Preliminary evidence for the feasibility of at-home online cognitive training with older adults

Kathryn L. Gigler MS[a]
E: kathryn.gigler@gmail.com
Kelsey Blomeke BA[b]
Evelyn Shatil PhD[c]
Sandra Weintraub PhD[d]
Paul J. Reber PhD[a]
E: preber@northwestern.edu

[a]Department of Psychology, Northwestern University, Evanston, IL, USA; [b]Department of Psychology, University of Notre Dame, South Bend, IN, USA; [c]CogniFit™ Research, New York, NY, USA; [d]Department of Psychiatry and Behavioral Sciences, Cognitive Neurology and Alzheimer's Disease Center, Northwestern University, Evanston, IL, USA

K.L. Gigler, K. Blomeke, E. Shatil, S. Weintraub, P.J. Reber, Preliminary evidence for the feasibility of at-home online cognitive training with older adults, Gerontechnology 2013;12(1):26-35; doi:10.4017/gt.2013.12.1.007.00 Increased levels of cognitive activity may improve general cognitive function in older adults and potentially increase cognitive reserve, protecting against the onset of dementia associated with syndromes like Alzheimer's disease. To test the efficacy of cognitive training administered online, 18 participants (11 cognitively healthy; 7 mild cognitive impairment) were recruited from a clinical population of older adults to complete an online training intervention (CogniFit™). Before and after training, participants completed a separate battery of assessment measures, including measures of quality of life and competency at everyday activities, as well as a series of tests assessing cognitive function. Participants generally adhered to the online training protocol and completed a computerized assessment battery pre- and post-training. However, participants with mild cognitive impairment (MCI) were somewhat less likely to adhere to the protocol, suggesting that more direct contact is needed with this population in intervention research. Furthermore, participants demonstrated significant improvement on a measure of working memory and also in processing speed across several assessments, though these data are tentative, as no control data exist. These results, along with the generally good adherence observed, suggest that online cognitive training is feasible for this population and a potentially valuable tool for the wider dissemination of cognitive training.

Keywords: cognitive training, human factors, mild cognitive impairment

The relationship between cognitive activity and age-related cognitive decline has been framed as the cognitive reserve hypothesis[1,2], a theory which suggests that resistance to cognitive decline is positively correlated with cognitive activity across the lifespan. Indeed, individuals with more education[3], higher levels of lifetime educational complexity[4,5], and/or richer leisure time activities[6] all show later onset of the cognitive dysfunction and dementia associated with Alzheimer's disease than individuals lower on these measures[2]. These findings suggest that increasing cognitive reserve prior to the onset of AD neuropathology could allow individuals to maintain a higher level of cognitive functioning early on in disease progression, improving quality of life and reducing associated care costs. A key question is whether increasing cognitive activity in later life can still lead to increased cognitive reserve and improved cognitive functioning, and if so, how this increase in cognitive activity can be brought about in healthy and non-healthy older adults.

Several studies have investigated the question of the efficacy of cognitive interventions in older adults. The Advanced Cognitive Training in Vital Elderly (ACTIVE) study[7] examined a range of cognitive training protocols in a large population of older adults. Participants generally improved on tasks measuring trained domains, but there was limited evidence for general transfer to other cognitive abilities. The Improvement in Memory with Plasticity-based Adaptive Cognitive training (IMPACT) study[8] found benefits of training, although these were generally within trained auditory attention and memory tasks. However, several other large-scale studies have found that it is difficult to observe transfer to untrained cognitive tasks following cognitive training[9,10]. This has led to some debate over whether such interventions are effective in older adults[11,12]. However, a review of the literature on adults with mild cognitive impairment (MCI) in particular[13] found evidence of some promise, although results were somewhat mixed. While in some cases no transfer effects were found after training, significant improvements, notably in episodic memory function, have been observed[14,15]. Overall, the current evidence, though mixed, does suggest that improving cognitive reserve may be possible in older adults. This raises critical questions regarding how training effectiveness can be increased and how training effects transfer to general cognitive function. A potentially important element of increasing efficacy may be making training more consistently available in order to increase the intensity and frequency with which participants train, which in turn could lead to increased cognitive benefits.

The theory behind cognitive training interventions is that the approach relies on mechanisms of neuroplasticity serving basic learning processes, even in older adults. Reorganization that follows as a consequence of these learning processes has been hypothesized to take one of several possible forms. The neural scaffolding hypothesis, proposed by Park and Reuter-Lorenz[16], points to increased frontal activity associated with aging as a neuroprotective mechanism. This increased activity may serve as protective 'scaffolding', accounting for some of the declining function elsewhere in the brain and leading to changed patterns of neural activity. Somewhat similarly, the neural compensation hypothesis describes the differential reorganization of neural networks in cognitively successful versus unsuccessful aging, with low-performing older adults using the same unilateral networks as young adults, whereas high-performing older adults recruit bilateral networks[17]. Both of these hypotheses fit in with a suggested framework of adult cognitive plasticity[18] in which mismatch between neural organization and environmental demands can lead to changes in functional flexibility, a framework in which cognitive training could lead to the adaptation of cognitively optimal neural reorganization in older adults, resulting in better cognitive function.

If cognitive training can lead to cognitive improvements in older adults, ease of administration of the intervention is extremely important. A notable difference in approach between earlier large-scale studies was that the ACTIVE study used regular in-person group meetings, while the IMPACT study provided computers to participants for intensive, adaptive individual training. The approach used in the ACTIVE study likely provides some social benefits to participants, but is very labor-intensive to administer. In contrast, the IMPACT study is more easily administered, though only after providing computers to all participants. If effective cognitive training could be administered using an online interface via existing computational facilities to older adults, it eventually may be possible to provide widespread access at far lower costs. As a recent study examining video games in cognitive interventions found, adherence can vary across tasks and individuals, with low compliance sometimes occurring for even a previously-described beneficial task, relating to lack of enjoyment with this task[19]. This suggests that making a variety of tasks easily available is an essential component of successful cognitive interventions. Other studies have also utilized interactive computerized cognitive training in intervention work with older adults and have had varying degrees of success. Long-term improvements have been observed in older adults following computer-assisted cognitive training[20]. A randomized control study conducted with MCI patients indicated that patients benefited cognitively from participation in a computer-based cognitive training program, and interactive computer training has been well-received by Alzheimer's patients[21,22]. However, all of these interventions were conducted in-person, with researchers aiding participants with use of computers. The Pew Internet and American Life Project has found that over half of adults age 65 and older are now online, and as the baby boom cohort ages, this number continues to rise[23]. With rising interest in online technology for older adults, as well as increased availability of internet access, online administration of these protocols could lead to improved ease and increased access for researchers and participants[24]. This approach also raises questions about the usability and comfort of older adults with this type of technology, topics of increasing importance as computers and the internet become more widely integrated with human behavior[25].

If effective cognitive training can be deployed via this approach, an opportunity for widespread administration of cognitive training interventions to improve aging outcomes becomes available. Internet-based cognitive training would allow the deployment of a non-platform-specific protocol, easing the equipment requirements of older adults not overly familiar with the technology. Furthermore, as training interventions require large investments of both researcher and participant time and effort, online administration would greatly facilitate expanded research in this area. Online administration of cognitive training could lead to the enrollment of significantly more individuals in training protocols, leading to larger sample sizes and an increased ability to run randomized control trials of cognitive training, something greatly needed in this field. Online cognitive training would also improve data collection through instant and widespread upload, allowing researchers to instantly access participant performance. This would allow better and more accurate feedback, as well as improved adaptation of training level difficulty. It would also allow researchers to track participant engagement in training in real-time.

In the current study, cognitive training was administered via internet-based access to a fully online-based personalized training program from CogniFit™ (CogniFit Ltd, New York, USA). We recruited participants both with and without episodic memory dysfunction in order to see whether these two groups would be able to successfully complete online training and whether both groups would benefit from the intervention. To take advantage of the potential benefits of online cognitive training, it will be necessary to verify that this training approach produces reasonable levels of participant compliance with online training. To measure potential transfer, improvements in cognitive processing were examined with assessments that show transfer novel measures of untrained cognitive function collected in separate in-person sessions. This study therefore aimed to test the feasibility of an online training protocol in both healthy and non-healthy (MCI) older adults and to explore the potential training benefits of such an intervention.

Methods

Participants

Eleven cognitively healthy older adults (9 women) and 7 patients (4 women) exhibiting memory dysfunction were recruited from Northwestern University's Cognitive Neurology and Alzheimer's Disease Center (CNADC) (*Table 1*). All participants at the CNADC Clinical Core registry are engaged in longitudinal research, including annual cognitive assessments drawn from the Uniform Data Set neuropsychological battery (UDS[26]), though participants were an average of 89.33 days (SE=16.33) away from the last assessment of the UDS at the time of their enrollment in the current study. Healthy participants scored within normal range on the UDS battery and had no history of cognitive impairment. All but one memory-impaired participant had a diagnosis of amnestic MCI (which by CNADC criteria requires a clinical dementia rating of 0.5), no deficits on the Functional Assessment Questionnaire[27], and classification as amnestic without other cognitive impairments). The final participant included in the memory impairment group was considered as amnestic by examination, and was clinically diagnosed with probable frontotemporal dementia (FTD). To participate in the study, individuals were required to have access to a computer with internet for the duration of the training protocol either at home or in another location (excepting the FTD patient, who came into the laboratory for training). The Institutional Review Board of Northwestern University approved this study, and all participants signed an informed consent prior to beginning participation. Participants received $20 as compensation for their participation in this study.

Materials and procedure

All participants were informed that participation would include the training protocol (completed in any location with internet access) and two assessments at our laboratory, completed before and after training. Each assessment session lasted for approximately 1.5 hours and the training protocol itself consisted of 17 separate half-hour sessions. The entire protocol was designed to be completed over a period of eight to ten weeks, with participants completing an average of two sessions each week CogniFit™ provided our laboratory with adherence data on a week-by-week basis. If more than 1.5 weeks went by without a participant logging in, a researcher would call the participant to check in on how s/he was faring with the protocol.

*Table 1. Demographic information is presented for all participants; MMSE=Mini Mental Status Examination; RAVLT=Rey Auditory Verbal Learning Test; SE=Standard Error; *=not available for one healthy person and two patients*

Variable	Healthy persons (n=11; 9 females)			Patients (n=7; 4 females)		
	Mean	SE	Range	Mean	SE	Range
Age	75.5	1.54	66.23-86.88	76.4	2.81	68.62-85.80
Years of education	17.4	0.54	14-20	15.9	1.08	12-20
MMSE*	29.4	0.34	27-30	29.0	0.63	26-30
Digit span-forward*	7.2	0.28	6-8	6.7	0.33	6-8
Digit symbol substitution*	45.9	3.76	26-61	44.0	4.92	27-59
RAVLT total	60.1	2.41	51-72	37.6	4.09	25-47
Immediate recall	13.7	0.45	12-15	7.0	1.92	3-13
Delayed recall	13.2	0.62	10-15	6.2	2.01	2-12
Recognition	29.6	0.23	28-30	27.2	1.20	23-30

Assessment measures

CogState assessment battery

The CogState assessment battery includes a variety of tasks intended to measure cognitive function and has been validated in populations of both healthy adults and adults with MCI[28]. As the testing battery is fully computerized, detailed information regarding accuracy, error rate, and reaction time is available for all tasks in the battery. The battery has also been found reasonably resistant to practice effects and its measures acceptably stable for test-retest protocols[29,30]. For the current study, cognitive tasks measured processing speed (via a detection task), attention (an identification task), working memory (a one-back task), visual motor function (a chase task), executive function (a set-shifting task) and memory (a maze learning task, a paired associate learning task and a list learning task). This battery was selected for use for the majority of participants because of its differences from the UDS battery, with which the participants had greater familiarity. As stated, many participants were involved in longitudinal testing involving repeated testing, so the selection of a testing battery (i) different from that with which they were familiar and (ii) resistant to test-retest effects was essential.

OTDL-R

The OTDL (Observed Tasks of Daily Living-Revised) is intended to measure the ability of older adults to complete everyday tasks within a laboratory setting[31,32]. Examples of tasks include identifying correct dosage on medication bottles, using the telephone, and filling out health information forms. The OTDL consists of nine separate tasks and 13 questions participants answer. Each question also has subcomponents, resulting in a total of 28 items to be scored. Item scores are summed and overall scores can range from 0-82.

QOL-AD

The QOL (Quality of Life Questionnaire in Alzheimer's Disease) is a self-report measure of participants' own subjective satisfaction with their quality of life and was created using input from patients, caregivers and researchers[33]. The measure includes 13 items, each of which lists a domain in which participants (and/or caregivers) rate current satisfaction. Domains include family life, financial health, memory, and physical health. Descriptive ratings (poor, fair, good, excellent) are converted to numerical values and summed, with possible scores ranging from 13-52.

IADL

The IADL (Instrumental Activities of Daily Life Questionnaire) is a self-report, and when applicable, also spouse-report questionnaire designed to quantify the extent to which older adults remain able to complete daily tasks on their own[34]. Eight separate activities are included on the inventory, including laundry, food preparation, housekeeping, shopping and finances. A point is awarded for each task at which a participant is rated acceptably competent, with possible scores ranging from 0-8.

CogniFit assessment battery

The CogniFit training program, as supplied by the company of one of the authors, begins with an evaluation of a wide range of cognitive abilities. Participants complete 15 tasks intended to assess a total of 20 cognitive functions. Each of the 20 separate cognitive functions receives a score calculated from the raw scores yielded by the 15 assessment tasks. Each of these function scores is a composite of raw assessment scores, which are calculated by weights determined by factor analysis (information courtesy of CogniFit™; further examples of this assessment weighting in practice[35-37]). The overall evaluation has been validated against several major neuropsychological tests, including Raven's Progressive Matrices, the Cambridge Neuropsychological Test Automated Battery, and the Wisconsin Card Sorting Test[38]. The CogniFit™ assessment battery is game-like in nature and differs from the CogState assessment battery in that it assesses participants on a variety of cognitive components within each task and derives cognitive-specific scores across tests. In contrast, each CogState assessment task measures one aspect of cognitive function at a time.

Participants completed the CogniFit™ assessment battery before and after their completion of the training protocol. For the current study, this assessment was also used to measure improvement on the CogniFit™ training tasks.

Training protocol

CogniFit™ was used for the training protocol due to its validation as a training program in several populations with cognitive deficits, including older adults and individuals with multiple sclerosis, dyslexia, bipolar disorder, and insomnia[35-37,39-42]. The CogniFit™ training program is a computer-based protocol consisting of two brief assessments (described above) and 17 training sessions. Each of the 17 sessions lasts between 20 and 30 minutes and includes three separate cognitive tasks. There are a total of 12 cognitive tasks in the training battery, all of which are intended to improve the cognitive functions tested via the CogniFit™ assessment battery. Tasks targeting working memory, auditory processing and visual function are examples of the tasks completed during the training sessions. All training sessions are completed online and require participants to use both a mouse and keyboard.

Training is personalized for each participant based on performance on the pre-training assessment. While all participants receive practice on all 12 training tasks, the amount of time spent on each task during training is dependent on assessment ability scores. Tasks are designed to be game-like, in order to be enjoyable and facilitate adherence to the training protocol. For example, one working memory task in the training battery is similar to the arcade game 'Whack-A-Mole'. In this task,

*Table 2. Data on completion of pre- and post-assessments are presented here; CF=CogniFit™; CS=CogState; OTDL=Observed Tasks of Daily Living; IADL=Instrumental Activities of Daily Living; QOL=Quality of Life-Alzheimer Disease; *=not available for one healthy person and two patients*

Item	Healthy persons (n=11)		Patients (n=7)	
	Pre-test	**Post-test***	**Pre-test**	**Post-test***
CF	11	10	7	5
CS*	7	11	4	3
OTDL	11	11	6	3
IADL	10	10	7	4
QOL-AD	11	11	7	4
Sessions	16.0		12.3	

a grid of mole holes is presented on the computer screen. A series of moles will pop up from the holes, and the participant must hold the order of these appearances in mind. After a brief delay interval, the participant must click the moles in the order in which they appeared, stressing working memory. As the participant improves at the task, more moles appear. An example of an auditory processing task is one intended to test auditory discrimination. In this task, tones of different lengths and pitches are presented as coming from various household machines, such as a telephone. After two tones have been presented, the participant is asked to make a judgment on either length or pitch. The participant must determine between two tones which is the longer or shorter, if asked to judge length, and which is the higher or lower, if asked to judge pitch. Participants' performance is scored for accuracy of judgment on length and pitch. Finally, an example of a visual performance task involves the viewing of world flags. A flag will be presented in the middle of the screen, with two similar flags flanking it. The participant must determine whether either of the flanking flags matches the center target flag and must click on the matching flag. If there is no match, the participant must click on the target flag to indicate that no visual match was found. Performance is scored based on the number of correct matches/non-matches identified.

Results

Overall, training and assessment compliance was generally better for the healthy controls (10/11) than for the patients, only two of whom (of 7 total) completed the training and both pre and post-training assessments, χ^2 (1,18)=9.73, $p<0.01$ (*Table 2*). Participants who completed the training protocol did so in an average of 82.6 days (SE=9.9), or 11.8 weeks, with participants completing training sessions ranging from as rapidly as once a day to as slowly as once a week.

Of the 18 participants who enrolled in the study, two participants did not engage with the online training (both MCI) and one completed only five of the targeted 17 training sessions (healthy control). The healthy participant who failed to engage with the training informed researchers that she would not complete the training sessions, but that she would come in for post-assessment. The other non-compliant participants continually responded to the reminder phone calls by saying that they intended to begin training sessions soon, implying a lack of motivation and/or interest. The healthy participant who only completed five sessions reported the training sessions as unentertaining and/or boring. However, exit interview data indicate that participants who successfully completed training found it "challenging and interesting". These participants also reported that they enjoyed working through the sessions, feeling that they "improved throughout training" and found the CogniFit™ training protocol "fun and helpful". Of note, the MCI individuals who did not complete the study both indicated that they "did not appreciate negative feedback from the program". An additional three participants (all MCI) did not return for a second post-training assessment session following completion of online training, indicating either poor health (two) or long-term travel plans (one).

Table 3. CogniFit™ assessment results for healthy persons and patients who completed both pre and post-tests; Means as z-scores; p<0.05 in bold type; 0.05<p<0.10 in italics

Measure	Pre-test		Post-test		Change	p-value
	Mean	SE	Mean	SE		
Auditory memory span	-0.47	0.24	0.08	0.25	0.56	**0.04**
Eye-hand coordination	-1.29	0.56	-0.75	0.21	0.54	**0.35**
Working memory	-0.87	0.30	-0.39	0.30	0.49	**< 0.01**
Visual memory	-1.00	0.31	-0.64	0.26	0.36	**0.04**
Auditory processing	-0.57	0.25	-0.23	0.13	0.34	*0.07*
General memory	-0.68	0.30	-0.37	0.40	0.30	0.21
Processing speed	0.69	0.19	0.41	0.17	-0.28	*0.09*
Divided attention	-1.29	0.24	-1.05	0.24	0.24	0.28
Visual performance	-0.85	0.36	-0.64	0.29	0.21	0.26
Reaction time	-0.73	0.18	-0.55	0.15	0.18	0.18
Naming	-0.83	0.25	-0.66	0.25	0.17	0.11
Recognition	-0.37	0.29	-0.53	0.34	-0.15	0.49
Visual scanning	-0.96	0.25	-1.10	0.24	-0.13	0.60
Planning	-0.58	0.32	-0.70	0.26	-0.12	0.56
Shifting	-1.08	0.17	-0.96	0.21	0.11	0.53
Spatial performance	-0.82	0.53	-0.89	0.42	-0.10	0.84
Monitoring	-0.72	0.31	-0.64	0.38	0.08	0.66
Visual memory span	-0.82	0.34	-0.74	0.40	0.08	0.72
Inhibition	-0.79	0.27	-0.76	0.30	0.03	0.85
Updating	-1.13	0.21	-1.13	0.26	0.00	> 0.99

Table 4. CogState assessment results for healthy persons and patients who completed both pre- and post-tests; 0.05<p<0.10 in italics

Measure means	Pre-test		Post-test		Change	p-value
	Mean	SE	Mean	SE		
Paired associates learning (# errors)	141.00	10.26	125.54	15.57	15.46	0.54
PAL speed (log RT)	3.740	0.044	3.740	0.047	<0.001	0.99
Set shifting (# errors)	20.10	2.90	22.85	5.51	-2.75	0.81
Set shifting speed (log RT)	2.974	0.046	2.916	0.047	0.057	*0.06*
1-back (# errors)	7.37	2.71	5.40	1.97	1.97	*0.06*
1-back speed (log RT)	2.939	0.033	2.919	0.029	0.030	0.20
Identification (# errors)	5.36	3.16	3.60	2.53	1.76	0.11
Identification speed (log RT)	2.775	0.020	2.756	0.011	0.029	*0.08*
Chase (# correct moves)	24.18	2.33	25.33	2.56	1.52	0.54
Chase speed (moves/second)	0.81	0.08	0.87	0.06	0.06	0.54
Detection (# errors)	1.73	0.86	0.90	0.41	0.83	0.63
Detection speed (log RT)	2.561	0.031	2.580	0.032	-0.016	0.34
List learning (items recalled)	24.00	2.08	23.21	1.48	-0.79	*0.08*
Processing speed (composite score)	2.987	0.019	2.957	0.020	0.03	**0.03**
List learning delayed recall (items recalled)	7.45	1.12	7.57	0.88	0.12	0.20

Post-training cognitive assessments within CogniFit™ for two participants (both MCI) could not be retrieved due to technical issues. Participants completing both assessments showed improvement on 16 of 20 domains (*Table 3*).

The degree of improvement was reliable for three tests: auditory memory span, t(11)=2.38, p<0.03; visual memory, t(9)=2.38, p=0.04; and working memory, t(8)=3.60, p<0.05. For the auditory memory span and working memory tasks, the gains were evident for both the healthy controls (auditory span, M=0.56 SD gained, SE=0.31; working memory, M=0.53 SD gained, SE=0.17) and patients (auditory span, M=0.66 SD gained, SE=0.20 working memory, M=0.32 SD gained, SE=0.04). Improvement in the visual memory task was numerically greater for healthy controls (M=0.52, SE=0.16) than for the patients (M=0.03, SE=0.25).

Cognitive transfer was measured by performance on the CogState assessment battery, which evaluates performance in similar cognitive domains but with a completely separate set of assessment measures. A trend towards improvement was observed on CogState's measure of working memory, though a downwards trend in verbal memory was also observed (*Table 4*). As trends towards improvement on several processing speed measures (identification and set shifting: *Table 4*) were found, a composite measure of individual processing speed (log RT) scores from the attention, working memory, and executive function tasks was calculated, in order to assess overall general improvement in processing speed. This aggregate processing speed measure showed a reliable increase following training, t(7)=2.73, p<0.03, indicating that training led to a slight but statistically significant increase in general processing speed.

Table 5. Questionnaire and survey data for healthy persons and patients who completed all questionnaires; IADL=Instrumental Activities of Daily Living; OTDL=Observed Tasks of Daily Living; QOL-AD=Quality of Life in Alzheimer Disease; Means in scores per published instructions of each measure

Measure	Pre-test		Post-test		Change	p-value
	Mean	SE	Mean	SE		
IADL	8.00	0.00	8.00	0.00	0.00	0.99
OTDL	77.71	0.97	79.64	1.06	1.07	0.14
QOL-AD	39.50	1.25	41.53	1.40	1.00	0.25

Healthy participants had near-ceiling levels of performance for the IADL and OTDL both before and after training (*Table 5*). No difference in score was found for any participant on the IADL from pre- to post-assessment. Scores on the OTDL improved numerically for all participants from the pre-test (M=77.7, SD=4.0, SE=0.97) to the post-test (M=79.6, SD=3.98, SE=1.06), although the improvement was not reliable, t(13)=1.59, ns. However, the two patients who completed the OTDL inventory both before and after training both demonstrated some improvement on this measure, with scores increasing from 78 to 82 and from 79 to 83. While these data are from only two patients, this result suggests that, at least on the level of the case study, that the cognitive gains observed on the CogniFit™ and CogState measures may have led to improvement in some activities of daily life. Scores on the QoL-AD improved numerically from pre-assessment (patient M=39.14, SE=2.43; healthy M=39.73, SE=1.45) to post-assessment (patient M=42.75, SE=3.07; healthy M=41.09, SE=1.63), but this difference was not reliable, t(13)=1.12, ns.

Discussion

Compliance with the online training protocol for the cognitively healthy older adults was good, with 10 of 11 participants completing all training sessions and all 11 participants returning for post-training assessments. These data suggest that online cognitive training may be an effective way to engage older adults with cognitive training programs with less in-person reinforcement from research personnel. Fewer MCI individuals enrolled in the study than healthy individuals and participants with MCI were significantly less likely to complete training and return for the post-training assessment. For memory-impaired patients, it appears that additional support may be needed in order to encourage them to complete the cognitive training protocol.

Additional support for these patients could be implemented throughout the training protocol via increased social contact with researchers and other study participants. It may be useful in future studies to utilize a mix of online training with occasional group sessions supervised by research personnel (e.g., once per week). The group sessions would be intended to provide social support and encouragement and, if patients continued training at home, this approach would still lead to a large reduction of in-person hours required for cognitive training interventions. Alternatively, structured and regular contact via phone calls to participants might be either planned regularly or cued based on progression through the training protocol. It may be helpful to begin intervention as early as possible with these individuals and to provide additional support with the technologies that will be used during training. With additional support, it seems that patients would be more likely to complete online training protocols, and that they would benefit cognitively from inclusion in such protocols.

Patients with MCI make up an excellent target population for training given their high risk of development of AD and relatively intact cognitive status. However, these patients are generally aware that their cognitive functioning is declining and this may present a challenge for designing training interventions. Previous work suggests that the adjustability of the difficulty on training tasks is important for maximizing training gains[43,44] and that training should be completed at high levels of difficulty for best effect. However, this necessarily leads to more incorrect responses and to the potential for negative feedback that may be discouraging. While somewhat speculative given the small sample of patients with MCI, the levels of difficulty used in training may need to be carefully fine-tuned for patients with cognitive dysfunction and feedback may need to be designed to focus on positive results and success. Of note, the similarly low rate of return for the post-training assessment by patients in our study may also reflect a sense of poor performance on these tasks that measure general cognitive function. However, exit interview data from patients successfully completing the protocol demonstrate that they felt it was as effective as did healthy participants.

As no control group (either active or waitlist/no-treatment) was available for comparison, the data on improved cognitive functioning should be regarded as 'open trial' data and a mere first step towards more firmly establishing the benefit of online cognitive training with older adults and memory-impaired patients. The current findings do not rule out the hypothesis that participants may have expected the training to provide cognitive benefits and were therefore motivated to perform better on the post-training assessments[45,46]. However, the non-CogniFit™ assessment battery used, CogState, is one that is reasonably resistant to test-retest effects, particularly in non-healthy older adults, and therefore may represent real improvement in cognitive performance for trained participants[30,47]. In addition, gains on the CogniFit™ assessment at least demonstrate that participants were improving upon the specific tasks trained, a necessary precursor to exhibiting the goal of distant transfer to both general cognitive function and activities of daily life.

Several measures of performance within the CogniFit™ training and assessment battery exhibited reliable gains, though retest effects cannot be ruled out. In particular, measures associated with working memory and auditory memory span increased after training. These findings show tentative support for recent reports stating that cognitive training focused on working memory tasks can lead to cognitive improvement[44]. Additionally, the tentative, yet reliable improvement on the composite measure of processing speed derived from the CogState battery is consistent with the gains in working memory as these two measures are often found to be highly inter-related[48]. While the goals of cognitive training programs include the improvement of quality of life in all older adults, robust gains on these measures have been fairly difficult to achieve reliably in prior studies[7]. As described, several participants stated during exit interviews that the training seemed helpful to them, and it is not clear if this reflects a placebo effect of training, or if more sensitive measures of functional outcomes than those used here would have demonstrated the practical value of the intervention.

In terms of accessibility, it is encouraging that participants in our sample were willing to enroll in an online training study, and agreed to complete training sessions wherever internet access was available. While our sample completed their training sessions largely at home, locations with internet access are often already incorporated into the lives of older adults (e.g., library), so it is likely that individuals would be interested in participating in internet-based cognitive training research even if they are offline at home. While equipment may be a concern in some cases (e.g., the mouse and keyboard required by CogniFit™), necessary devices may be routinely provided to participants at extremely low cost to researchers. For example, age-related decline in hearing is common in older adults, and so headphones may be provided to participants, with instructions to make sure that volume is at a high level, and that headphones are worn. It may be possible at pre-assessment to take into consideration sight or hearing impairments, and to provide tasks with larger font and/or headphones as required. Such provisions will improve the quality of the intervention, and such impairments must still be taken into consideration when planning and analyzing interventions, along with such factors as internet speed and lag time, which may affect reaction time data. Furthermore, the online nature of programs such as CogniFit™, run via software such as Java, means that they may be accessible via a variety of platforms and devices (e.g., Windows, Mac, Android). If resources for such device distribution are not available, online training may be conducted using a variety of testing platforms, including touch-screen devices (which, like the iPad, may be hooked up to keyboard devices) and/or flexible software packages, such as Java, which may be run on a variety of devices. Such seemingly distant possibilities are now a reality, and the expansion of internet-based cognitive training research on older adults could be conducted with increased ease as a variety of different internet and accessibility technologies continue to improve.

One final advantage to internet-based cognitive training is the researcher's ability to track the progress of older adults through the training protocol in real time as a marker of general cognitive functioning. Online cognitive testing scores may not track only gains, but also cognitive decline, through the tracking of health events of participants inferred from protocol adherence. For example, a participant in regular cognitive training who is negatively affected by a new medication might exhibit a decline in performance on training tasks, and this decline could be used as a diagnostic for the effects of the medication on the participant. Training protocols available from home on a regular basis may therefore not only support cognitive enhancement/or slow down cognitive decline, but may also provide a means of consistent monitoring of cognitive function for participants, especially patients at risk of cognitive decline. Internet inventions will make such continuous updates on progress and condition ever more feasible.

Overall, the results of this study suggest that online cognitive training is a viable alternative to in-person training and should not only rely on providing computers to all participants. For memory-impaired patients or others already experiencing cognitive decline, it may be necessary to explore additional mechanisms, such as remote contact or social structure, in order to encourage adherence to the training protocol. However, the data indicate a generally high level of enthusiasm in online cognitive training from older adults and a willingness to complete both training sessions and assessment batteries, though adherence may itself be related to both interest in the training itself and belief in whether it will be effective[19]. As internet technologies become further integrated into the lives of people across the lifespan[23], it seems likely that online training will become not only more accessible, but also more desirable, for older adults. The results of the current study suggest that this type of training approach holds merit as a feasible alternative for cognitive training studies. Beyond further exploration of online training studies with different populations, future studies should test the efficacy of online training as an intervention tool for researchers, and a training protocol identified as supporting transfer enhanced through online administration.

Acknowledgements
Funding for this study was provided by Northwestern University's Alzheimer's Disease Center, Award #AG1385. CogniFit™ software was provided free of charge to Paul Reber for use by the participants.

References

1. Whalley LJ, Deary IJ, Appleton CL, Starr JM. Cognitive reserve and the neurobiology of cognitive aging. Ageing Research Reviews 2004;3(4):369-382; doi:10.1016/j.arr.2004.06.001
2. Stern, Y. Cognitive reserve and Alzheimer disease. Alzheimer Disease and Associated Disorders 2006;20(2):112-117; doi:10.1097/01.wad.0000213815.20177.19
3. Roe CM, Xiong C, Miller JP, Morris JC. Education and Alzheimer disease without dementia. Neurology 2007;68(3):223-228; doi:10.1212/01.wnl.0000251303.50459.8a
4. Andel R, Kareholt I, Parker MG, Thorslund M, Gatz M. Complexity of primary lifetime occupation and cognition in advanced old age. Journal of Aging and Health 2007;19(3):397-417; doi:10.1177/0898264307300171
5. Karp A, Ross A, Parker M, Wang HX, Winblad B, Fratiglioni L. Mentally stimulating activities at work during midlife and dementia risk after age 75. American Journal of Geriatric Psychiatry 2009;17(3):227-236; doi:10.1097/

JGP.0b013e318190b691
6. Fratiglioni L, Paillard-Borg S, Winblad B. An active and socially integrated lifestyle in late life might protect against dementia. Lancet Neurology 2004;3(6):343-363; doi:10.1016/S1474-4422(04)00767-7
7. Ball K, Berch DB, Helmers KF, Jobe JB, Leveck MD, Marsiske M, Morris JN, Rebok GW, Smith DM, Tennstedt SL, Unverzagt FW, Willis SL. Effects of cognitive training interventions with older adults: A randomized controlled trial. Journal of the American Medical Association 2002;288(18):2271-2281; doi:10.1001/jama.288.18.2271
8. Smith GE, Housen P, Yaffe K, Ruff R, Kennison RF, Mahncke HW, Zelinski EM. A cognitive training program based on principles of brain plasticity: results from IMPACT. Journal of the American Geriatrics Society 2009;57(4):594-603; doi:10.1111/j.1532-5415.2008.02167.x
9. Ackerman PL, Kanfer R, Calderwood C. Use it or lose it?: Wii brain practice and reading for domain knowledge. Psychology and Aging 2011;25(4):753-766; doi: 10.1037/a0019277
10. Owen AM, Hampshire A, Grahn JA, Stenton R, Dajani S, Burns AS, Howard RJ, Ballard CG. Putting brain training to the test. Nature 2010;465(7299):775-778; doi:10.1038/nature09042
11. Salthouse TA. Mental exercise and mental aging: evaluating the validity of the "use it or lose it" hypothesis. Perspectives in Psychological Science 2006;1(1):68-87; doi:10.1111/j.1745-6916.2006.00005.x
12. Schooler C. Use it- and keep it, longer, probably: A reply to Salthouse (2006). Perspectives in Psychological Science 2006;2(1):24-29; doi:10.1111/j.1745-6916.2007.00026.x
13. Jean L, Bergeron ME. Cognitive intervention programs for individuals with mild cognitive impairment: A systematic review of the literature. American Journal of Geriatric Psychiatry 2010;18(4):281-296; doi:10.1097/JGP.0b013e3181c37ce9
14. Belleville S, Gilbert B, Fontaine F. Improvement of episodic memory in persons with mild cognitive impairment and healthy older adults: evidence from a cognitive intervention program. Dementia and Geriatric Cognitive Disorders 2006;23(3):486-499; doi:10.1097/WAD.0b013e31819c6137
15. Rapp S, Brenes G, Marsh AP. Memory enhancement training for older adults with mild cognitive impairment: a preliminary study. Aging and Mental Health 2002;6(1):5-11; doi:10.1080/13607860120101077
16. Park D, Reuter-Lorenz P. The adaptive brain: Aging and neurocognitive scaffolding. Annual Review of Psychology 2009;60:173-196; doi:10.1146/annurev.psych.59.103006.093656
17. Cabeza R, Anderson ND, Locantore JK, McIntosh AR. Aging gracefully: compensatory brain activity in high-performing older adults. NeuroImage 2002;17(3):1394-1402; doi:10.1006/nimg.2002.1280
18. Lovden M, Backman L, Lindenberger U, Schafer S, Schmiedek. A theoretical framework for the study of adult cognitive plasticity. Psychological Bulletin 2010;136(4):659-676; doi:10.1037/a0020080
19. Boot WR, Champion M, Blakely DP, Wright T, Souders DJ, Charness N. Video games as a means to reduce age-related cognitive decline: attitudes, compliance, and effectiveness. Frontiers in Psychology 2013;4(31):1-16; doi:10.3389/fpsyg.2013.00031
20. Gunther VK, Schafer P, Holzner BJ, Kemmler GW. Long-term improvements in cognitive performance through computer-assisted cognitive training: a pilot study in a residential home for older people. Aging and Mental Health 2003;7(3):200-206; doi:10.1080/1360786031000101175
21. Barnes DE, Yaffe K, Belfor N, Jagust WJ, DeCarli C, Reed BR, Kramer JH. Computer-based cognitive training for mild cognitive impairment: Results from a pilot randomized, controlled trial. Alzheimer Diseases and Associated Disorders 2009;23(3):205-210; doi:10.1097/WAD.0b013e31819c6137
22. Hofmann M, Hock C, Kuhler A, Muller-Spahn F. Interactive computer-based cognitive training in patients with Alzheimer's disease. Journal of Psychiatric Research 1996;30(6):493-501; doi:S0022395696000362
23. Zickuhr K, Madden M. Older adults and internet use. A project of the Pew Research Center 2012 June 6:1-23; www.pewinternet.org/~/media/Files/Reports/2012/PIP_Older_adults_and_internet_use.pdf; retrieved July 1, 2013
24. Gates N, Valenzuela M. Cognitive exercise and its role in cognitive function in older adults. Current Psychiatry Reports 2010;12(1):20-27; doi:10.1007/s11920-009-0085-y
25. Wagner N, Hassanein K, Head M. Computer usage in older adults: A multi-disciplinary review. Computers in Human Behavior 2010;26(5):870-882; doi:10.1016/j.chb.2010.03.029
26. Weintraub S, Salmon D, Mercaldo N, Ferris F, Graff-Radford NR, Chui H, Cummings J, DeCarli C, Foster NL, Galasko D, Peskind E, Dietrich W, Beekly, DL, Kukull WA, Morris JC. The Alzheimer's disease center's Uniform Data Set (UDS): the neuropsychological test battery. Alzheimer Disease and Associated Disorders 2009;23(2):91-101; doi:10.1016/j.neuropsychologia.2008.12.006
27. Pfeffer RI, Kurosaki TT, Harrah CH, Chance JM, Filos S. Measurement of functional activities in older adults in the community. Journal of Gerontology 1982;37(3):323-329; doi:10.1093/geronj/37.3.323
28. Maruff P, Thomas E, Cysique L, Brew B, Collie A, Synder P, Pietrzak R. Validity of the CogState Brief Battery: relationship to standardized tests and sensitivity to cognitive impairment in mild traumatic brain injury, schizophrenia, and AIDS dementia complex. Archives of Clinical Neuropsychology 2009;24(2):165-178; doi:10.1093/arclin/acp010
29. Collie A, Maruff P, Darby D, McStephen

M. The effects of practice on the cognitive test performance of neurologically normal individuals assessed at brief test-retest intervals. Journal of the International Neuropsychological Society 2003;9(3):419-428; doi:10.10170S1355617703930074
30. Falleti MG, Maruff P, Collie A, Darby D. Practice effects associated with the repeated assessment of cognitive function using the CogState battery at 10-minute, one week and one month test-retest intervals. Journal of Clinical and Experimental Neuropsychology 2006;28(7):1095-1112; doi:10.1080/13803390500205718
31. Diehl MK, Marsiske M, Horgas AL, Rosenberg A, Saczynski JS, Willis SL. The Revised Observed Tasks of Daily Living: a performance-based assessment of everyday problem solving in older adults. Journal of Applied Gerontology 2005;24(3):211-230; doi:10.1177/0733464804273772
32. Diehl MK, Willis SL, Schaie KW. Everyday problem solving in older adults: observational assessment and cognitive correlates. Psychology and Aging 1995;10(3):478-491; doi:10.1037/0882-7974.10.3.478
33. Logsdon RG, Gibbons LE, McCurry SM, Teri L. Assessing quality of life in older adults with cognitive impairment. Psychosomatic Medicine 2002;64(3):510-519; www.psychosomaticmedicine.org/content/64/3/510.full; retrieved July 1, 2013
34. Lawton M, Brody E. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist 1969;9(3):179-186; doi:10.1093/geront/9.3_Part_1.179
35. Shatil E, Metzer Z, Horvitz O, Miller A. Home-based personalized cognitive training in MS patients: a study of adherence and cognitive performance. NeuroRehabilitation 2010;26:143-153; doi: 10.3233/NRE-2010-0546
36. Peretz C, Korczyn AD, Shatil E, Aharonson V, Birnboim S, Giladi N. Computer-based, personalized cognitive training versus classical computer games: a randomized double-blind prospective trial of cognitive stimulation. Neuroepidemiology 2011;36:91-99; doi:10.1159/000323950
37. Horowitz-Kraus T, Breznitz Z. Can the error detection mechanism benefit from training the working memory?: a comparison between dyslexics and controls (an ERP study). PloS ONE 2009;4(9); doi: 10.1371/journal.pone.0007141
38. Haimov I, Hanuka E, Horowitz Y. Chronic insomnia and cognitive functioning among older adults. Behavioral Sleep Medicine 2008;6(1):32-54; doi: 10.1080/15402000701796080
39. Shatil E. Does combined cognitive training and physical activity training enhance cognitive abilities more than either alone?: A four-condition randomized controlled trial among older adults. Frontiers in Aging Neuroscience 2013;March 26; doi:10.3389/fnagi.2013.00008
40. Verghese J, Mahoney J, Ambrose AF, Wang C, Holtzer R. Effect of cognitive remediation on gait in sedentary seniors. Journals of Gerontology: Series A: Biological Sciences and Medical Sciences 2010;65(12):1338-1343; doi:10.1093/gerona/glq127
41. Preiss M, Shatil E, Cermakova R, Cimermannova D, Flesher I. Personalized cognitive training in unipolar and bipolar disorder: a study of cognitive functioning. Frontiers in Human Neuroscience 2013;May 13; doi:10.3389/fnhum.2013.00108
42. Haimov I, Shatil, E. Cognitive training improves sleep quality and cognitive function among older adults with insomnia. PLoS ONE 2013;8(4); doi: 10.1371/journal.pone.0061390
43. Westerberg H, Hirvikoski T, Forssberg H, Klingberg T. Visuo-spatial working memory span: a sensitive measure of cognitive deficits in children with ADHD. Child Neuropsychology 2002;10(3):155-161; doi: 10.1076/jcen.24.6.781.8395
44. Morrison AB, Chein JM. Does working memory training work?: The promise and challenges of enhancing cognition by training working memory. Psychonomic Bulletin and Review 2011;18(1):46-60; doi: 10.3758/s13423-010-0034-0
45. Rabbitt P, Diggle P, Holland F, McInnes L. Practice and drop-out effects during a 17-year longitudinal study of cognitive aging. Journals of Gerontology: Series B: Psychological Sciences and Social Sciences 2004;59B(2):84-97; doi: 10.1093/geronb/59.2.P84
46. Shipstead Z, Redick TS, Engle, RW. Is working memory effective? Psychological Bulletin 2012;138(4):628-654; doi: 10.1037/a0027473
47. Hammers D, Spurgeon E, Ryan K, Persad C, Heidebrink J, Barbas N, Albin R, Frey K, Darby D, Giodani B. Reliability of a repeated cognitive assessment of dementia using a brief computerized battery. American Journal of Alzheimer Disease and Other Dementias 2011;26(4):326-233; doi:10.1177/1533317511411907
48. McCabe DP, Roediger HL, McDaniel MA, Balota DA, Hambrick DZ. The relationship between working memory capacity and executive functioning: evidence for a common executive attention construct. Neuropsychology 2010;24(2):222-243; doi: 10.1037/a0017619