16 trials, two at each span with a maximum span of nine digits. Additional versions of this test were developed simply by utilising strings of random numbers. The total Digits Forward raw score was used in the analysis.

2.3.5 Control task

A multiple choice Vocabulary test was used as a control task. It measures semantic knowledge. These items were taken from preparatory books for standardised college entrance exams (PSAT, SAT). Target items were presented with four choices and participants had to identify the synonym or word closest in meaning to the target word. Pretesting was used to develop five equivalent 50-item versions. As noted, improvement via the MC Square device was not expected for this measure.

2.4 Statistical analyses

Statistical analyses involved a repeated measures analysis of variance on the pre and post test scores of the two sessions with two within-subject factors both two-level in nature: Session (First, Second), Training Condition (pre-test, post-test). Order (MC Square condition then Sham, or vice versa) served as a between subject factor. Additional analyses of variance were run on pre- or post-test scores with Experimental Condition (MC Square, Sham) and Session (First, Second) as between-subject factors. All analyses were subject to Type I error correction using the Bonferroni method for 14 tests. An observed alpha of $p < .001$ was required to maintain an effective alpha of $p < .05$.

3 Results

The sample mean scores and standard deviation for each measure are shown in Table 3. We will first examine the effect of training with the MC Square device by focusing on the Repeated Measures Analysis. Here, the key effect in the model testing the hypothesis of improved performance following MC Square training involves the interaction between Session, Training Condition, and Order. The statistical results for the Repeated Measures Analysis are shown in Table 4.

Of the 14 Repeated Measures Analyses of Variance the triple interaction of Session, Training Condition, and Order was significant for Verbal Paired Associates Total Recall ($F\{1,37\} = 6.975$, $p < .05$), Digits Forward ($F\{1,37\} = 12.846$, $p < .01$) and Backwards ($F\{1,37\} = 6.104$, $p < .05$), and Total Digit Span ($F\{1,37\} = 14.988$, $p < .01$). In each instance the difference between the pre- and post-training scores was greater in the MC Square condition compared to Sham with improved scores at the post-training session. However, when Bonferroni correction for Type I Error was applied, only the effect for Digit Span Forward (see Figure 1) and Total Digit Span (see Figure 2) scores remained significant. This training effect for Digit Span Forward and Total Digit Span remained significant after accounting for baseline Digit Span performance. This was tested by re-running the Repeated Measures Analysis of Variance and including the baseline Digit Span scores as a covariate. A similar check of the finding was conducted using the Spielberger Trait and State Anxiety measures as covariates (each run in separate models); again, the results (triple interaction) or Digit Span Forward and Total Digit Span remained significant. On the Digit Span Forward test a total of 24 participants improved at least a .5 standard deviation relative to their baseline. Seven subjects showed no change and eight showed a decline. The average number of digits improved relative to baseline was .73.

Table 4 Results from repeated measures analysis of variance

Domain/Dependent variable with model effects	*F*	*df*	*P Value*
Verbal episodic memory			
1 HVLT-Total Recall			
Session	14.05	1,37	0.001
Session*Order	0.824	1,37	0.37
Training Condition	3.37	1,37	0.074
Training Condition*Order	0.025	1,37	0.876
Session* Training Condition	0.011	1,37	0.916
Session*Training Condition*Order	0.42	1,37	0.521
2 HVLT-Delayed Recall			
Session	2.09	1,37	0.156
Session*Order	5.22	1,37	0.028
Training Condition	4.7	1,37	0.037
Training Condition*Order	0.648	1,37	0.426
Session* Training Condition	1.2	1,37	0.267
Session*Training Condition*Order	2.01	1,37	0.164
3 HVLT-Percent Retention			
Session	0.425	1,37	0.518
Session*Order	0.379	1,37	0.542
Training Condition	1.337	1,37	0.255
Training Condition*Order	0.046	1,37	0.832
Session* Training Condition	0.036	1,37	0.85
Session*Training Condition*Order	0.262	1,37	0.612
4 HVLT-Recognition Discrimination Index			
Session	1.46	1,37	0.234
Session*Order	0.802	1,37	0.376
Training Condition	3.04	1,37	0.089
Training Condition*Order	0.02	1,37	0.887
Session* Training Condition	1.02	1,37	0.317
Session*Training Condition*Order	2.16	1,37	0.15

Table 4 Results from repeated measures analysis of variance (continued)

Domain/Dependent variable with model effects	*F*	*df*	*P Value*
Verbal associative learning			
1 VPA-Total Learning			
Session	10.925	1,37	0.002
Session*Order	10.064	1,37	0.003
Training Condition	7.274	1,37	0.01
Training Condition*Order	0.151	1,37	0.7
Session* Training Condition	8.98	1,37	0.005
Session*Training Condition*Order	6.975	1,37	0.012
2 VPA-Total Delayed Recall			
Session	6.214	1,37	0.017
Session*Order	0.041	1,37	0.841
Training Condition	1.868	1,37	0.18
Training Condition*Order	0.119	1,37	0.732
Session* Training Condition	6.375	1,37	0.016
Session*Training Condition*Order	1.563	1,37	0.219
3 VPA-Learning Slope			
Session	5.518	1,37	0.024
Session*Order	4.375	1,37	0.043
Training Condition	0.77	1,37	0.386
Training Condition*Order	2.852	1,37	0.1
Session* Training Condition	0.054	1,37	0.817
Session*Training Condition*Order	2.419	1,37	0.128
4 VPA-Percent Retention			
Session	0.459	1,37	0.502
Session*Order	0.249	1,37	0.621
Training Condition	0.721	1,37	0.401
Training Condition*Order	1.147	1,37	0.291
Session* Training Condition	0.889	1,37	0.352
Session*Training Condition*Order	0.31	1,37	0.581
5 VPA-Delayed Recognition			
Session	0.768	1,37	0.386
Session*Order	0.768	1,37	0.386
Training Condition	0.768	1,37	0.386
Training Condition*Order	0.768	1,37	0.386
Session* Training Condition	0.768	1,37	0.386
Session*Training Condition*Order	0.768	1,37	0.386

Table 4 Results from repeated measures analysis of variance (continued)

Domain/Dependent variable with model effects	*F*	*df*	*P Value*
Verbal working memory			
1 LN-Sequencing			
Session	6.653	1,37	0.014
Session*Order	17.823	1,37	0
Training Condition	2.428	1,37	0.128
Training Condition*Order	0.282	1,37	0.599
Session* Training Condition	1.192	1,37	0.282
Session*Training Condition*Order	3.208	1,37	0.081
2 Digit Span (Backward)			
Session	5.93	1,37	0.2
Session*Order	2.52	1,37	0.121
Training Condition	5.822	1,37	0.021
Training Condition*Order	0.355	1,37	0.555
Session* Training Condition	0.004	1,37	0.949
Session*Training Condition*Order	6.104	1,37	0.018
Attention/Concentration			
1 Digit Span (Forward)			
Session	0.115	1,37	0.736
Session*Order	3.468	1,37	0.071
Training Condition	2.229	1,37	0.144
Training Condition*Order	1.365	1,37	0.25
Session* Training Condition	0.274	1,37	0.604
Session*Training Condition*Order	12.846	1,37	0.001
2 Total Digit Span			
Session	3.481	1,37	0.07
Session*Order	5.161	1,37	0.029
Training Condition	6.673	1,37	0.014
Training Condition*Order	0.086	1,37	0.771
Session* Training Condition	0.226	1,37	0.609
Session*Training Condition*Order	14.988	1,37	0.001
Control Task			
Vocabulary			
Session	1.114	1,37	0.298
Session*Order	1.735	1,37	0.196
Training Condition	0.51	1,37	0.48
Training Condition*Order	2.101	1,37	0.156
Session*Training Condition	0.438	1,37	0.512
Session*Training Condition*Order	0.001	1,37	0.971

Figure 1 Mean raw scores on the Digit Span Forward test

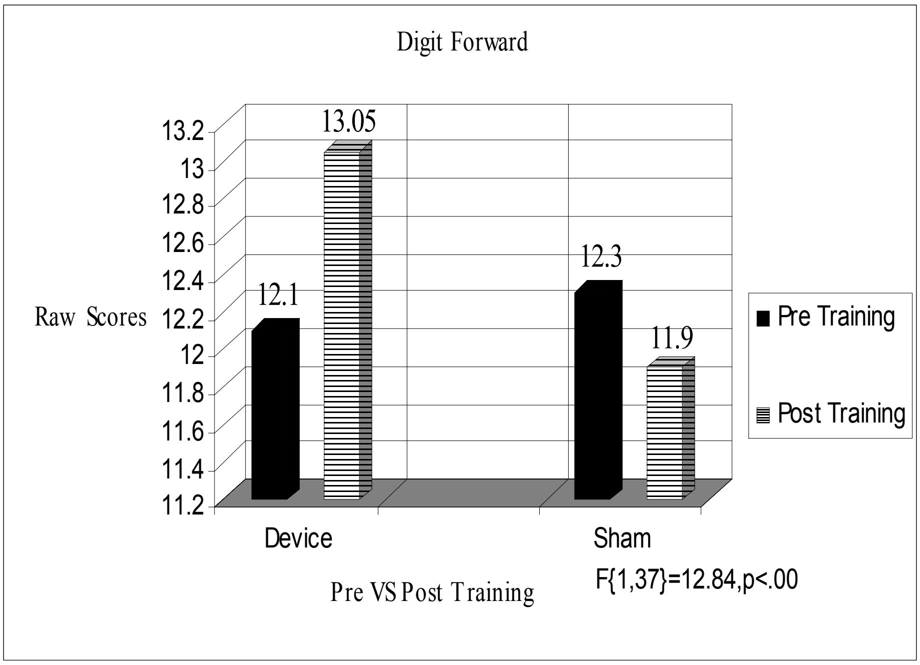
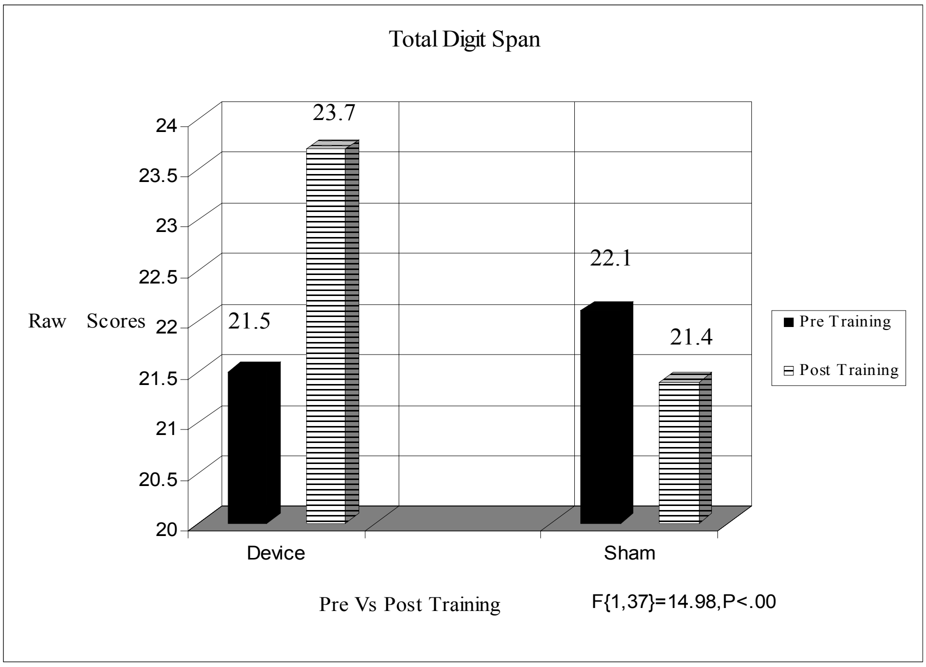


Figure 2 Mean raw scores on the Total Digit Span measure



The Analyses of Variance run on pre- or post-test scores with Experimental Condition (MC Square, Sham) and Session (First, Second) as between-subject factors revealed a significant advantage for the MC Square device at post-training for the Hopkins Verbal Learning Test Delayed Recall (Wechsler, 1997), Letter Number Sequencing (Wechsler, 1997), Digit Span Forward (Wechsler, 1997), Backward and Total Score (Wechsler, 1997). After accounting for Type I error through the Bonferroni correction (28 tests), none remained significant. When we collapsed across the pre- and post-test scores and utilised their mean score, an advantage for performance under the MC Square device was evident on the Letter Number Sequencing task that was initially significant ($p < .05$), but this effect became non-significant under Bonferroni Correction (14 tests).

4 Discussion

We conclude that there was a statistically reliable improvement on a measure of attention and concentration, the Digit Span Forwards test, following MC Square training. There was improvement on a measure of associative verbal learning and working memory in the initial analyses, but these findings did not survive Bonferroni correction. As expected the MC Square device had no influence on our control task involving vocabulary. The lack of an effect in most areas measured, including our control task, provided assurance that the MC Square was not having a general effect on cognitive activity and that when reliable change occurred it was a fairly specific effect. The training effect on Digit Span Forwards held true even after accounting for the participant's baseline level of Digit Span skill or their state and trait level of anxiety. A total of 24 out of 39 subjects (61.5%) showed at least a half standard deviation improvement (an increase of .73 digits, or approximately one digit) on the digit span task following training with the device. This increase may be of practical benefit in terms over holding on to more 'heard' information over the short term.

In terms of performance on the individual tests, ignoring the training aspects of the study, participants using the MC Square Device subjects showed generally better performance on a working memory measure, the attention measure, and aspects of the associative learning test. However, here again these effects can only be considered trends as they were not statistically reliable after accounting for potential error rates (Type I error) that can occur when conducting multiple statistical tests.

The large number of tests conducted (14) certainly worked against obtaining statistically robust results that could remain significant after the stringent Bonferroni test. A Type II error, particularly in the case of the Associative Learning (Verbal Paired Associates, Total Recall) and Working Memory measures (Digits Backwards) was certainly possible. Initial analyses suggested an effect that was not sustained with Bonferroni correction. Note, in the repeated measures ANOVA examining the training effect for Verbal Paired Associates Total Recall the power present was .73. The power estimate for Digit Span Backwards was .67. Note, that the power for the training effect that did remain significant after Bonferroni correction, Digit Span Forwards, was .94. Therefore, power was at adequate levels and the relatively small sample size did not play as large a role in the loss of statistical significance as did the multiple tests and Bonferroni criteria. A larger sample size may show an effect for verbal learning, and further study is warranted.

We observed improvement in response to an AVE device on the same task, the digit span task, as did Budzynski and colleagues (1999). It is important to note that our effect was achieved with fewer training sessions. Also, our finding of increased attentional skill is interesting in light of previous results that suggest AVE devices can reduce inattention, impulsiveness, and reaction time in Attention Deficit Disorder children (Cohen and Douglas, 1972; Joyce and Siever, 2000).

The exact neural mechanism behind audio-visual entrainment is not known. We did not collect EEG data on brain wave activity on our participants and thus cannot confirm that entrainment actually occurred, or that it involved a switch to alpha or theta rhythms. Also, it is unclear whether the MC Square works through relaxation or a more direct impact on the brain areas implementing specific cognitive functions such as attention. Though baseline anxiety did not account for the effects on attention we observed here, we did not directly measure anxiety or stress through techniques such as skin conductance while subjects were performing the tests. This would allow determination of whether measures of physiologic arousal and relaxation taken during cognitive performance are related to and account for the level of skill or accuracy that is displayed.

It is difficult to know whether the improvement we found in attention would translate into improved test performance in academic settings. The data do suggest the device provides some modest enhancement in the ability to focus, attend, and report information over the short term. There were trends in the data indicating the MC Square may have a direct effect on verbal learning, as indicated by the initially significant finding for Verbal Paired Associates, yet the reliability of this effect is unclear. It certainly points to a potential area of gain the device may confer, but replication studies with fewer, and more selective set of measures focused on verbal learning will be needed.

Future studies should determine how underlying brain activation actually changes during use of the MC Square device, particularly in a manner that correlates with improved attention, learning, and memory. This could be accomplished through functional magnetic resonance imaging. Further, delineation and confirmation of the device's effect on EEG entrainment is also needed and is planned. Finally, as the possible mechanism of action of the device in terms of influencing cognition may involve changes in blood flow, a study verifying the MC Square device's effect on blood flow is needed. This could be accomplished by perfusion MR imaging. A technique that increases blood flow may at least partially remediate certain cognitive deficits if applied regularly over a period of time, and could certainly have application to clinical samples such as stroke and normal populations as the elderly where there is a documented decrease in cerebral blood flow (Gur *et al*., 1987; Hagstadius and Risberg, 1989; Heiss *et al*., 1992; Meyer *et al*., 1993; Nagahama *et al*., 1997). Improving cognitive performance is a goal of students and others in the normal population who participate in college preparatory courses, occupational training or lifelong learning programmes. This type of technology-enhanced learning could be more generally applied to optimise worker efficiency in industry and organisations. As learning technologies to enhance teaching shift to include more learner-centred approaches emphasising the situational contexts of the learner, advances in optimising the biological state of the learner are needed (Uden, 2004). This is particularly true as the teaching environment shifts to the medium of e-teaching where the learning is highly individualised, and where the learner tends to work in isolation at their computer, at their own pace (Bork, 2004). For such situations, where the learning environment is controlled by the individual, the MC Square technology seems ideally suited. The search continues for tools that help improve brain function directly by effecting neural functioning, or indirectly through the benefit of relaxation during periods of learning and test performance. Such practical applications remain a goal of researchers in instructional technology, education, occupational training, cognitive psychology, and neuroscience more broadly.

4.1 Definitions

Alpha Rhythm – The frequency for brain waves in the 8 to 12 Hz range. It is characteristic of a relaxed, alert state of consciousness.

Theta Rhythm – The frequency for brain waves in the 4 to 8 Hz range. It is associated with drowsiness.

Cerebral Synchronisation – Cerebral synchronisation is a neurologic phenomenon that occurs when the brain waves of both hemispheres are oscillating at the same rhythm or wavelength. In this state, the brain works harmoniously and uses each hemisphere's capacities equally. It can also refer to a state where the separate cerebral hemispheres have symmetric brain waves.

Cerebral perfusion – The rate and volume of blood flow to the brain.

Peak Alpha Rhythm – A pattern of brain waves characterised by a maximum amplitude and frequency that is consistently in the alpha range.

Photic stimulation – A type of treatment or exposure to the brain in which light stimuli is delivered to eyes in a particular pattern or at a particular intensity with the goal of creating specific visual conditions. The stimuli are often presented through goggles to ensure controlled administration.

Sympathetic Activation – Activation of the part of nervous system most sensitive to external stimuli and the outside environment. This system is characterised by behavioural output involving either a 'fight' or 'flight' reaction in response to a perceived stimulus.

Alpha Entrainment – A technology whereby brain waves are triggered to consistently flow in the alpha range. Entrainment refers to a specific technique where the triggering external stimulus such as a flickering light or pulsing tone is set at a frequency close to alpha with the goal of training brain waves to follow that same rhythm. Brain waves adopting an alpha pattern and inducing a relaxed/alert state of mind because of this technique are said to have gone through alpha entrainment.

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