Computerised Cognitive Training for Older Persons With Mild Cognitive Impairment: A Pilot Study Using a Randomised Controlled Trial Design

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The results of a pilot randomised controlled trial of computerised cognitive training in older adults with mild cognitive impairment (MCI) are reported. Participants (N = 25) were randomised into either the treatment or waitlist training groups. Sixteen participants completed the 30-session computerised cognitive training program using exercises that target a range of cognitive functions including attention, processing speed, visual memory and executive functions. It was hypothesised that participants would improve with practice on the trained tasks, that the benefits of training would generalise to nontrained neuropsychological measures, and that training would result in improved perceptions of memory and memory functioning when compared with waitlist controls. Results indicated that participants were able to improve their performance across a range of tasks with training. There was some evidence of generalisation of training to a measure of visual sustained attention. There were no significant effects of training on self-reported everyday memory functioning or mood. The results are discussed along with suggestions for future research.

Keywords: human, aged, cognition, cognitive training, mild cognitive impairment, randomised controlled trial

Most cognitive training research in the elderly has utilised either healthy samples or those with a diagnosed dementia. A relatively neglected group has been older people with mild cognitive impairment (MCI). MCI is defined as cognitive decline on objective tests relative to age-matched peers but without functional impairment in activities of daily living (Petersen et al., 1999) and is associated with an increased risk of dementia (Feldman & Jacova, 2005). A distinction can be drawn between two types of MCI, amnestic MCI with a primary memory deficit, and nonamnestic MCI where domains other than memory are affected. Cognitive deficits reported in amnestic MCI include deficits in episodic and semantic memory, with difficulties encoding and storing information, especially on nonverbal tasks. Apart from memory difficulties, there can be deficits on tasks assessing inhibition (Belleville, 2008), perceptual speed and visuospatial abilities (Bennett et al., 2002).

These cognitive changes reflect pathological changes in the brain. Neuroimaging studies reveal both structural and functional changes in MCI with progressive loss of both grey and white matter, as well as reductions in cerebral metabolic rate and cerebral blood flow. These changes begin in the entorhinal cortex and hippocampal regions and later spread to the parietal, then temporoparietal and frontal lobes (Schuff & Zhu, 2007).

Until recently, treatment options have been limited to either medications such as cholinesterase inhibitors or compensation strate-

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gies (e.g., the use of diaries, reminders, or association). The teaching of memory strategies has been aimed at compensating for functions that are impaired by using external assistance and there is an extensive literature on their application both in healthy elderly and in early Alzheimer's disease (Clare & Woods, 2003; Papp, Walsh, & Snyder, 2006). These efforts to compensate (rather than remediate) impairment have been the norm in studies of older people with cognitive impairment until quite recently. However, neither medications nor compensatory strategies appear to be very effective at either improving cognitive functioning or at preventing dementia (Belleville et al., 2006; Birks & Flicker, 2006; Petersen et al., 2005; Rapp, Brenes, & Marsh, 2002).

An alternative approach draws on the concept of *neuroplasticity*, the ability of the brain to change in response to environmental stimulation throughout the lifespan (Dinse, 2006). The processes involved are not yet fully understood but are thought to involve the growth of new brain cells, the elaboration and strengthening of neural networks and the up-regulation of neurotransmitter systems (Mahncke et al., 2006). It may be possible to utilise these neuroplastic processes to train discrete areas of cognition in the hope of maintaining or improving cognitive functioning in MCI.

There are two lines of evidence to support the utility of brain plasticity in this regard. The first is data suggesting changes in brain structure and functioning following cognitive training. In animal studies, exposure to an enriched environment may result in both structural changes within the brain *and* the prevention or delayed emergence of neuropathology. For example, there are specific changes in the brain such as neurogenesis, thickened grey matter, elaboration of dendrites and synapses when older rats are placed in stimulating environments (Kempermann, Gast, & Gage, 2002). In transgenic mice, both the neuropathology and the cognitive deficits associated with Alzheimer's disease are modulated by learning and environmental enrichment (Billings, Green, McGraugh, & LaFerla, 2007; Jankowsky et al., 2005; Lazarov et al., 2005). In humans the evidence is more limited. A study by Valenzuela et al., (2003) found increased creatinine and choline signals in the hippocampus after training healthy elderly participants in memory strategies. Further, there is some evidence that training on a working memory task results in increased activation in the frontal and parietal regions typically associated with working memory tasks (Olesen, Westerberg & Klinberg, 2004). The same training paradigm may also increase the density of cortical dopamine receptors in young adult participants (McNab et al., 2009). However, changes noted in younger adults following training, may not be found in older adults (Nyberg et al., 2003).

The second line of evidence comes from treatment studies using computerised exercises that are designed to provide a progressive challenge to participant's cognitive abilities. In theory, these exercises harness neuroplastic processes to produce changes in brain structure and function that, over time, result in improved cognitive functioning (Mahncke et al., 2006). These exercises are used to train a variety of cognitive domains, utilising tasks that may be either based on, or have similarities to, established neuropsychological tests. Computerised cognitive training has been shown to improve the cognitive deficits associated with schizophrenia, with reported medium effect sizes across a range of cognitive domains (McGurk, Twamley, Sitzer, McHugo & Mueser, 2006). An adapted version of the on-line training software used in this study has shown promise in improving cognitive functioning in other populations such as children with cancer-related brain injury (Kesler, Lacayo & Jo, 2011), however, there is much less research in older people with MCI. There are several studies that use computerised cognitive training that report positive findings. For example, Rozzini, Costardi, Vicini, Chilovi, & Franzoni (2007) reported that MCI participants who were also taking cholinesterase inhibitors showed improved performance on measures of memory and abstract reasoning after three month-long blocks of training, interspersed with two months of no training between each block, when participants were re-assessed three months after training concluded. Talassi, Guerreschi, Feriani, & Fedi (2007) found improved performance on visuospatial ability and visual memory immediately following a three-week training computerised training program. Cipriani, Bianchetti, & Trabucchi (2006) noted improvements in behavioural memory following two blocks of training each lasting four weeks.

However, while these results are promising, all these studies have methodological problems such as nonrandom allocation to groups and inadequate control groups. A study by Barnes et al., (2009) that used an Randomised Controlled Trial (RCT) design reported a trend toward significance on measures of verbal learning and memory for the treatment group but the results of the study were difficult to interpret as the intended inert control group also showed effects, albeit on different measures. The study reported here seeks to address some of those limitations by randomising

participants into either treatment or waitlist groups and by using software designed to improve a range of cognitive domains.

Mood and Cognition

The impact training may have on mood have also been the subject of investigation. While it has been suggested that training may adversely affect mood by increasing participant's awareness of their cognitive deficits (Small et al., 1997), there is no convincing evidence of either cognitive rehabilitation or training having any negative impact on mood. Clare & Woods (2003) found no evidence of any change in self-rated mood following cognitive rehabilitation in their review of studies carried out using participants with Alzheimer's disease, while in the treatment studies using MCI participants cited above (Cipriani et al., 2006; Rozzini et al., 2007; Talassi et al., 2006), the findings suggested either improved mood or no change following cognitive training.

Aims

This study was designed to examine the effects of a computerised cognitive training program on cognitive functions in a group of older adults diagnosed with MCI. The computer program was broad based, with tasks designed to improve attention, processing speed, visual memory and cognitive control. Consequently, it was hypothesised that such training would lead to observable changes on neuropsychological measures of sustained attention, working memory, visual learning and set shifting. Improvements following training were also expected on secondary outcome measures such as perceptions of control of memory, perceived performance of everyday memory tasks. To gauge the impact of training on mood, a measure of mood was also included.

Method

The diagnosis of MCI was originally determined by the consensus opinion of a Staff Specialist Geriatrician, Psychogeriatrician and Clinical Psychologist following a comprehensive Memory Clinic evaluation including detailed neuropsychological testing, psychiatric assessment, physical examination, blood pathology, Apolipoprotein (APOE) genotype testing and cerebral imaging. All participants were reevaluated on entry to the study against standardised criteria (see later). Participants who were on stable doses of cholinesterase inhibitors for the duration of the study were eligible to take part, but participants who commenced taking these medications during the study were excluded. Participants provided written informed consent in accordance with HREA requirements. Entry criteria were as follows.

Diagnosis of MCI — Amnestic (Single domain) and/or Multiple domain. Participants with nonmemory domain MCI were not eligible to participate. MCI was determined using standardised diagnostic criteria (Winblad et al., 2004) as follows:

1. Not normal, not demented (does not meet DSM-IV, ICD-10 criteria for a dementia syndrome)
2. Cognitive decline

   (a) self and/or informant report and impairment on objective tasks and/or

   (b) evidence of decline over time on objective cognitive tasks.
3. Preserved basic activities of daily living / minimal impairment in complex instrumental functions.

In addition, participants were required to have intact global cognitive functioning (score > 23) on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975); and absence of untreated psychiatric illness or substance abuse problems; and absence of visual, auditory or motor impairment that would hinder use of a computer.

Sample

Twenty-seven community-dwelling older (age > 60 years) clients of the Department of Aged Care and Rehabilitation Medicine Memory Clinic at Royal North Shore Hospital, with a current diagnosis of MCI completed the baseline assessment. Two participants were excluded at baseline due to a MMSE score of < 24. Participants with both MCI — Amnestic (n = 11) and MCI — Multiple domain (n = 14) were randomised into the study. Basic demographic data for the 25 participants who were originally recruited into the study are shown in Table 1. There were 16 females and 9 males who completed baseline testing.

Twelve participants were randomly assigned to the treatment group and 13 to the waitlist group. Randomisation was achieved by having an independent person place slips of paper, with either 'treatment' or 'waitlist' written on them, into opaque envelopes that were then sealed. At the completion of baseline testing, participants were then asked to select an envelope at random and were assigned on the basis of the slip contained

TABLE 1
Baseline Demographic Data For All Participants Randomised Into the Study (N = 25)

	Mean	(SD)	(Range)
Age (years)	74.20	(8.13)	(61–89)
Education (years)	12.50	(2.47)	(8–16)
MMSE score	27.76	(1.96)	(24–30)

within. The treatment group commenced training straightaway, and were re-assessed once training was completed, whereas the latter waited approximately six to eight weeks, and were then re-assessed. Following this second assessment, the waitlist group then commenced training and were re-assessed at the completion of training. All post-training assessments were carried out by trained assessors who were blind to treatment group.

Due to attrition, 16 participants completed the study, with 4 treatment and 5 waitlist group participants either withdrawing or being excluded. Noncompleters did not differ from those who completed the study in terms of age, sex, education, depressive symptoms or cognitive function scores. The primary reasons for drop out included unrelated medical or personal issues (7), or being commenced on a cholinesterase inhibitor (2). Participants took an average of 11.43 weeks to complete the training exercises. The flow of participants through the study to the posttest assessment is shown in Figure 1.

Primary Outcome Measures

Selected tests from the Cambridge Automated Neuropsychological Test Battery (CANTAB, 2005) were used to provide measures of cognitive functioning. The CANTAB is a reliable and well-validated computerised neuropsychological test battery, which automates data collection and scoring. The tests included measures of the following cognitive functions.

Visual Memory

Paired-associates learning (PAL — assesses visual episodic memory). Normal performance on PAL requires intact functioning of the medial temporal lobe while *Pattern recognition memory* (PRM) requires intact functioning of both the medial temporal and frontal lobes (Owen, Sahakian, Semple, Polkey, & Robbins, 1995). For PAL the outcome measure used was the total number of errors (adjusted). Errors are made when the participant selects a box that does not contain the target stimulus. The number of errors is adjusted to allow for the number of stages attempted. For PRM, the outcome measure used was percent correct on a forced-choice recognition task.

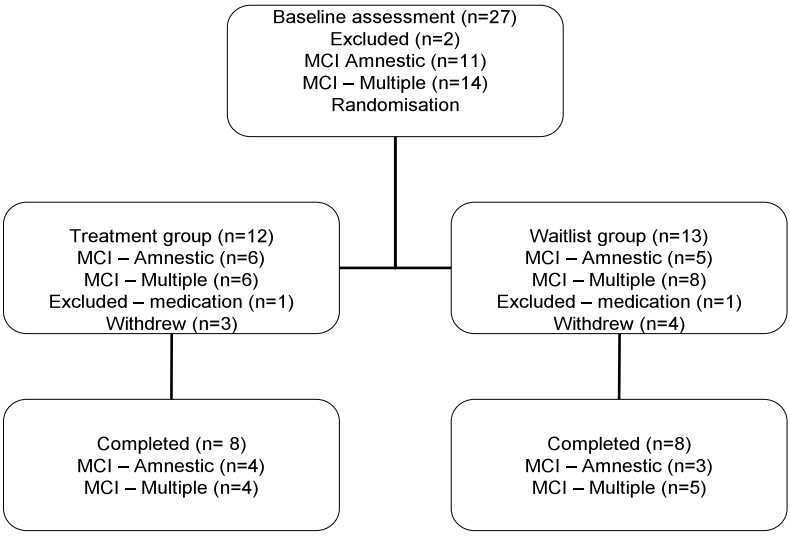

FIGURE 1
Participant flow through the study to post-test

Executive Functions

Intra-/extra-dimensional set shifting (IED — assesses rule acquisition and attentional set shifting). The extra-dimensional shift component of IED has been shown to be sensitive to frontal lobe lesions with a decrease in accuracy on this aspect of the task. In contrast, patients with medial temporal lobe lesions retain accuracy but exhibit markedly slower performance compared with normal controls (Owen, Sahakian, Semple, Polkey, & Robbins, 1996). The outcome measure used was *total errors* (adjusted), a measure of efficiency in attempting the test. The number of errors is automatically adjusted by the CANTAB scoring program to allow for any stage not completed.

Spatial working memory (assesses working memory and executive functions/ strategy use) is primarily sensitive to damage to the frontal lobes (Owen, Roberts, Polkey, Sahakian, & Robbins, 1991; Owen et al., 1995). The outcome measures used were *total errors*, which is the number of times a box is selected that is certain not to contain the target; and *strategy,* which is the number of times the participant begins a new search with the same box (i.e., uses an efficient search strategy).

Attention

Rapid visual information processing (RVP) a measure of visual sustained attention. This test is sensitive to damage in the parietal and frontal lobes (Robbins, Elliot, & Sahakian, 1996). The outcome measure used is RVP A', a measure of sensitivity to the target (range 0.00 to 1.00, bad to good), in this case a measure of how quickly and accurately targets (three separate triple-digit sequences; e.g., 2–4–8) are detected from among distractors. This measure is sensitive to neurological damage associated with Alzheimer's disease (Sahakian, Jones, Levy, Gray, & Warburton, 1989).

Secondary Outcome Measures

Subjective memory impairment was assessed using the Memory Functioning Questionnaire (MFQ; Gilewski, Zelinski, & Schaie, 1990) a 64-item questionnaire. Respondents rated all items on a 7-point Likert scale. There are four subscales: frequency of forgetting, change in functioning, seriousness of problems, and use of mnemonics. Higher scores indicate less memory problems. Reliability of each the subscales is high (reported alpha > 0.83). Concurrent validity studies indicate that scores on the MFQ are related to performance on psychometric measures of memory (Zelinski, Gilewski, & Anthony-Bergstone, 1990).

Perceived control over memory was measured using the Memory Controllability Inventory (Lachman, Bandura, Weaver, & Elliott, 1995), which consists of 12 items forming six subscales (present ability, potential improvement, inevitable decrement, effort utility, independence and Alzheimer's likelihood) and has acceptable reliability (internal consistency of each subscale reportedly ranges between alpha .58 to .77) and validity (scores on the MCI subscales are associated with age, self-rated health, and performance on memory tests). Respondents rated each item on a 7-point Likert scale.

Mood was measured using the Depression Anxiety and Stress Scale (Lovibond & Lovibond, 1995) 21-item version. This shortened version of the DASS has been shown to have excellent reliability (internal consistency for each subscale of at least .87) and concurrent validity, being highly correlated with well-established measures of depression and anxiety such as the Beck Depression Inventory and the Beck Anxiety Inventory (Antony, Bieling, Cox, Enns, & Swinson, 1998).

Computerised Cognitive Training Package

The training software was supplied by Lumosity Inc. It consisted of 30 training sessions each containing four or five cognitive exercises. There were four broad cognitive domains targeted: nominally attention, processing speed, visual memory and cognitive control. All participants began at the same level of difficulty. On each exercise, once a predetermined criterion of performance was reached, the level of difficulty was increased. The six training exercises reported here are described in detail.

Birdwatching

The silhouette of a bird appears briefly (initial exposure time 400 ms) somewhere on the screen while simultaneously a letter of the alphabet appears for the same duration in a small box in the centre of the screen. The participant has to firstly click on the area where the bird appeared and, if correct, is then asked to choose which letter appeared from a choice of five alternatives. The exercise commences at level one with a maximum of ten possible levels. Once the participant reaches a certain threshold level of performance, both the duration of exposure and the location of the bird stimulus are varied, with decreasing exposure time and more distance between the bird stimulus and the letter stimulus in the centre of the screen. These parameters change systematically at each level.

Colour Match

Two words appear adjacent to each other on the screen, each of which is a colour. Participants have to identify if the meaning of the word on the left hand side matches the ink colour of the word on the right hand side. The task is to give the correct answer as many times as possible in a 45-second period.

Lost in Migration

A graphical depiction of a flock of five birds appears. The participant has to press the arrow key that corresponds to the direction of the bird in the centre of the flock. The direction of the central bird can be either the same of those of the other birds or different. The task is to get as many correct as possible in a 45-second period.

Memory Match

Two symbols appear on the screen adjacent to each other. The initial task is to identify whether or not the two symbols match. Once this is done the symbol on the far left is displaced by the symbol from the right hand side, which is itself replaced. As the task progresses, the symbol on the left hand side gradually fades from view, forcing the participant to rely on working memory. The task is to complete as many correct in 45 seconds.

Raindrops

Simple arithmetical equations appear inside droplets that fall from the top of the screen towards the bottom. The participant has to enter the correct answer before the droplet reaches the water at the bottom the screen. As the participant solves more equations, the droplets fall towards the bottom of the screen at increasing speed. The task continues until three droplets reach the water at the bottom of the screen.

Spatial Speed Match

A single symbol appears briefly in the centre of the screen and is then replaced by another. The task is to identify whether or not the new symbol matches the previous one. The task is to get as many correct as possible in a 45-second period.

The software provided feedback to participants as they completed each exercise and after each session. The participants completed the training at home using their own computers and Internet access. All participants attended the clinic and were provided with their own user identification and password and shown how to access the software. They were also given a demonstration of how to use the software and observed completing a training session. Participants were asked to complete approximately four to five sessions of training per week. Adherence was monitored remotely by visual inspection of the progress recorded on the Lumosity web site. To promote training adherence, all participants were followed up with weekly telephone calls (and home visits as required) during training. Participants who completed at least 80% of the sessions were eligible for reassessment. The posttreatment assessments were carried out by assessors who were blind to treatment group.

Data Analysis

All analyses were carried out using PASW Statistics -version 18. Planned analyses included the following:

Pre/posttreatment effects for neuropsychological tests (CANTAB), memory questionnaires (MFQ, MCI) and mood (DASS) were examined using 2 (group) × 2 (time) ANCOVA with MMSE score as a covariate.

Trained Tasks

Data from all training sessions was consolidated into four data points representing average performance for 4 session blocks (e.g., sessions 1–4, 5–8, 9–12, 13–16). Learning effects were examined using a repeated ANOVA. The training exercises that were available for analysis were Birdwatching, Colour Match, Lost in Migration, Memory Match, Raindrops, and Spatial Speed Match.

Results

All data reported here are from the 16 participants who completed training. Unless otherwise indicated the data reported below are the comparisons between the two groups at baseline and at posttest (after the treatment group had completed training, and before the waitlist group commenced training). At baseline, there were no significant differences between the two groups other than a trend toward the treatment group being younger than the waitlist group, see Table 2.

Preliminary Analyses

In order to determine whether treatment effects were influenced by initial variability within and between groups in demographic and cognitive factors, correlations were conducted between age, years of education, MMSE scores, self-reported

TABLE 2
Baseline Comparisons by Group for the Participants (N = 16) Who Completed Training on Basic Demographic Details and the MMSE

	Treatment (n = 8)		Waitlist (n = 8)		*t*	p value
	Mean	(SD)	Mean	(SD)		
Age (years)	69.00	(7.69)	76.38	(6.47)	-2.074	ns
Education (years)	13.25	(2.22)	12.00	(2.77)	1.01	ns
MMSE	28.5	(2.26)	27.5	(2.39)	0.858	ns
Gender	5 females, 3 males		3 females, 5 males			

memory functioning (MFQ subscales) and perceptions of memory controllability (MCI subscales) and posttraining outcome measures. On this analysis, the only significant correlations were between baseline MMSE score and all the neuropsychological outcome measures (except spatial working memory strategy score, Pearson's *r* range .553 to .706). Subsequently, all posttraining data were analysed using an ANCOVA with MMSE score as a covariate. Results of the ANCOVA for the primary and secondary outcome measures are detailed in Table 3 showing overall group differences, practice (time) effects and treatment (group × time) effects. There were no significant practice (time) effects for any of the neuropsychological outcome measures.

Primary Outcome Measures: CANTAB

There was evidence of a treatment effect (group × time interaction) on a measure of visual sustained attention (RVP A). No other treatment effects were found on neuropsychological outcome measures. The interaction is shown in Figure 2.

Inspection of means (see Table 4) indicates that the significant effect on visual sustained attention was due to the combined effect of a gain in the treatment group following training, and a decline in the waitlist group scores on this task.

Secondary Outcome Measures: Self-Reported Memory Functioning and Mood

There was no effect of training on self-reported everyday memory functioning as measured by the MFQ, or on perceptions of memory controllability as measured by the MCI. There was no effect of training on depression, anxiety or stress as measured by the DASS21.

Impact of training on waitlist group. After completing posttest, the waitlist group then commenced training and were re-assessed on completion. There was no effect of training on the waitlist group with all outcome measures non-significant.

Performance on Trained Tasks

The data for the trained exercises for all participants ($N = 16$) are presented in Table 5. In order to facilitate comparison across tasks, results are shown as a proportion of the best obtained score, with 1.00 representing the best score. As can be seen, in each case a significant improvement

TABLE 3
Summary Results From ANCOVA of Primary Outcome Measures

		Main effect of group		Main effect of time (Practice effect)		Group by Time (Treatment effect)	
	CANTAB test	*F*(2,14)	*p* value	*F*(2,14)	*p* value	*F*(2,14)	*p* value
Attentional set shifting	IED Errors (adj)	6.27	.025*	0.35	.563	0.01	.915
Visual learning	PAL errors (adj.)	5.90	.029*	1.17	.297	0.05	.832
Visual recognition	PRM % correct	4.50	.052	0.67	.428	0.14	.715
Visual sustained attention	RVP A'	2.28	.153	0.78	.391	11.95	.004**
Visual working memory	SWM Errors (adj.)	5.29	.037*	3.55	.080	0.00	.973
	SWM Strategy	4.28	.058	2.27	.154	2.91	.110

Note: *p < .05, **p <. 001

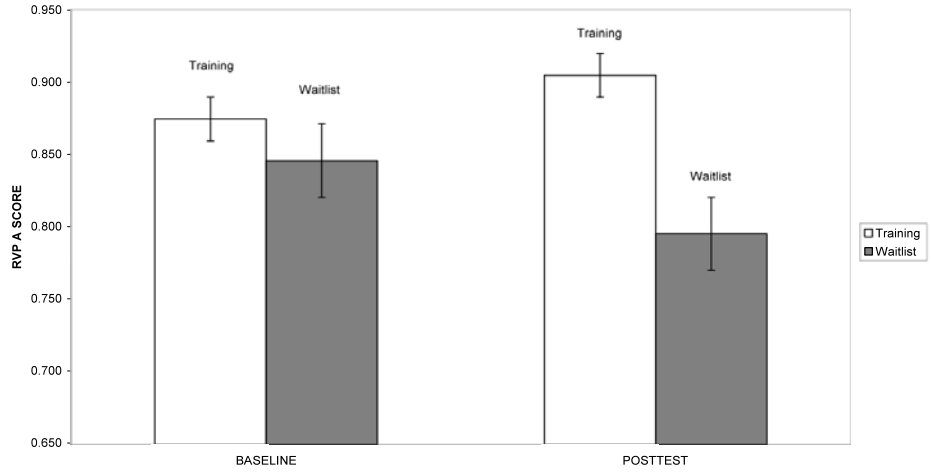

FIGURE 2
Effect of training on visual sustained attention

occurred on the trained tasks across learning trials, although this varied across tasks. For example, on the Birdwatching exercise participants achieved only 35% of their best score initially and this improved substantially with practice, whereas on the Memory Match exercise they achieved 71.8% of their best score initially, showing relatively less improvement over time.

Relationship Between Trained Tasks and Neuropsychological Measures at Baseline

Finally, in order to determine whether the training exercises were, indeed, targeting the same domains as measured by the primary outcome measures, correlational analyses were carried out to determine the relationship between each cognitive training exercise in the first training session and the CANTAB neuropsychological test scores at baseline. The correlational matrix is presented in Table 6 and the results did not suggest a singular relationship between individual domains. Exercises deemed to train visual attention related to visual working memory, but also to executive functions and learning. The cognitive control task (Colour Match) related to executive function but also learning. Indeed, overall, data indicated that all exercises were related primarily to measures of visual working memory, and to a lesser extent visual memory and executive functions. The pattern of relationships suggests that each exercise trains more than one cognitive domain.

TABLE 4
Means (and SD) for Primary Outcome Measures for the Baseline and Posttest Assessments

	Baseline				Posttest			
	Treatment		Waitlist		Treatment		Waitlist	
CANTAB	Mean	SD	Mean	SD	Mean	SD	Mean	SD
IED errors (adj.)	31.13	48.70	100.25	78.79	22.25	22.11	94.13	78.61
PAL errors (adj.)	33.13	31.62	98.50	67.50	28.63	30.28	91.75	71.72
PRM % correct	89.06	11.57	76.04	15.05	90.62	9.39	80.22	15.39
RVP A	0.87	0.07	0.85	0.09	0.90	0.05	0.79	0.13
SWM errors	41.13	11.74	62.13	25.73	34.13	17.28	55.33	21.53
SWM strategy	33.75	4.89	37.13	3.09	33.62	6.47	39.13	2.10

TABLE 5
Scores on the Computerised Training Tasks Over Sessions

Training exercise	Time 1	Time 2	Time 3	Time 4	*F* value (1,15)	*p* value
Birdwatching	0.350	0.501	0.814	0.996	170.70	< .001
Colour Match	0.622	0.721	0.807	0.946	25.30	< .001
Lost in Migration	0.479	0.820	0.847	0.926	45.88	< .001
Memory Match	0.718	0.728	0.864	0.861	5.17	.042
Raindrops	0.713	0.799	0.890	0.935	18.61	< .001
Spatial Speed Match	0.427	0.578	0.802	0.912	29.97	< .001

Note: Time 1 (sessions 1–4); Time 2 (sessions 5–8) Time 3 (sessions 9–12) Time 4 (sessions 13–16)
Scores provided are proportion of best score (where 1.00 equals best score).

Discussion

The purpose of this study was to evaluate the effectiveness of a computerised cognitive training program for older adults with MCI. Training was broadly based, focusing on attention, processing speed, visual memory and cognitive control. In general, participants in the training program demonstrated improved performance on the trained tasks over time, although this varied markedly across tasks. Using an RCT design, it was found that the training program led to a significant improvement on a measure of visual sustained attention when compared with waitlist control. No significant changes were noted on other primary outcome measures. Nor was there generalisation to self-reported memory functioning or perceptions of control over memory.

There are several possible reasons why generalisation beyond that reported here was not seen in this study, including factors such as the dose and sequencing of training, variations in task difficulty and the gap between the trained tasks and everyday life. However, before considering those issues, it could be argued that older adults with memory loss are simply unable to generalise trained skills of the kind utilised here. On this view, any improvements on trained exercises simply highlights a preserved learning capacity that would be better utilised using a cognitive rehabilitation approach applied to specific everyday tasks. However, evidence from the ACTIVE study (Ball et al., 2002; Willis et al., 2006) suggests otherwise. While participants in that study were nominally healthy elderly, Unverzagt et al., (2007) retrospectively identified a subset of participants as memory impaired (those who had cognitive test scores at baseline at least 1.5 *SD* below that expected). While they reported that these participants did not appear to benefit from training in memory strategies, there *was* evidence of benefit from other forms of training (e.g., reasoning training improved reasoning, processing speed training improved processing speed), suggesting that memory-impaired participants retain the capacity to transfer trained skills, at least on nonmemory domains.

Dose of Training

Another possible reason for the lack of generalisation across most outcome measures is that the dose of training received was too low. The dose of training is potentially an important issue as neuroplastic changes following cognitive stimulation require a range of processes that occur over different timeframes. Thus, a low dose of training may stimulate only relatively transient processes such as upregulation of neurotransmitters rather than medium and longer term changes such as neurogenesis, synaptogenesis and the formation of new neural networks (Valenzuela, Breakspear & Sachdev, 2007). In the literature there is currently no consensus as to what dose of training is required in order to see effects and the amount of training varies widely. Relatively brief cognitive training (600 minutes), a similar dose to that used in this study, has been shown to have transfer effects on a healthy elderly sample in the large scale ACTIVE study (Ball et al., 2002; Willis et al., 2006), whereas other studies have used a significantly larger dose. For example, the training program used by Barnes et al., (2009) consisted of relatively long sessions (100 minutes/day, 5 days/week) delivered in a shorter duration (6 weeks) a total dose of approximately 3000 minutes.

It is possible there was a dose–response effect in our study. As all the training exercises used here require visual attention skills, participants may have received a larger dose of visual attention training (the only measure to show change follow-

TABLE 6
Correlations Between Training Exercises and Neuropsychological Outcome Measures

CANTAB Measure	IED errors Set shifting	PAL errors Episodic visual memory	PRM per cent Visual memory	RVP A Visual attention	SWM errors Visual working memory	SWM strategy Visual working memory
Lumosity						
Birdwatching	**-.537*** **P = .032**	-.487 P = .056	.444 P = .085	.407 P = .117	**-.586*** **P = .017**	-.238 P = .375
Colour Match	**-.507*** **P = .045**	**-.580*** **P = .018**	.496 P = .051	.464 P = .070	**-.685**** **P = .003**	-.508* P = .045
Lost in Migration	**-.680**** P = .004	**-.627**** **P = .009**	**.616*** **P = .011**	.230 P = .391	**-.664**** **P = .005**	-.438 P = .090
Memory Match	-.479 p =.061	-.463 p = .071	**.630**** **P = .009**	.360 P = .171	**-.694**** **P = .003**	-.429 P = .098
Raindrops	-.469 P = .067	-.360 P = .171	**.654**** **P = .006**	.437 P = .091	**-.607*** **P = .013**	-.330 P = .212
Spatial Speed Match	**-.584*** P = .017	**-.546*** **P = .029**	.297 P = .264	.473 P = .064	**-.649**** **P = .006**	-.358 P = .173

Note: ** Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

ing training) when compared with other domains such as visual memory, processing speed, or divided attention. By implication, it is possible that the dose of training received on those other domains was simply too low to show effects in this population.

Task Complexity

The training exercises used in this study appeared to target several different cognitive domains as can be seen by the correlations with baseline CANTAB scores. This may have had unintended consequences as participants were faced with exercises that called upon a range of impaired skills simultaneously. For example, the training exercise that showed the least improvement with training (Memory Match) relies on intact processing speed, working memory and visual memory, domains that were often attenuated or impaired in this sample. Salthouse (1996) suggests that tasks requiring effective encoding and retrieval rely on intact working memory and processing speed, so problems with these domains may have had detrimental effects on learning and recall exercises.

Sequencing of Training

The problems with task complexity suggest that MCI participants may require training in non-memory domains prior to tackling complex memory exercises. In our study, memory tasks were given in the same session with executive tasks. This may have made participants more aware of the contrast in difficulty between exercises, leading to problems such as loss of motivation on those exercises or directing greater effort at exercises they found easier to master. This suggests that training may be better delivered in two phases, an initial phase where training focuses on executive skills (e.g., attention, processing speed, working memory) and a second phase where memory tasks are introduced. Training executive skills potentially has a range of benefits as these skills are useful for everyday tasks such as driving and planning. Intact executive skills may also aid individuals in compensating for memory loss.

Dissimilarity Between Training Exercises and Everyday Activities

Another possible explanation for the lack of generalisation across tasks or in everyday life may be the dissimilarity between training exercises and everyday activity. Computer training may be more likely to generalise if it focuses upon tasks that closely resemble daily life rather than the game-like environment of the cognitive training program used here. For example, Foreman, Stanton-Fraser, Wilson, Duffy, and Parnell (2005) asked a small sample of healthy elderly participants to explore a virtual shopping mall, and reported that this exercise led to greater accuracy in how well they could point out the direction in which certain locations

lay, perform tasks, navigate and make maps when taken to the same shopping mall in real life. This suggests that practising everyday memory tasks in a virtual environment may enhance transfer of training to real life.

Limitations and Future Directions

Some limitations of the study should be acknowledged. Firstly, the study was small and underpowered, which limited the ability to see real effects. The extent to whether improvement in visual attention was related to improvement in the treatment group rather than a decline in the waitlist group also requires replication. Given the small number of participants and the number of analyses conducted, the possibility of a Type I error cannot be entirely excluded. Secondly, while the reported improvement with practice on the trained tasks indicated that computerised cognitive training promotes learning, this promising finding awaits comparison using a normal elderly control group. This would enable us to quantify a normal level of performance on the training exercises against which the performance of our MCI sample could be compared. For example, in a study reported by Belleville et al. (2006), MCI participants were able to improve their level of performance to that commensurate with untrained normal elderly following training on memory strategies. Thirdly, participants completed the training at home, using their own computers. A more structured and standardised clinical environment may have enhanced the training experience. Adherence to the treatment schedule was variable, with most participants taking longer than anticipated to complete training (an average of 11.43 weeks vs. an anticipated 6–10 weeks) which may have diluted any effects.

Conclusion

This research demonstrates that a sample of older adults with MCI can improve their performance significantly when given repeated practice on computerised cognitive exercises. It also highlights some of the practical problems in delivering this form of cognitive training. It suggests that future research should examine more critically issues to do with the dose and sequencing of training to turn this nascent area of research into a valuable addition to clinical practice.

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