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Mobile app learning in memory intervention for acquired brain injury: Neuropsychological associations of training duration

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ABSTRACT

Memory impairment is a common consequence of acquired brain injury, often leading to functional difficulties day-to-day and decreased independence. Memory Link is a theory-driven training programme for individuals with moderate-to-severe memory dysfunction, which enables the acquisition of digital device skills for functional compensation. The present study examined how neuropsychological functioning and initial training performance contribute to training duration in our outpatient memory rehabilitation programme. A retrospective chart review was conducted, extending 12 years into the past, yielding data from 37 eligible participants. All participants demonstrated skill learning of the calendar function in their digital device to the criterion point. The results showed that performance on neuropsychological tests of explicit memory (e.g., CVLT-II, BVMT-R), processing speed (e.g., Digit Symbol Coding, Trail Making sequencing), executive functioning (e.g., Trail Making switching), and perceptual ability (i.e., Block Design) were significantly associated with training duration to learn the core steps of calendar use. Furthermore, linear regression revealed that initial training performance was a significant predictor of training duration. Lastly, profile of cognitive impairment, with regard to severity of memory functioning and the presence of additional deficits, was found to be a significant factor contributing to how many training trials were required to learn application skills.

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Cognitive rehabilitation; memory intervention; memory impairment; implicit learning; skill acquisition

Introduction

Anterograde memory impairment, or difficulty forming new episodic memories, is a common consequence of brain injury broadly (Baddeley et al., 2002), and is known to be associated with many specific neurological

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conditions such as stroke, cerebral anoxia, tumour, epilepsy, encephalitis, Korsakoff's syndrome, and traumatic brain injury. When anterograde memory impairment is moderate to severe, individuals have significant difficulty learning and retaining new information, which can impact many aspects of daily life, compromise independence, and interfere with social and occupational functioning. In this study, we examine factors that are associated with performance on a memory training programme that is designed to alleviate problems of daily living.

The best evidence to date indicates that, for individuals with severe memory deficits, external compensations directly applied to functional activities should be the primary focus of cognitive rehabilitation (Cicerone et al., 2019). Paper-based memory aids such as notepads, calendars, and journals, are intuitive and commonplace and can be used to compensate for memory impairment. Technological memory aids, however, have a number of qualities that make them a superior choice for implementing compensatory strategies in a memory-impaired population: alert notifications can be set for prospective reminders, information is infinitely editable and searchable, events can be set to repeat, and the devices are very portable. Research directly contrasting technological vs. paper-based memory aids have provided support for the superiority of digital devices in improving functional memory (Dowds et al., 2011; Lannin et al., 2014; McDonald et al., 2011).

Commercial technologies first exhibited these advantages in the form of personal digital assistants (PDAs), though these have now been functionally replaced by modern smartphones and a near endless supply of downloadable software applications. The successful utilization of prosthetic technology to improve functional memory has been demonstrated by numerous studies and systematic reviews (Charters et al., 2015; De Joode et al., 2010; Ferguson et al., 2015). A meta-analysis on the topic revealed that prosthetic technology improved performance on everyday tasks requiring memory, with a large effect size of $d = 1.27$ (Jamieson et al., 2014).

Smartphones have reached widespread adoption in developed countries including among older adults, a group for which, in only five years following 2012, smartphone use has quadrupled in the United States (Anderson & Perrin, 2017). Although the technology is quite pervasive, many non-brain injured smartphone users do not rely on their devices as external memory aids. Thus, these individuals are left lacking the skillset or any kind of established strategy to compensate for memory impairment following a brain injury. Unfortunately, despite their benefits, digital prosthetic memory aids are somewhat less intuitive than paper-based methods, and for a memory impaired person, learning the large number of steps required to enter a single event in a calendar can be an insurmountable barrier. Restated, learning and memory impairments negatively affect the ability of individuals to adapt their behaviour to rely on smartphones for optimal memory compensation.

Our clinical service provides a theory-driven training programme for individuals with moderate to severe memory impairment that enables the use of commercial technologies such as smartphones (Richards et al., 2020; Svoboda & Richards, 2009). The memory intervention programme is based on multiple memory systems theory, and specifically on the idea that implicit memory is most often preserved following brain injury, permitting the learning of new skills (Corkin, 1968; Glisky & Schacter, 1987; Graf & Schacter, 1985; Milner et al., 1968; Moscovitch, 1984). Our method incorporates evidence-based instructional techniques to facilitate new learning (see Methods for details). Previously, it has been demonstrated that acquiring new skills of digital device use in anterograde amnesia is possible across a variety of aetiologies (Svoboda & Richards, 2009; Svoboda et al., 2012; Svoboda et al., 2010). Furthermore, it was shown that individuals with moderate-to-severe memory impairment continue to use their devices successfully as external memory aids to function more independently up to 19 months following the completion of training (Svoboda et al., 2015).

Though our intervention programme is effective for improving functional memory following acquired brain injury (ABI), individuals progress through the programme at different rates. In a sample of 10 brain injured participants, those classified as having a focal memory impairment completed the programme with a median of 69 training trials, compared with 191 training trials for those with more global cognitive impairment (Svoboda et al., 2012). The training duration difference observed in this sample identifies a central question: do cognitive abilities other than explicit memory processes play a role in the acquisition of new implicit skills? Knowledge of training duration has important implications with respect to client triage and determining training assignments for memory rehabilitation. It would also be useful to communicate to clients more accurate information about the expected time commitment necessary to complete training so that they may plan accordingly.

One theory proposes that the acquisition of new skills through implicit "procedural" learning does not occur independently of other cognitive abilities. According to the Adaptive Control of Thoughts model, procedural learning progresses through three different phases: cognitive, associative, and autonomous (Anderson, 1999). During the cognitive and associative phases, more complex cognitive skills such as executive control, are needed to support the acquisition of new skills before they can be established as completely automatic in the final phase. Though amnesic individuals are able to learn through implicit procedural routes, impediments to the acquisition process have been attributed to dysfunction of executive abilities (Butters et al., 1985) and episodic memory (Winter et al., 2001; Xu & Corkin, 2001). The research on cognitive procedural learning supports the involvement of multiple cognitive abilities during skill acquisition. It is unknown, however, to what extent various cognitive abilities scaffold the new learning of a meaningful functional skill in individuals with memory impairment due to ABI.

In the present study, we investigated various factors involved in skill acquisition through the implicit learning protocol of our memory intervention programme, applied to mobile application training on digital devices in a group of individuals with ABI. The memory intervention programme begins with training on core calendar application steps (identified as stage 1), which consist of entering and saving an event on the present day, with an alert notification. Once the client has learned how to do this without support on 98% of the steps, they are recognized as reaching our learning criterion and new steps are added on the subsequent session (e.g., entering future events). Our main goal was to determine whether neuropsychological variables and initial training performance would be prognostic of length of training. Secondly, we sought to characterize the learning process, and explore relationships between cognitive abilities and training performance. In objective 1, we examined whether cognitive performance predicted the number of trials to reach our learning criterion for the first training stage (core application steps) – reflecting learning speed. We hypothesized that measures of explicit memory and executive functioning would be most strongly associated with learning, based on the work discussed previously (see Butters et al., 1985; Winter et al., 2001; Xu & Corkin, 2001). In objective 2, we explored the learning of application steps (quantified as training performance) across the first 10 sessions, and then investigated whether initial/first session training performance (indicating the training start point) was predictive of the number of trials to reach the learning criterion. We hypothesized that as training progressed, mean independent step performance would increase and variability of this measure would decrease while the skillset was acquired. Furthermore, we hypothesized that initial training performance would predict the number of trials required to reach criterion in stage 1. In objective 3, we examined whether there was any relationship between cognitive abilities and initial training performance. We hypothesized that executive functioning performance would be associated with measures of learning.

Methods

Participants

With approval from the hospital's Research Ethics Board, neuropsychological and rehabilitative behavioural training data were retrospectively collected from clients who attended our memory intervention programme within the last 12 years. Client files were included in the final analyses if they were enrolled in the memory intervention programme during the study time period, had raw neuropsychological testing data available, had training data available, and successfully completed at least the first stage of training (core steps) in the use of a digital calendar application (see Figure 1 for a flowchart of the participant inclusion process). Thirty-seven individuals met inclusion criteria; all had acquired brain

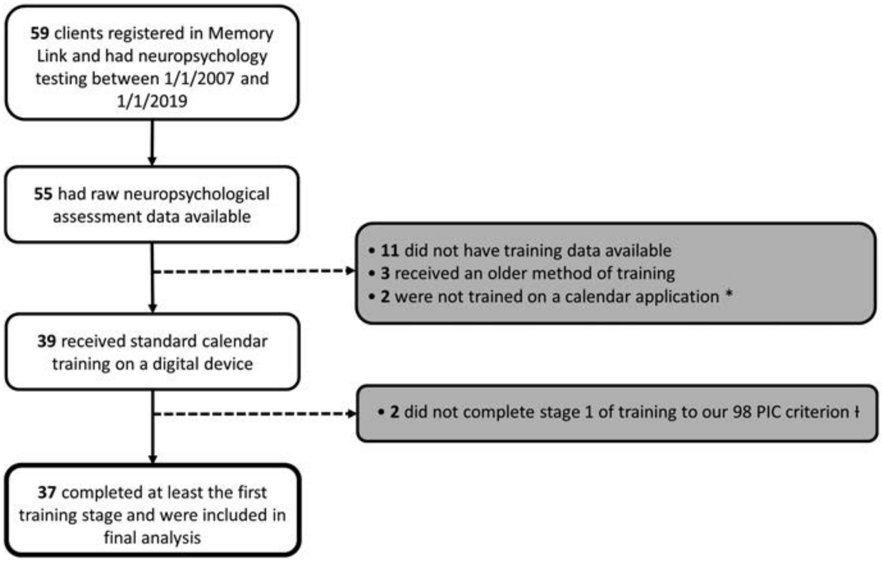

Figure 1. Flowchart of participant data inclusion/exclusion process. * These individuals were trained on a journal application instead of a calendar as it was determined to better suite their memory functioning needs. ƚ Individualized clinical decisions were made to progress through our programme without meeting stage 1 learning criterion in order to align with new intervention goals.

injuries including both traumatic and non-traumatic types (most commonly stroke, brain tumour, anoxic brain injury, or Wernicke-Korsakoff Encephalopathy; see Table 1), which were verified from their medical records. All individuals were referred to the programme based on significant functional memory difficulties, and these reports were confirmed through consultation interview before enrolment. If participants met inclusion criteria as above, but returned to the clinic years later for a second round of training on a new device, only the first training period was used. From these 37 charts, the sample consisted of 20 men and 17 women (mean age = 40.27 years, range = 16–62 years; see Table 1), and the following data were collected: demographic information (age, sex, years of education, brain injury etiology, mobile device used), raw neuropsychological testing data, and training data from digital calendar applications only.

Study design

A retrospective chart review study design was employed, which involved reviewing the files of previous memory intervention clients and extracting the relevant data contained within. Data were collected retrospectively from clients who attended our memory intervention programme between 1/1/2007 and 1/1/2019. These data from multiple client visits were analysed to examine the relationship between cognitive performance and training pattern and duration.

Table 1. Participant demographics and injury type (values are means ± standard deviation).

Injury type	*n*	Age (years)	Gender	Education (years)	Time from injury or diagnosis to onset of training (years)
Stroke (haemorrhagic or ischaemic)	9	43.7 ± 8.9	6M; 3F	12.9 ± 1.8	6.3 ± 7.5
Brain Tumour	7	32.6 ± 15.2	1M; 6F	14.3 ± 2.2	3.1 ± 3.8
Anoxic Brain Injury	7	44.1 ± 18.5	5M; 2F	14.0 ± 3.6	3.4 ± 4.3
Traumatic Brain Injury	7	39.0 ± 16.2	6M; 1F	14.1 ± 2.0	8.7 ± 8.5
Wernicke-Korsakoff Encephalopathy	3	45.7 ± 2.5	1M; 2F	14.0 ± 3.5	1.6 ± 0.5
Other	4	37.5 ± 17.2	1M; 3F	14.0 ± 3.7	7.0 ± 8.1
Totals:	*37*	*40.27 ± 14.23*	*20M; 17F*	*13.83 ± 2.56*	*5.28 ± 6.41*

Memory intervention

Memory Link is a memory intervention programme for individuals with moderate to severe memory impairment due to acquired brain injury. Our memory rehabilitation approach involves training on digital devices (e.g., smartphones) with the goal of enabling fluency in application use to compensate for functional memory difficulties, primarily prospective memory failures. Clients in the programme attend two sessions per week for an hour each, and usually accomplish 10 training trials during a single session. Programme completion time varies depending on a variety of factors (some being evaluated in the present study), but generally takes between 12 and 16 weeks on average.

Memory training initially focuses on the acquisition of procedural skills in using a digital device, primarily the calendar function. Learning how to operate a digital calendar independently is considered Phase 1 of training, which is followed by generalization to real-life situations in Phase 2. Within each phase, device skill learning is facilitated by gradually increasing the complexity of the skill learned using a stratified staging approach. For example, within Phase 1, calendar training begins with learning the steps to enter an event for the current day (stage 1), then progressing to entering a future event (stage 2), and then any additional functions such as attaching a note to the event (stage 3).

The Memory Link training method incorporates the principles of errorless learning (Wilson et al., 1994) and vanishing cues (Glisky et al., 1986) into what we refer to as an errorless-fading-of-cues protocol. Training begins in the first session with trainers fully demonstrating (scored as level 4 support) each step of an action (e.g., entering an event into the calendar) before allowing the client to participate while providing cuing support. As the trainee becomes more adept, the trainer fades the support provided using pointing and verbal prompts (level 3), pointing OR describing the step only (level 2), providing a verbal nudge (e.g., “what’s next?”; level 1), and then allowing the trainee to complete the step independently (level 0). During a trial, a trainer will step in with the appropriate level of support when they judge that the trainee runs the risk of committing an error without such intervention. Clients are explicitly asked not to practice on their own between sessions to maintain the errorless learning protocol, and we have found that they generally adhere to this rule. Progression to the next stage or phase of training occurs when the trainee reaches 98 percent independent completion of all trials in a single session consisting of at least 6 trials, as determined by the following calculation: 1−(average numeric value of cue/4) × 100%. A trainee who has reached 98% criterion is considered to have acquired the respective device skill and is able to complete steps independently and nearly perfectly each time. Independent completion of 98% of task steps was chosen as the criterion point for stage and/or phase progression because it is close to perfect performance while allowing for occasional mistakes unrelated to skill acquisition, and indicates that the skill is embedded in memory and can be successfully built upon with further training if required.

Phase 2 – Skill Generalization focuses on building the habit of real world device use to support functional memory difficulties. Phase 2 is accomplished through a continued training process consisting of homework assignments, checking, and troubleshooting, with the occasional involvement of family members. Importantly, generalization was successful for all included participants, and the effectiveness of the programme with regard to real world utility has been demonstrated in previously published work (Svoboda et al., 2015). Since the present study is focused on the prediction of learning during Skill Acquisition (Phase 1), generalization data is not included or discussed further. See Figure 2 for an overview of the intervention phases and stages, highlighting the focus of the present study.

Trainers

Training was performed by clinical neuropsychologists who run the programme, research assistants, and graduate student trainees. Junior trainers went through a training protocol that involved reading a manual, practice scoring with videos and role play, and direct supervision with a client during their first training sessions to ensure consistency in intervention (for a more complete description see Svoboda et al., 2012). Trainers were considered themselves trained in the errorless-fading-of-cues protocol after their scores were 98% similar to those recorded by a neuropsychologist in training videos and in the first supervised session. Over the course of training clients, all trainers were supervised by a registered psychologist on an ongoing basis.

Outcome measures

Training performance

The primary outcome measure with regard to training data was the percent independent completion (PIC) which was calculated for each trial (mean

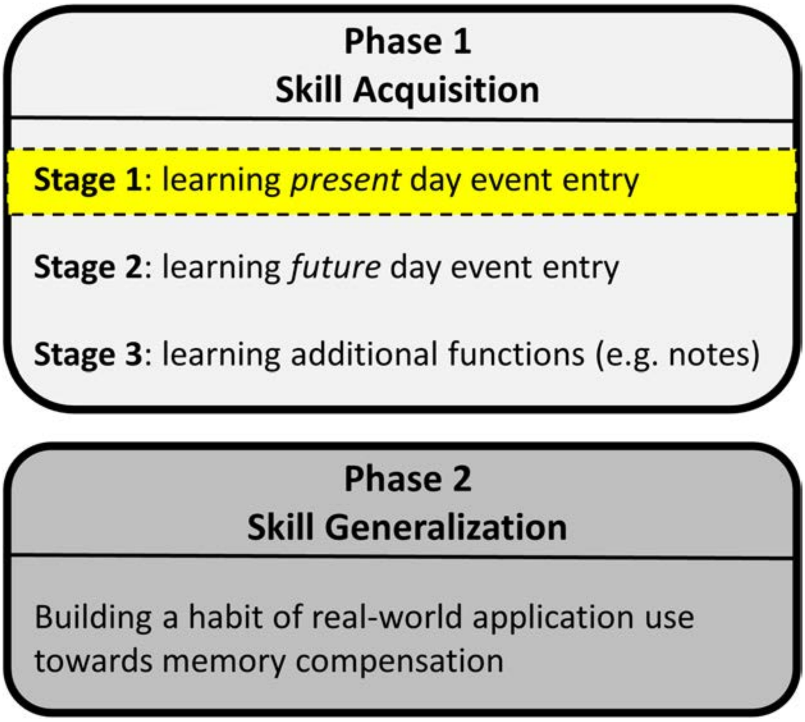

Figure 2. Outline of the memory intervention programme (Memory Link). The focus of the present study is on Phase 1 Skill Acquisition, Stage 1 (highlighted).

across steps) and session (mean across trials) for each participant, as well as the standard deviation of those samples. The PIC for each of the first ten sessions was used in the analysis of device skill learning – PIC will increase as learning progresses and less support is required to complete application steps. The PIC for the first session was used in analyses involving initial training performance. See objectives 2 and 3.

Learning and forgetting

The degree of learning within a session was calculated by subtracting the PIC of the final trial in a session from the PIC of the first trial in that session. Similarly, the amount of forgetting between sessions was calculated by subtracting the PIC of the first trial in a session from the PIC of the final trial in the previous session, if there was one. These scores were averaged across stage 1 training and used in exploratory analyses to examine the potential for within-session learning and between-session forgetting being related to training duration.

Note that since the first three trials of the first training session were demonstrated by the trainer and passively observed by the participant, they were not included in any calculation of PIC. Only non-demonstrative trial PIC values were used in order to get a more accurate measure of the trainee's independent abilities.

Training duration

Training length was quantified by the number of trials required to reach the learning criterion (i.e., the number of trials completed in stage 1 until 98 PIC was reached) – see objectives 1 and 2. The learning criterion of stage 1 was chosen as an endpoint for training length as it represents the most important steps necessary for operating the calendar application and it is also institutes a degree of uniformity between clients, after which different steps may be added to training in an individualized manor.

Neuropsychological battery

Neuropsychological assessment was completed by a registered neuropsychologist, who was part of the neuropsychology department and the memory intervention programme, prior to initiation of memory training. Data from the following tests were included in the analyses: Wechsler Adult Intelligence Scale III (WAIS-III) (Wechsler, 1997a), Delis Kaplan Executive Function Scale (DKEFS) (Delis et al., 2001), California Verbal Learning Test (CVLT) (Delis et al., 2000), Boston Naming Test (BNT) (Kaplan et al., 1983), Wisconsin Card Sorting Task (WCST) (Heaton et al., 1993), Behavior Rating Inventory of Executive Function for Adults (BRIEF-A) (Roth et al., 2005), Rey Complex Figure Test (RCFT) (Meyers & Meyers, 1995), Wechsler Abbreviated Scale of Intelligence II (WASI-II) (Wechsler, 2011), Brief Visuospatial Memory Test-Revised (BVMT-R) (Benedict, 1997), Wechsler Memory Scale III (WMS-III) (Wechsler, 1997b), Trail Making Test parts A & B.

Statistical analysis

The analysis plan was preregistered during the chart review, before any statistical procedures were performed. Preregistration can be found at the following link: https://osf.io/kstjc. Data extraction revealed a number of missing data points across neuropsychological measures. As the cognitive test data were collected for clinical purposes over many years, there was no standardization in the battery administered. Where the impact of different test versions was anticipated to be high (e.g., original Trail Making vs. DKEFS Trail Making), the measure with a larger sample size was chosen (in this case, the DKEFS version; $n = 21$), and only participants who completed that version were included in the analysis. If the impact of test version discrepancy was thought to be low, all measures were included (e.g., WASI and WASI-II subtests analyzed as a single version). To further accommodate the presence of non-systematic missing data points, it was decided to minimize the number and complexity of linear regression analyses that were originally planned, and perform correlation instead.

Preregistered hypotheses involving percent independent completion (PIC) focused on testing effects of variability. It was thought that variability in PIC may represent instability of skill learning or attentional fluctuations that could lead to prolonged training. It also became apparent, however, that learning progression should firstly be quantified relative to mean PIC. Thus, the analysis plan below includes both mean and standard deviation PIC, though the preregistration only described standard deviation measures.

(1) Examining the relationship between neuropsychological performance and length of stage 1 skill acquisition. As a first step, age was regressed from all measures of interest – available raw neuropsychological test scores and the training duration variable (the number of trials required to reach the 98% criterion of the core calendar app steps, i.e., stage 1). Bivariate correlation (two-tailed conservatively chosen) was then performed between these age-regressed residual variables. The following neuropsychological test measures were analyzed:
   a. Intellectual functioning – WASI vocabulary, WASI similarities, WASI block design, WASI matrix reasoning
   b. Simple attention and working memory – WAIS-III Digit Span, WAIS-lll Letter-Number Sequencing
   c. Processing speed – WAIS-III Digit Symbol Coding, Trail Making Test A
   d. Verbal memory – CVLT-II learning total, CVLT-II short delay free recall, CVLT-II short delay cued recall, CVLT-II long delay free recall, CVLT-II long delay cued recall, WMS-III Logical Memory I & II
   e. Visual memory – BVMT-R immediate recall total, and BVMT-R delayed recall, WAIS-III Digit Symbol Coding (incidental paired and free recall)
   f. Executive functioning – Letter Fluency, Trail Making Test B, Wisconsin Card Sorting Test categories
(2) Examining the pattern of learning over time, across sessions. Mean and standard deviation of PIC for the first ten training sessions were each subject to separate repeated measures analysis of variance (ANOVA). No between-subjects factor or covariate was added.
(3) Examining whether initial training performance is predictive of training duration to learn the core calendar app skills. A linear regression was performed with the independent predictor variable being mean PIC of training session 1, and the dependent variable being the number of trials required to reach the 98% criterion of the core calendar app steps (i.e., stage 1). The linear regression was then re-run using standard deviation PIC of session 1 as the predictor. The mean and SD PIC of session 1 were calculated while excluding initial demonstration trials that did not involve client engagement.
(4) Examining the association between neuropsychological performance and initial calendar app training performance. Bivariate correlation was performed

between available age-regressed raw neuropsychological test scores (same as analysis 1) and the age-regressed mean and SD of session 1 PIC.

Exploratory analyses were conducted to investigate additional aspects of the data that were not identified at the point of preregistration.

Cognitive profile

Findings previously published on a subset of these data ($n = 10$) found that individuals with global cognitive impairment, including memory, took substantially longer than those with only a focal memory deficit to acquire smartphone skills (Svoboda et al., 2012). We sought to confirm this finding, now with a larger sample size. Participants were binned into three groups depending on the number and type of neuropsychological tests with impaired performance (T score < 30). Participants were classified into the moderate focal memory group if they were significantly impaired on only 1 memory measure. Those who were impaired on 2 or more memory measures were categorized as either severe focal memory or severe memory + impairment depending on the presence of additional cognitive deficits. Impairment on 1 non-memory test, or no weaknesses outside of memory was classified as a focal memory deficit. Scoring in the impaired range on 2 or more non-memory measures, in addition to 2 or more memory measures, earned the classification of severe memory + impairment. Note that one participant was excluded for having insufficient neuropsychological data for categorization. The classification system yielded 8 moderate focal memory, 10 severe focal memory, and 16 severe memory + impaired participants (Table 2). Analysis of variance was performed to determine whether there was a significant difference between groups with regard to number of trials required to reach the 98% criterion for completion of stage 1 training (core calendar app steps; dependent variable).

Within-session learning

It is possible that some individuals are more efficient at picking up new skills during a single training session. To further investigate individual learning profiles, mean within-session progression was examined using a difference score calculation between the first and final trial PIC of each training session until the 98 PIC criterion for stage 1 steps was reached. These mean difference score values were then correlated with number of trials to reach criterion.

Between-session forgetting

It is also possible that the learning rate of some individuals is hindered by accelerated forgetting between training sessions. That is, brain injured individuals may not be able to pick up right where they left off when starting a new session due to the deterioration of memory between sessions. Between-session forgetting was evaluated using a difference score calculation based

Table 2. Neuropsychological data.

	MODERATE FOCAL MEMORY		SEVERE FOCAL MEMORY		SEVERE MEMORY +		OVERALL	
	Raw Score	*T*-Score	Raw Score	*T*-Score	Raw Score	*T*-Score	Raw Score	*T*-Score
Age (years)	42.75 ± 10.10		41.30 ± 15.41		39.38 ± 16.38		40.28 ± 14.43	
Sex	4M; 4F		5M; 5F		10M; 6F		19M; 17F	
Education (years)	14.75 ± 2.32		13.30 ± 2.58		13.56 ± 2.78		13.83 ± 2.56	
N	8		10		16		36	
F4IQ	108.6 ± 17.30		97.13 ± 13.63		97.50 ± 37.11		99.78 ± 26.45	
Vocabulary	51.14 ± 16.06	48.83 ± 12.70	51.70 ± 10.15	53.40 ± 12.64	48.71 ± 12.60	47.71 ± 12.87	48.85 ± 13.50	49.22 ± 12.67
Block Design	41.88 ± 14.66	54.29 ± 8.20	41.70 ± 14.59	52.00 ± 10.63	24.38 ± 13.05	40.00 ± 10.20	35.12 ± 15.87	47.47 ± 11.30
Similarities	33.13 ± 8.95	50.57 ± 12.93	31.00 ± 5.46	48.70 ± 9.50	31.07 ± 5.98	45.29 ± 9.04	31.09 ± 6.61	47.12 ± 9.93
Matrix Reasoning	23.38 ± 6.21	55.71 ± 9.46	20.80 ± 5.92	49.50 ± 9.93	17.57 ± 8.75	41.50 ± 18.70	20.09 ± 7.32	47.73 ± 15.03
WAIS Digit Span Forwards Max Span	7.14 ± 2.00	50.58 ± 14.24	5.70 ± 0.82	40.50 ± 7.13	6.33 ± 1.99	40.38 ± 9.99	6.24 ± 1.71	41.95 ± 10.65
WAIS Digit Span Backwards Max Span	4.57 ± 1.62	43.42 ± 13.71	4.10 ± 1.37	42.44 ± 9.52	4.40 ± 2.38	38.19 ± 8.90	4.35 ± 1.86	40.83 ± 9.85
WAIS Digit Span Total	18.43 ± 6.63	51.57 ± 16.47	14.80 ± 3.39	45.80 ± 8.12	13.43 ± 3.67	42.50 ± 7.76	15.06 ± 4.56	45.79 ± 10.32
WAIS Letter-Number Sequencing	10.57 ± 2.76	51.00 ± 9.78	7.63 ± 3.07	40.63 ± 12.14	9.42 ± 4.25	47.08 ± 15.79	9.00 ± 3.70	45.50 ± 13.78
WAISIII Digit Symbol Coding	68.29 ± 15.64	49.14 ± 11.60	54.40 ± 12.60	40.60 ± 8.93	39.58 ± 20.14	34.25 ± 10.22	51.52 ± 19.27	39.84 ± 11.07
WAISIII Digit Symbol Coding Paired Recall	11.50 ± 8.06	40.75 ± 17.93	3.50 ± 4.72	24.00 ± 15.61	4.78 ± 5.65	29.61 ± 13.20	5.79 ± 6.38	30.18 ± 15.38
WAISIII Digit Symbol Coding Free Recall	7.75 ± 1.50	47.25 ± 6.85	3.33 ± 2.07	26.50 ± 10.04	3.56 ± 2.51	27.78 ± 12.24	4.37 ± 2.75	31.47 ± 13.14
DKEFS Category Fluency	35.43 ± 13.13	45.14 ± 16.08	31.88 ± 9.00	41.63 ± 11.61	17.91 ± 5.97	25.64 ± 5.10	27.44 ± 12.00	36.33 ± 13.82
DKEFS Letter Fluency	37.71 ± 18.60	48.71 ± 17.64	35.63 ± 16.33	48.38 ± 16.40	21.00 ± 8.89	33.17 ± 9.09	29.32 ± 15.56	41.29 ± 15.35
DKEFS Number Sequencing[1]	27.40 ± 11.74	56.60 ± 8.14	42.29 ± 11.74	41.43 ± 9.48	73.67 ± 35.83	26.44 ± 11.73	52.19 ± 31.27	38.62 ± 15.67
DKEFS Number-Letter Switching[1]	91.20 ± 45.57	48.20 ± 11.08	102.86 ± 18.37	41.43 ± 4.39	188.00 ± 52.80	23.89 ± 7.79	134.00 ± 60.32	35.52 ± 12.96
Trails A[1]	70.67 ± 29.23	20.50 ± 21.92	33.48 ± 2.92	44.33 ± 5.51	52.14 ± 18.99	33.57 ± 11.62	49.27 ± 19.37	33.57 ± 12.60
Trails B[1]	114.50 ± 24.75	33.50 ± 13.44	59.57 ± 7.33	55.00 ± 4.00	131.33 ± 81.64	33.86 ± 14.98	101.98 ± 63.04	39.57 ± 14.14
Trails sequence composite		46.29 ± 20.85		42.30 ± 8.29		27.57 ± 11.24		36.18 ± 14.86
Trails switch composite		44.00 ± 12.78		45.50 ± 7.71		26.29 ± 11.31		36.85 ± 13.59
CVLT-II Immediate Recall Total	45.00 ± 9.59	46.83 ± 10.82	32.44 ± 6.56	32.00 ± 5.94	23.80 ± 5.81	22.93 ± 7.50	30.38 ± 10.29	29.75 ± 11.86
CVLT-II Short-Delay Free Recall	6.57 ± 5.38	37.86 ± 17.76	2.50 ± 2.42	21.50 ± 4.74	1.60 ± 2.03	19.67 ± 6.00	3.00 ± 3.51	23.82 ± 11.53
CVLT-II Short-Delay Cued Recall	7.00 ± 5.40	35.00 ± 17.61	4.00 ± 2.75	19.30 ± 7.01	3.53 ± 2.39	20.00 ± 8.58	4.42 ± 3.31	22.52 ± 11.48
CVLT-II Long-Delay Free Recall	8.71 ± 4.61	42.86 ± 12.86	1.80 ± 2.10	19.50 ± 6.26	1.73 ± 2.34	20.93 ± 8.88	3.29 ± 3.93	24.65 ± 12.85
CVLT-II Long-Delay Cued Recall	8.86 ± 4.41	39.29 ± 14.27	2.90 ± 2.08	18.60 ± 4.99	2.73 ± 2.46	19.33 ± 7.67	4.21 ± 3.67	23.12 ± 11.80
WMS Logical Memory 1	36.80 ± 12.30	53.20 ± 7.46	25.88 ± 10.04	40.75 ± 14.75	19.29 ± 9.12	30.29 ± 12.33	24.32 ± 11.49	37.82 ± 14.65
WMS Logical Memory 2	20.80 ± 8.23	49.40 ± 10.50	7.38 ± 8.83	29.63 ± 12.11	4.36 ± 6.69	24.29 ± 12.04	8.07 ± 9.51	30.14 ± 14.65
BVMT-R Immediate Recall	19.50 ± 6.55	38.88 ± 11.41	12.36 ± 3.68	26.00 ± 3.61	7.27 ± 3.00	20.00 ± 2.68	12.41 ± 6.73	27.43 ± 10.32
BVMT-R Delayed Recall	7.13 ± 3.09	38.00 ± 14.50	2.93 ± 1.74	20.43 ± 2.94	1.05 ± 1.12	19.00 ± 0.00	3.50 ± 3.25	25.43 ± 11.54
BNT Spontaneous & Semantic	35.83 ± 28.04	39.40 ± 22.48	42.38 ± 18.74	36.43 ± 15.65	46.67 ± 10.63	39.71 ± 13.33	42.09 ± 18.74	37.81 ± 15.37

WCST Total Categories	5.43 ± 0.98	38.86 ± 4.85	3.89 ± 2.52	36.33 ± 6.16	3.79 ± 2.16	35.93 ± 5.89	4.28 ± 2.08	36.94 ± 5.57
WCST Perseverative Errors	12.00 ± 9.36	48.71 ± 9.46	19.67 ± 13.93	44.78 ± 10.53	22.38 ± 12.50	41.31 ± 12.39	19.03 ± 12.19	43.81 ± 10.95

1. 14 participants received Trails A / B and 21 others received DKEFS Number Sequencing / Number-Letter Switching; one participant from the Moderate Focal Memory group and one from the Severe Memory + group received neither test.
2. One participant was excluded from all groups, including overall, due to incomplete neuropsychological data. Two additional participants were excluded from the cognitive profile subgroups as they were classified as outliers with regard to training duration

on the final trial PIC of one session compared to the first trial PIC of the following session until the 98 PIC criterion for stage 1 steps was reached. Again, these mean difference score values were correlated with number of trials to reach criterion.

Results

Prior to conducting each analysis, the data were checked for outliers. The intention was for the dataset to be representative of true clinical practice, and thus, a secondary analysis with outliers removed was only conducted if the values were judged to have a substantial effect on the results. This situation only occurred once, and here we present the results with and without outliers removed – see exploratory analysis on cognitive profile.

Neuropsychological correlates of training duration

As a first exploratory step, the association between demographic variables and number of trials to reach stage 1 training criterion was examined. The results yielded significance for age ($r = .346$, $p = .036$) (Figure 3), but not education ($r = -.039$, $p = .820$), or time since injury ($r = .101$, $p = .565$). Following pre-registered analysis 1, bivariate correlations between age-regressed residual neuropsychological test scores and number of trials to reach training criterion were significant for Block Design ($r = -.390$, $p = .022$), Digit Symbol Coding ($r = -.444$, $p = .012$), DKEFS Trail Making Number-Letter Sequencing ($r = .567$, $p = .007$), CVLT-II Short Delay Free Recall ($r = -.352$, $p = .041$), CVLT-II Long Delay Free Recall ($r = -.457$, $p = .007$), CVLT-II Long Delay Cued Recall ($r = -.414$, $p = .015$), BVMT-R Delayed Recall ($r = -.439$, $p = .019$), Digit Symbol Paired Recall ($r = -.475$, $p = .040$), Digit Symbol Free Recall ($r = -.535$, $p = .018$), and DKEFS Trail Making Switching ($r = .469$, $p = .037$). Performance on the remaining neuropsychological tests was not significantly associated with number of trials to reach training criterion at the 0.05 alpha level. For ease of interpretation, significant correlations for a select few *raw* test scores are presented graphically in Figure 4; these include CVLT-II Long Delay Free Recall ($r = -.437$, $p = .010$), BVMT-R Delayed Recall ($r = -.438$, $p = .020$), Block Design ($r = -.385$, $p = .024$), and Digit Symbol Coding Free Recall ($r = -.481$, $p = .037$). Note that the Pearson r and line of best fit slope were similar between correlations performed with age-regressed and raw data (both shown in Figure 4).

Characterization of skill acquisition

Participants were trained on the native calendar application pre-installed on their device, which differed depending on the operating system (i.e., Palm

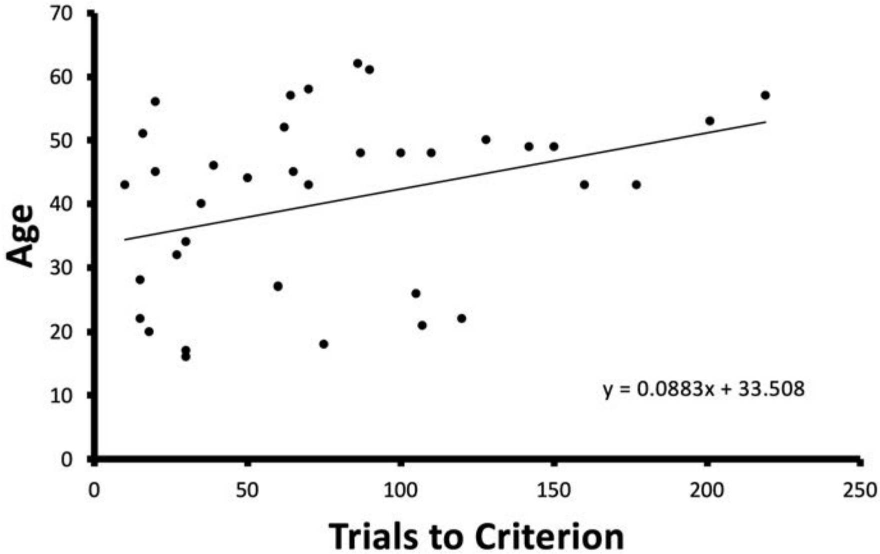

Figure 3. Trials to Criterion is the number of trials required for the individual to learn the core set of calendar steps and reach the criterion point of 98 percent independent completion (PIC). Typically, 10 trials are completed per in-person session. Trials to Criterion is used as an index of training duration. ($r = .346$, $p = .036$)

[22], iOS [12], Android [3]), and as a result the number of steps required to be learned varied across individuals. The mean number of steps included in stage 1 was 16.00 (SD = 1.77), and the mean number of steps necessary to fully complete training was 22.00 (SD = 2.36). To test the possibility that differences in the number of steps might contribute to training duration, bivariate correlation was performed on number of stage 1 steps and number of trials to reach criterion (in stage 1); the results indicated no significant association ($r = -.104$, $p = .541$). It is also possible that the usability of the operating system could have contributed to learning, beyond simply a difference in the number of steps. To rule out operating system as a training influence, an ANOVA was conducted with number of trials to reach criterion (in stage 1) as the dependent variable, and operating system type (Palm or iOS/Android) as the between-subjects factor; the results yielded no significant effect of operating system, $F(1, 35) = 0.018$, $p = .895$.

Though clients are typically trained twice a week in our programme, there can be situations that arise causing clients to miss training sessions, thereby increasing delay between sessions. The mean delay between sessions during stage 1 of training was 4.98 days (SD = 2.97). Greater delays between sessions would undoubtedly hinder learning progress, and so we tested the hypothesis, examining correlations between mean between-session delay and number of trials to reach training criterion, which yielded no significant effect ($r = -.019$, $p = .914$).

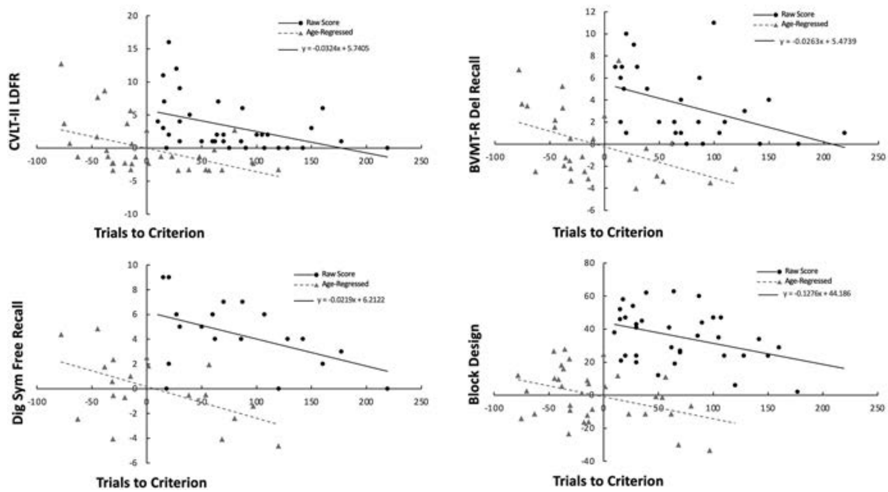

Figure 4. The circles and the solid line of best fit reference the raw data, whereas the triangles and the dashed line reference the age-regressed residual values (controlling for age). The equation of the line shown is for the raw data only. CVLT-II LDFR is California Verbal Learning Test-II – Long Delay Free Recall (raw $r = -.437$, $p = .010$; age-regressed $r = -.457$, $p = .007$); BVMT-R is Brief Visual Memory Test Revised Delayed Recall (raw $r = -.438$, $p = .020$; age-regressed $r = -.439$, $p = .019$); Digit Sym Free Recall refers to the Wechsler Adult Intelligence Scale-III subtests Digit Symbol Coding Incidental Learning – Free Recall (raw $r = -.481$, $p = .037$; age-regressed $r = -.535$, $p = .018$); Block Design refers to the Wechsler Abbreviated Scale of Intelligence (I and II) subscale Block Design (raw $r = -.385$, $p = .024$; age-regressed $r = -.390$, $p = .022$). Trials to Criterion is the number of trials required for the individual to learn the core set of calendar steps and reach the criterion point of 98 percent independent completion (PIC). Typically, 10 trials are completed per in-person session. Trials to Criterion is used as an index of training duration.

Following pre-registered analysis 2, the pattern of learning was investigated across the first 10 training sessions. Repeated measures ANOVA yielded a significant linear effect for mean PIC, $F(1, 25) = 62.61$, $p < .001$, $\eta^2 = .715$, as well as a significant quadratic effect for mean PIC, $F(1, 25) = 37.50$, $p < .001$, $\eta^2 = .600$. These results demonstrate that across the first 10 training sessions, participants gradually acquired the skills of using the calendar application core features, so as to require less and less support to complete the steps. Initially in session 1, participants were only able to complete a mean of 65% of the steps independently, but by session 10, they were able to complete 94% without support (Figure 5). A significant linear effect was also found for standard deviation PIC, $F(1, 24) = 37.30$, $p < .001$, $\eta^2 = .608$, as well as a significant quadratic effect, $F(1, 24) = 4.37$, $p = .047$, $\eta^2 = .154$. As training progressed across the first 10 sessions, the variability in support required to complete calendar steps decreased (Figure 5).

Linear regression was then performed to determine whether initial training performance was predictive of training duration (number of trials to reach training criterion). Mean PIC from session 1 was found to be a significant predictor [$F(1, 34) = 18.58$, $p < .001$ (R-squared = .353)] (Table 3), but not PIC standard deviation from session 1 [$F(1, 34) = 0.02$, $p = .877$].

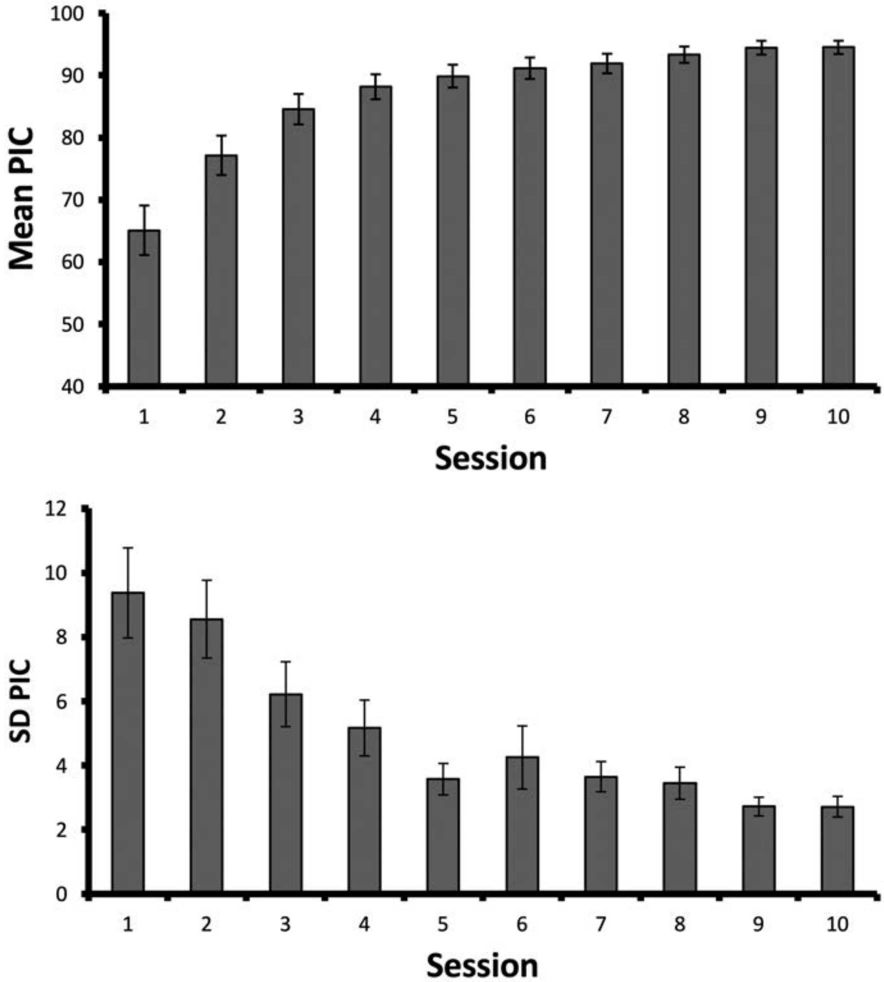

Figure 5. PIC is percent independent completion; SD is standard deviation. Error bars are standard error.

Cognitive-skill learning associations

Following the final pre-registered analysis (analysis 4), bivariate correlation was applied to examine the associations between cognition and training performance, using age-regressed raw neuropsychological test scores and age-regressed first training session PIC respectively. Analysis with mean PIC revealed significant correlations for DKEFS Trail Making Number-Letter Sequencing ($r = -.541$, $p = .011$), CVLT-II Short Delay Free Recall ($r = .413$, $p = .015$), and CVLT-II Long Delay Free

Table 3. Linear Regression – Session 1 mean PIC predicting training duration.

Predictor	R^2	Adj. R^2	*F*	*p*	constant	gradient	*t*	*p*
Model	0.353	0.334	18.576	<0.001	159.897			
Session 1 PIC						−1.290	−4.310	<.001

Recall ($r = .354$, $p = .040$). No other associations reached significance at the $p < .05$ level. Similarly, associations with standard deviation PIC were analyzed using bivariate correlation, but yielded no significant results.

Exploratory analyses

Cognitive profile

The mean number of training trials for participants to complete skill acquisition of all calendar steps (all stages) and complete Phase 1 of the programme was 176.97 (range 15–588), or approximately 18 sessions. Participants required a mean of 76.57 trials (range 10–219), or approximately 8 sessions, to reach the 98 PIC criterion of stage 1 steps.

Participants were categorized into moderate focal memory, severe focal memory, and severe memory + impaired groups to investigate whether cognitive profile contributed to application learning. Examination of the data indicated a wide range of training durations within each of the three groups, and it was clear that there were several remarkably fast learners in the “severe focal memory” and “severe memory +” impaired groups. For example, one participant in the “severe focal memory” group reached criterion in only 10 trials, and another in the “severe memory +” impaired group achieved this proficiency in only 15 trials. Clinically, such rapid success observed in individuals with significant memory impairment is quite unusual, and so we treated these two participants as outliers, removing them prior to running the analysis.[1] Analysis of Variance (with polynomial contrast) was then performed on training duration (number of trials to stage 1 criterion), with cognitive profile group as the between-subjects factor. The analysis revealed a significant linear effect across groups, [$F(1, 31) = 6.13$, $p = .019$], with the following means and SDs for number of trials to reach criterion: 45.00 (34.03), 79.70 (48.72), and 101.00 (60.62) (Figure 6). Note that the same outcome was achieved without removing the outliers – a significant linear effect for cognitive profile, [$F(1, 33) = 4.86$, $p = .035$], with the following mean number of trials for each group respectively: 45.00 (34.03), 73.36 (50.77), and 95.94 (62.29). Thus, training duration was successively longer in those with more complex cognitive deficits.

Within-session learning

The analysis revealed no association between within-session learning and duration of training to criterion ($r = -.080$, $p = .637$).

Between-session forgetting

The analysis showed no association of between-session forgetting with duration of training to criterion ($r = .173$, $p = .312$).

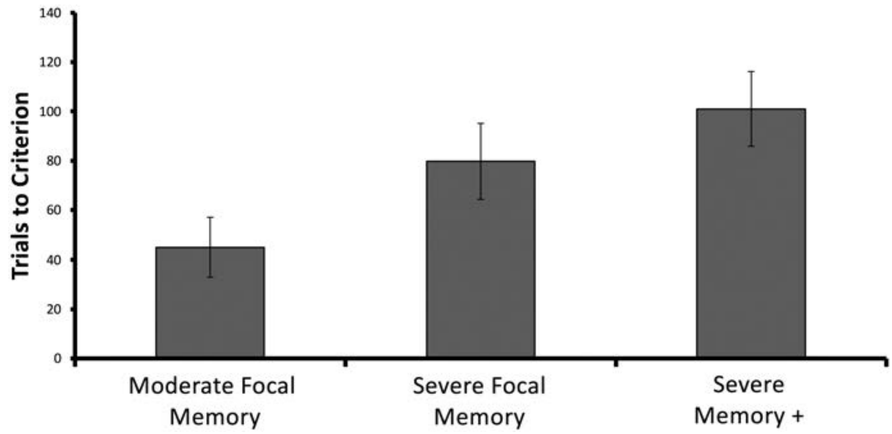

Figure 6. Moderate Focal Memory, Severe Focal Memory, and Severe Memory +, refer to the degree of memory impairment, where Severe Memory + represents individuals with impairments to memory and other cognitive domains. Trials to Criterion is the number of trials required for the individual to learn the core set of calendar steps and reach the criterion point of 98 percent independent completion (PIC). Typically, 10 trials are completed per in-person session. Trials to criterion is used as an index of training duration. Error bars are standard error.

Discussion

The ability to use intact implicit learning mechanisms to acquire new skills is essential for brain injured individuals to compensate for explicit memory deficits and improve functional independence. Calendar applications in digital devices can be used as flexible memory aids for those with significant day-to-day memory problems. The present study examined factors that affect skill learning of calendar applications using an established evidence-based memory intervention protocol. Neuropsychological test performance and training data from previous clients of an outpatient memory intervention programme were analyzed to characterize skill acquisition of calendar steps and determinants of learning. The results revealed that age and performance on several neuropsychological tests were significantly related to training duration to reach learning criterion of the core set of calendar steps. It was also discovered that initial training performance was predictive of training duration, and that profile of cognitive impairment was a significant contributing factor to the number of trials needed to acquire the skillset.

Neuropsychological correlates of training duration

The positive association between age and training duration suggests that age-related cognitive changes contribute to impairments due to ABI, resulting in a slowing of device skill acquisition (e.g., learning the steps to use a calendar application). An important consideration, however, is that digital device familiarity and experience were not accounted for in this study. The present data were collected through retrospective chart review spanning twelve years and include training data from personal digital assistants and smartphones before their use was common. Smartphone adoption has accelerated at a rapid rate over this time, and it is likely that older individuals in the study did not have the experience or a baseline set of skills with these devices to build from. Future research will be needed to confirm this suspicion using more detailed information on the extent of device expertise.

Neuropsychological performance on explicit memory tasks, as well as non-memory measures, was significantly associated with training duration. With regard to memory, weaker performances on CVLT-II SDFR, CVLT-II LDFR, CVLT-II LDCR, BVMT-R DR, Digit Symbol Coding Paired Recall, and Digit Symbol Coding Free Recall correlated with the number of trials required to reach the learning criterion. The memory intervention is effective for a wide range of memory deficiencies and was designed to target implicit memory systems when explicit memory abilities are compromised. That being said, the pattern observed across a number of memory measures supports our knowledge that residual explicit memory is highly important to learning (Tulving, 2002). Interestingly, weaker performance on non-memory measures (i.e., Block Design, Digit Symbol Coding, and Trail Making switching) was also found to correlate with more trials to reach the learning criterion. It is possible that some of these tasks have a procedural component; for example, the skills of assembling blocks to match a pattern, and transcribing symbols, could be developed across trials in the respective tasks. If this hypothesis is correct, it could explain the correspondence between Block Design/Digit Symbol Coding and the skill learning that occurs during the memory intervention programme. A limitation of the correlational analyses is the elevated risk of Type I error due to multiple comparisons. Despite a priori insight into the directionality of associations, a conservative two-tailed significance testing approach was used to minimize the likelihood of making a false discovery. Since a clear pattern was observed in the memory domain, it is unlikely that those findings could be explained by chance alone. Still, replication using another data set would be beneficial to confirm the neuropsychological associations and rule out the possibility that family-wise error played a role in the results (particularly Block Design and speeded tasks).

The neuropsychological findings are congruent with the literature on cognitive procedural learning that supports the idea that higher level thinking abilities contribute to the process of acquiring new skills across three phases – cognitive, associative, and autonomous. Early research on the topic found that the cognitive phase of procedural learning is related to general intelligence and the associative phase to perceptual processing (Ackerman, 1988), both of which are abilities at least partially captured by Block Design. A more recent study emphasized the importance of perceptual processing to procedural skill acquisition, showing significant and stable correlations throughout learning (Beaunieux et al., 2006). The same study reported that explicit memory abilities were involved at the beginning of learning a new procedural skill, but then declined across subsequent trials (Beaunieux et al., 2006). In an investigation of cognitive procedural learning in amnesia, the authors concluded that intelligence was a significant determinant of learning, and that declarative memory likely plays a role if the explicit knowledge necessary for completing the task is greater than the individual's working memory capacity (Schmidtke et al., 1996). In our memory intervention task, the steps required to enter an event into a digital calendar are numerous and would easily exceed any client's working memory abilities.

As non-brain injured individuals would rely on a combination of explicit and implicit memory abilities to learn new skills, it is reasonable that those with brain injury would do the same, but with less explicit learning capability available to them. The present results support this idea through performance correlations with explicit memory tests. Furthermore, initial training performance was correlated with a number of cognitive measures including those in the memory domain. The correspondence between initial training performance and memory functioning bolsters the idea that learning a new sequence of steps of a particular skill is reliant on residual explicit memory ability. Future research should investigate the relative contributions of explicit and implicit memory systems to skill acquisition in a memory impaired sample. An additional hypothesis was that executive functioning abilities may also be associated with learning based on the idea that consistent exertion of supervisory control throughout training trials facilitates faster skill acquisition. This premise was partially supported through the significant association with a test of cognitive flexibility. Further effects involving executive functioning measures were not identified, which is potentially explained by the role of the trainer who provides so much support and guidance within each session that any kind of supervisory control requirement is prevented from impacting performance. It would be beneficial to explore this hypothesis further using more attentionally demanding experimental tasks. Executive functioning impairments were unlikely to have contributed to memory deficits, as this would have been detected through participants neuropsychological performance profile on memory testing.

Characterization of skill acquisition

Not surprisingly, it was found that learning (quantified by mean PIC) increased over time across sessions. Previous research from our programme has demonstrated the success of our training protocol in conveying digital device skills to individuals with moderate to severe memory impairment, and these skills are applied to enhancing functional memory day-to-day (Svoboda et al., 2012). The present data uniquely showed that the variability of independent step completion decreased across sessions as mean PIC increased. These findings are compatible with one another and both indicate learning; as individuals acquired the skillset of completing application steps autonomously, they also were able to do so more consistently.

The results also revealed that initial training performance was a strong predictor of training duration, which suggests that starting with a higher level of operational skills puts individuals in an advantaged position for further learning. Although the present study lacked data on previous device experience, we hypothesize that individuals who have greater experience using a particular operating system prior to training have already acquired a basic set of device skills that are generalizable across most other apps (including the calendar), which could facilitate their faster learning of a novel application. The results of initial training performance predicting training success support this premise.

Cognitive profile

The exploratory analysis on cognitive profile revealed that individuals with impairments in multiple cognitive domains (including memory) required significantly more trials to reach the learning criterion compared to those with only a focal memory deficit, replicating what was shown by Svoboda et al. (2012). Similar results have recently been found in research on healthy older adults – lower initial baseline cognitive performance predicted training success targeting domain abilities including attention, memory, and executive functioning (Roheger et al., 2020). Furthermore, research on a validated compensatory memory support system for amnestic mild cognitive impairment also indicated that global cognition was a significant predictor of learning (De Wit et al., 2021). Although our programme provides substantial structure and support throughout the learning process, impairments in multiple domains of cognition may create considerable difficulties that slow learning. For example, implicit memory systems that are crucial to circumvent deficits in explicit memory could be impacted in those with multiple domains of impairment, or, possibly, deficits to higher level thinking abilities could affect planning event entries in the calendar, most specifically the generation of content and organization of time.

Implications

The ability to acquire new generalizable skills is essential for brain injured individuals with moderate to severe memory impairment to gain independence. Applying our evidence-based memory training method facilitates new learning in this population. The prolonged training time, however, can be difficult for trainers to estimate and stressful for caregivers to manage. Understanding the predictors of training duration at an individual level allows clinicians to run the programme more efficiently by taking into consideration client triage and training assignments, and allows the communication of training expectations to caregivers so they can make informed care decisions. This rehabilitation programme is a significant time and energy investment for client and caregiver alike, so accurate initial setting of goals and expectations can relieve stress and improve client outcomes. Clinicians involved in compensatory memory rehabilitation for brain injured individuals will want to consider performance on neuropsychological tests of memory, and the degree of impairment across multiple cognitive domains (primarily those tapping into higher level thinking abilities), as indicators for training length and success.

The present sample of 37 participants took an average of 76.57 (range 10–219) trials to learn the core calendar skills, which translates to approximately 8 sessions spread over 4 weeks. Visual inspection of the data (see Figure 4) indicates that an individual who scored higher on neuropsychological tests of explicit memory, such as CVLT-II LDFR and BVMT-R delayed recall, will take substantially less time to be trained on the fundamental calendar steps. Non-memory measures give the same result; for example, higher scores on Digit Symbol Coding Free Recall or Block Design would suggest a shorter training duration. The equation for the line of best fit could also be applied to the estimation, with caution (see Figure 4); for example, a score of 3 on Digit Symbol Coding Free Recall corresponds to 147 trials, or approximately 15 sessions. Importantly, individual test scores do not accurately convey the whole picture with regard to the prediction of training duration. One should take into account a client's previous calendar application experience, general technological proficiency, and complete cognitive profile (as discussed above).

A final consideration should be the user interface of any application being trained. A more intuitively designed application would certainly be easier to learn. One limitation of the current dataset is that participants were trained on different calendar applications, and these have seen much innovation over the time span in which the data were collected. Our analysis indicated no difference in training duration between the Palm OS calendar application and more modern smartphone OS incarnations. However, future developments in mobile technology may lead to improvements in user experience that facilitate application learning.

Conclusions

The present research provides further validation of our theory-driven training programme for individuals with significant functional memory difficulties due to ABI. The ability of individuals in this population to learn and retain new information is often highly compromised, though residual cognitive abilities can be relied on to support the acquisition of new skills applied to real world functional improvement. Neuropsychological measures of explicit memory, executive ability (i.e., cognitive flexibility), and possibly those tests tapping into implicit learning aptitude, seem to be most highly related to skill learning supported through a structured protocol. Importantly, a multitude of deficits across cognitive domains, in addition to memory, will invariably impede the rate of learning. Finally, performance at the start of training is predictive of training duration, and may be indicative of prior device experience and fluency. We hypothesize that greater device experience will boost the rate of learning, as universal operational knowledge may generalize well and start individuals off at a higher level; this factor is likely to increase over generations.

Note

1. Note that statistical analyses for all other objectives were re-run with the same outliers removed; the main findings reported were generally not affected.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Other notes

A subset of the present sample has been used in previous publications focused on a different data set (see Svoboda et al., 2012, 2015)

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