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ORIGINAL ARTICLE

Creating a digital memory notebook application for individuals with mild cognitive impairment to support everyday functioning

Nisha Raghunath[a], Jessamyn Dahmen[b], Katelyn Brown[a], Diane Cook[b] and Maureen Schmitter-Edgecombe[a]

[a]Department of Psychology, Washington State University, Pullman, WA, USA; [b]School of EECS, Washington State University, Pullman, WA, USA

ABSTRACT

Purpose: Memory impairment can necessitate use of external memory aids to preserve functional independence. As external aids can be difficult to learn and remember to use, technology may improve the efficacy of current rehabilitation strategies. We detail the iterative development of a digital application of a paper-and-pencil memory notebook.

Methods: Twenty participants (aged 54+) of varying levels of cognitive ability were recruited for four iterations of usability testing (five participants per iteration). Each participant completed a series of tasks using the digital memory notebook (DMN), followed by questionnaires that assessed satisfaction (Questionnaire for User Interface Satisfaction) and usability ratings (Post-Study System Usability Questionnaire) for the application.

Results and Conclusions: Between Iterations 2 and 5, participants demonstrated marked reductions in time to complete several types of tasks (e.g., add event, navigate interface) using the DMN. Participants in Iteration 5 also rated all subscales of both the usability and satisfaction questionnaires very highly. Faster task completion times were correlated with more favourable system ratings. However, neither task performance times nor system ratings were correlated with cognitive abilities, scheduling tool use or comfort with technology. Both the questionnaire and performance-based data indicate the final iteration of the DMN was easy to use. Furthermore, the application was user-friendly despite individual differences in cognitive ability, familiarity with scheduling tools and comfort with technology. Future work will demonstrate whether the DMN will support everyday retrospective and prospective memory lapses and increase the functional independence and quality of life for persons with cognitive impairment.

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Memory; older adults; iterative design; usability testing; rehabilitation; compensation

➤ **IMPLICATIONS FOR REHABILITATION**

- Building on practice standards and user-centred design, the digital memory notebook (DMN) application is an “all-in-one” memory aid and organizational tool with an intuitive interface designed to help improve everyday functioning.
- The DMN’s today page, to do list and calendar functions can support everyday prospective and retrospective memory abilities.
- The DMN’s notes, journaling and motivational functions can support longer-term goal planning and mood management.
- The DMN’s alarm functions can support learning to use the DMN and serve as reminders to support prospective memory and aid in activity completion.

Introduction

Memory impairment, one of the most problematic symptoms of Mild Cognitive Impairment (MCI) and Alzheimer’s disease (AD), can significantly impact a person’s quality of life and ability to live independently [1,2]. Training in the use of external compensatory devices to help with everyday memory impairment, including pagers and memory notebooks, is a Practice Standard for individuals with traumatic brain injury (TBI) and stroke [3]. Teaching a memory-impaired individual to use a memory notebook, however, can be time intensive and using a notebook is itself a memory exercise [2]. Recently, advances in technology have fuelled new opportunities for application development to improve the efficacy of current external compensatory devices. The present work details the iterative development of a digital memory notebook (DMN) application designed to support the everyday functioning of individuals with mild dementia and with MCI, an intermediate stage between healthy aging and dementia [4,5].

Caregivers can be helpful memory aids for individuals with cognitive impairment. However, the responsibility of serving as a memory aid puts increased strain on the caregiver [6,7] and can inadvertently undermine the autonomy of older adults who want to remain independent. Training in the use of external memory aids, such as paper calendars, sticky notes, daily planners and diaries is often used to assist individuals with overcoming memory impairments in their everyday lives. Memory notebooks are beneficial as they effectively organize several different types of external memory aids into one portable device. Memory notebooks often contain calendars, to do lists, permanent files, and other sections

CONTACT Maureen Schmitter-Edgecombe schmitter-e@wsu.edu Department of Psychology, Washington State University, P.O. Box 644820, Pullman, Washington, 99164-4820, USA

for important information such as contact information, addresses, medical information, maps and passwords. Memory notebooks are also valuable because they can support memory for past events (e.g., watered plants yesterday) as well as help individuals accomplish future events (e.g., doctor's appointment tomorrow).

Recent work by our group [8,9] and others [10,11] suggests that persons with MCI and mild dementia can learn to effectively use a paper-pencil memory notebook to independently plan, schedule and carry out daily activities. However, memory notebooks pose challenges as well. They can be easily misplaced and difficult to find without location capabilities (e.g., FindMyPhone), and require fine motor skills for writing with a pen or pencil. Memory notebooks can become bulky to use as additional pages are added to the notebook. This can decrease accessibility and usability as the paper tool becomes too cumbersome to carry around or flip through to find specific information. Furthermore, they require self-initiation to remember to use regularly because they do not have alarms to aid with this. Users must also develop a system for referencing the correct current date because the paper-pencil memory notebook cannot automatically update the date.

Several electronic compensatory memory aids have been developed and evaluated for their potential usefulness for individuals with impaired memory. A recent review of 18 commonly used memory aids listed diaries (77%), lists (78%) and calendars (79%) among the most commonly used memory aids and mobile phone reminders and alarms/timers as the most commonly used technological compensatory aid [12]. Use of technology aids was also found to increase nearly fourfold to over 38% in the past decade among those with a brain injury [12]. Existing technology like smartphones can be programmed to function as a memory aid. For example, to increase target behaviours among 13 individuals with memory impairment due to TBIs, Evald [13] designed a prospective memory aid in the form of a calendar program integrated into an unmodified smartphone. At the end of a 6-week intervention, although the targeted behaviour performance of the individuals with TBI did not improve significantly, participants self-reported significantly fewer memory issues [13]. In another study, use of a service that sends reminder messages to mobile phones at predetermined times (i.e., NeuroPage) [14] was found to significantly improve the number of daily diary items remembered and reduced psychological distress among individuals with multiple sclerosis [15].

Although these electronic methods have been shown to be effective, they often place burden on a caregiver to set up the application, program events, set alarms and/or input information into the device. Additionally, many of these types of programs or applications are designed for younger users or those that are cognitively healthy. They do not accommodate for age-related or pathologic declines in cognitive or perceptual abilities. For example, older adults struggle with viewing smaller fonts and low contrasting colours on the screens of electronic devices [16]. Complex interfaces also pose a challenge for older adults or those that are cognitively impaired because they can tax working memory, episodic memory, processing speed and visuospatial abilities [16]. These are all abilities that decline in individuals with MCI and AD. Furthermore, these difficult-to-use commercially available software applications cannot easily be customized for cognitively compromised populations and often have small screen displays that hinder older memory-impaired individuals from using these aids to their fullest potential [17–19]. These flaws of existing external memory aids underscore the importance of designing for and with older adults with MCI to create easy-to-use and intuitive interfaces customized for this target population to decrease memory load and simplify learning.

A more portable, accessible, effective and user-friendly external memory aid is needed that meets the needs and expectations of older adults and allows them to preserve their independence and quality of life. This external memory aid also needs to compensate for the shortcomings of existing external compensatory memory aids. We propose a DMN application with the following capabilities: prompts habitual use and initiation of activities, provides a space to record important personal and medical information, a space to journal and write notes, and a space to record past, present and future events to support recall and everyday functioning. Additionally, the integration of alarms for reminders, a home page set to the current date, and text to support entries are some missing features from paper-pencil notebooks that are expected to facilitate learning and use of the DMN. When partnered with a smart home system, the DMN is also capable of prompting for DMN use following periods of inactivity and at opportune times. The smart-home/DMN partnership also allows for automatic activity tracking so that completed everyday activities (e.g., mealtime) can be automatically integrated into the DMN thus reducing memory load while increasing self-efficacy.

The starting point for development of the DMN was the paper–pencil memory notebook used in prior work with individuals with MCI and mild dementia [8,9]. In designing the initial application, we also applied Diaz-Bossini and Moreno's [20] guidelines for designing mobile applications for older adults, including large targets (buttons), simple icons, confirmation feedback upon selecting a button, limited gestures to navigate (single tap, swipe and scroll) and sparse but contrasting colours. The first iteration was developed on an Android platform and tested with eight healthy older adults [21]. Participant feedback led us to translate the application onto an iOS platform as participants reported being more familiar with the iOS platform and felt it was more user friendly compared to some of the Android features. In this study, we report on four subsequent iterations (two through five) of the DMN development that used the iOS platform and were conducted with persons with MCI and caregivers. By working in cooperation with persons with memory impairment and their caregivers, we were able to tailor the DMN's design interface to the target population's needs. Across iterations, we expected that ease of interacting with and using the DMN application would improve as documented by faster completion of experimental tasks that required participants to add events, navigate the interface and add information. Satisfaction with and usability of the DMN application, as measured by participant self-report, was also expected to increase across iterations with final iteration ratings falling in the upper range of the QUIS and the Agree to Strongly Agree range on the PSSUQ (i.e., QUIS = 7–9 and PSSUQ = 1–2).

Materials and methods

Participants

There were 20 older adult study participants (ages 50+); five older adults participated in each of the four iterations detailed in this paper. Past research suggests that five participants per iteration is enough to determine approximately 85% of usability problems that can be discovered in that iteration, after which experimenters are likely only to observe the same issues with each subsequent participant [22]. Study participants were either experiencing memory deficits associated with a diagnosis of MCI or as a result of a TBI or were caregivers for an individual with memory impairment. Table 1 provides a summary of participant demographics for each

Table 1. Participant demographics (mean and standard deviation values) by iteration.

	Iterations			
	Iteration 2	Iteration 3	Iteration 4	Iteration 5
Participants	N = 5	N = 5	N = 5	N = 5
Age (years)	75.40 (12.60)	71.40 (4.34)	69.20 (12.28)	72.80 (3.96)
Range	62–94	67–77	54–88	67–77
Diagnosis	1 caregiver, 2 TBI, 2 MCI	2 caregivers, 3 MCI	4 MCI, 1 TBI	5 MCI
Gender	3 female 2 male	4 female 1 male	3 female 2 male	3 female 2 male
Education (years)	20.00 (0)	15.80[a] (1.79)	17.00 (2.65)	17.20 (2.28)
Range	20	14–18	13–20	14–20
MoCA	23.60 (2.88)	25.00 (2.92)	24.00 (1.41)	23.20 (2.28)
Range	20–27	22–29	23–26	21–26
Scheduling tool use	6.34 (0.46)	5.03 (2.35)	6.51 (0.48)	6.11 (0.50)
Range	5.71–6.86	1.00–6.86	6.00–7.00	5.43–6.71
Technology comfort	5.13 (0.81)	4.50 (1.17)	5.07 (1.57)	4.97 (1.05)
Range	4.33–6.00	2.83–5.83	2.67–6.50	3.83–6.17

MCI: mild cognitive impairment; TBI: traumatic brain injury; MOCA: Montreal Cognitive Assessment.
[a]Values that are significantly different than those of the other iterations.

iteration. Ages of participants in each iteration did not differ significantly, $F = 0.39$, $p = .76$ (see Table 1). Participants were generally well-educated, with an average of 17.5 years of education. Education level differed across iterations, $F = 4.10$, $p = .02$, with Iteration 3 participants having significantly less years of education than the other iterations (see Table 1). Despite high education levels, 70% of participants fell in the MCI range of functioning on a brief screening measure of cognitive abilities (i.e., the Montreal Cognitive Assessment, MoCA). All participants were recruited from prior studies conducted in our laboratory and had given permission to be re-contacted. The study was approved by the University Institutional Review Board.

Assessment instruments

The following instruments were used to gather information about participant cognitive status, comfort with technology and self-report of satisfaction and usability.

Montreal Cognitive Assessment [23]. The MoCA is a brief cognitive screening tool for MCI. The MoCA consists of eight categories of tasks that evaluate visuospatial/executive reasoning, naming, memory, attention, language, abstraction, delayed recall and orientation. A score of 26 out of 30 possible points is considered normal.

Scheduling Tool Use Questionnaire (STUQ). This questionnaire was developed for this study to establish how often participants use technological scheduling tools. Participants rated seven statements such as "I use scheduling tools and reminders in my everyday life" on a Likert scale of 1 (Strongly Disagree) to 7 (Strongly Agree); scores were calculated by averaging all responses for an overall score. Higher scores indicate greater use of scheduling tools (Cronbach's $\alpha = 0.43$).

Technology Comfort Questionnaire (TCQ) [24]. To establish participant comfort with technology use, participants rated 6 statements such as "I am generally comfortable with technology" on a Likert scale of 1 (Strongly Disagree) to 7 (Strongly Agree); scores were calculated by averaging all responses for an overall score. Higher scores indicate greater comfort with using technology (Cronbach's $\alpha = 0.76$).

Questionnaire for User Interface Satisfaction (QUIS) [25]. The QUIS measures an individual's perceived satisfaction with a system, in this case the DMN application. Comprised of 26 questions, participants rated statements on a Likert scale of 0 (bad) to 9 (good). The QUIS has been used in numerous studies and is proven to be reliable (Cronbach's $\alpha = 0.94$) [25]. The questionnaire measures participants perceptions of the following facets of the user interface: overall, screen, terminology, learning and system capability. Overall and subscale scores were calculated by averaging responses from each of the scales.

Post-Study System Usability Questionnaire (PSSUQ) [26,27]. The PSSUQ consists of 19 questions that measure an individual's opinions regarding the usability and acceptance of an interface after interacting with it, in this case the DMN app, on a scale of 1 (Strongly Agree) to 7 (Strongly Disagree). The questionnaire includes an overall score and three subscales measuring system usefulness, information quality and interface quality. Reliability coefficient alphas of 0.96, 0.91 and 0.91 in the above listed order, and an overall coefficient alpha of 0.97, support the validity of the PSSUQ [26,28]. The overall and subscale scores were calculated by averaging responses for each of the scales.

Digital memory notebook application

The DMN application was downloaded onto a 9.7-inch capacitive touchscreen iPad with the iOS operating system 9 or higher. The DMN has an intuitive design with simple functions and minimal pages (so as not to tax working memory). It has four main pages (i.e., Today or Home page, Calendar, Notes and Profile) and a sub-component accessible by the Today page (i.e., Add Task/Event). See Figure 1 for pictures of the second and fifth iteration of each page described below. Incorporating these elements into one application is one strength of the DMN; while other devices like smartphones have built-in applications like calendars, contacts, reminders and notes, they are still all separate entities on a small interface and do not allow for integration of external sources of information (e.g., smart home system data).

The Today page is comprised of a to-do list (user-entered tasks plus smart home-detected tasks) and the hourly view (time blocks associated with tasks), both of which can be used to support retrospective memory and prospective memory. The Today page features large blue buttons accompanied by text and icon signifiers. These blue buttons are present throughout all components of the application. The colour orange is used to highlight buttons that provide access to important features like adding tasks. The Today page includes visual indicators such as a thick, green line to indicate the current time on the hourly view. The main touch screen gestures that can be used on this component are tap and scroll up and down as well as swipe from left to right. Unlike the DMN, smartphones' Home screens

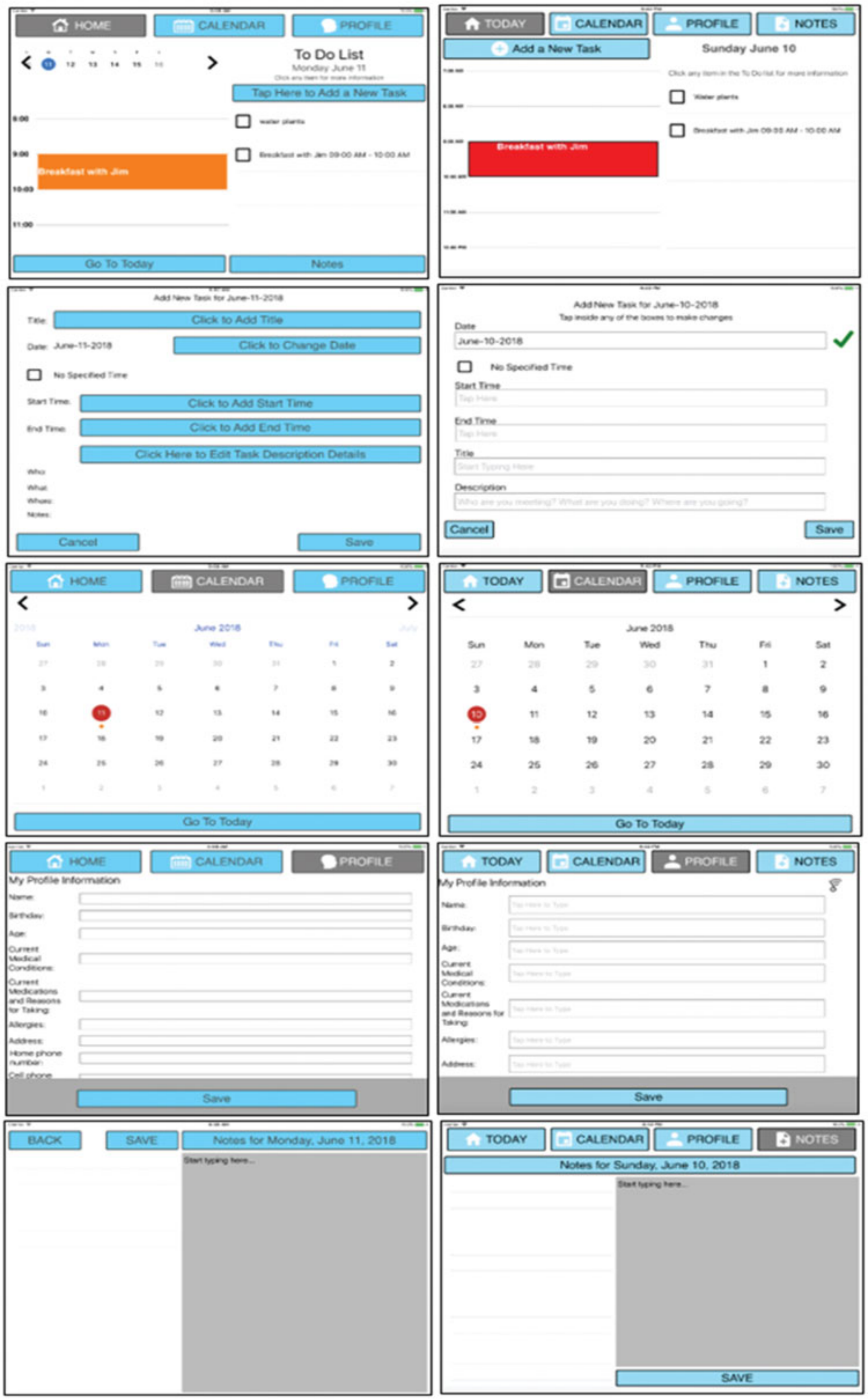

Figure 1. Pictured from top to bottom: The Today page, Add New Task page, Calendar page, Profile page and Notes page of Iteration 2 (left) and Iteration 5 (right).

show only an array of applications, requiring the user click on the appropriate one to see their schedule for the day. The DMN Add Task component, which is accessed from the Today page, is a simple form-style page that includes large text entry fields and buttons to add details about different types of tasks. This component features several textual hints as well as green check-boxes that appear as the user completes entering information in the text entry fields.

The Calendar is a monthly view that allows quick and easy access to any desired date using a standard monthly calendar visual. The Calendar features large text and simple descriptions for navigation purposes.

While smartphones do allow for setting up a contact card for oneself, information beyond email and phone number is not available to fill out. The Profile page offers a place to input personal information (i.e., name, address, medical history and doctor's contact details) to support a user's own memory as well as inform care providers. The profile page features large clearly labelled text entry boxes and well as green checkboxes that appear as the text entries are completed.

Finally, the Notes feature supports retrospective memory, long-term planning and activity completion by allowing users to organize information (e.g., telephone numbers), to jot down notes about events or thoughts associated with any calendar day, and to plan and monitor progress with longer-term projects [29]. The Notes component consists of a dated Journal portion and a titled note portion, each organized in a list style. Each type of note is opened by tapping on the note in the list and are edited and displayed with a simple large text display.

Procedure

Prior to being invited to the laboratory to interact with the DMN app, experimenters updated demographic, medical and cognitive history information via a telephone interview. Once in the laboratory, participants completed the scheduling tools (i.e., STUQ) and technology comfort (i.e., TCQ) questionnaires and were administered the cognitive screener (i.e., MoCA). Experimenters then familiarized participants with the DMN interface (i.e., a tour of the location and function of each button/feature/page) before beginning the study. Participants completed a series of nine tasks that allowed them to interact with the memory notebook application on an iPad. For example, one task required participants to add to the To Do List a book club meeting from 2:00 to 4:00 p.m., with the location of the public library and a reminder to bring their book. Another task required participants to navigate the interface to the calendar and check that an existing task – a day trip to Seattle on August 22nd – was correctly entered. A third task required participants enter information (i.e., name, date of birth, allergies) into the profile page. For each task, experimenters recorded how long (in seconds) participants took to correctly complete the task. The tasks were sorted into three categories and average response times computed for each participant: adding events (tasks one and four), navigating the interface (tasks two and five) and adding information (tasks three, six and nine). Tasks seven and eight were excluded from analysis due to overlap with more than one of these three categories. Tasks one, two and three included three trials of the same type of task that were similarly constructed (i.e., adding an event) so that learning could be assessed. Following completion of all DMN tasks, participants filled out the user interface satisfaction (i.e., QUIS) and system usability (i.e., PSSUQ) questionnaires and were asked a series of open-ended questions regarding the DMN's features and functions to gain feedback on how to better future iterations.

Analysis

Using one-way analysis of variance (ANOVA) with Bonferroni's *post hoc* testing, the data were first checked to determine if there was a need to account for differences across iterations in participants' cognitive status, familiarity with scheduling tools and familiarity with technology. To assess for change across iterations, DMN task completion times for each task category (i.e., adding events, navigating the interface and adding information) and the questionnaire data were averaged across participants in each iteration and are displayed as percent change, as suggested by Cardello [30]. Percent change was calculated as the difference between the previous and new iteration average time taken to complete each task category. The difference was then divided by the previous task average and the quotient was multiplied by 100. This procedure was used to compare Iterations two to three, three to four, four to five, and two to five. Changes in a positive direction between iterations are indicated by a plus sign and are preferable as they indicate an improvement in the task being measured.

To assess for learning, repeated measure ANOVAs were conducted to determine whether response times improved across repeated trials of similar tasks (i.e., trials 1, 2 and 3). Response times for tasks one, two and three were averaged together for each of the three similar trials of the task across all participants. Bivariate correlations were also conducted to examine for relationships between DMN task completion times, user satisfaction and usability ratings, MoCA scores, technology comfort and scheduling tool use scores.

Results: quantitative

As seen in Table 1, there were no differences in scores on the MoCA across iterations, $F = 0.50$, $p = .70$. Similarly, there were no differences in scores across iterations on self-reported use of scheduling tools, $F = 1.44$, $p = .27$, or comfort with technology, $F = 0.29$, $p = .83$.

Table 2. Percent change values across iterations for the digital memory notebook (DMN) task categories and questionnaires.

	Percent change			
	From iterations 2 to 3	From iterations 3 to 4	From iterations 4 to 5	From iterations 2 to 5
DMN task categories				
Adding events (to the to-do list)	+76.71%	−31.28%	+29.52%	+78.45%
Navigating the interface	+71.40%	−79.94%	+42.39%	+70.36%
Adding information (to profile)	+15.97%	−21.69%	−2.23%	−4.54%
QUIS overall score	+16.07%	−24.95%	+35.22%	+17.79%
Screen	+15.11%	−24.38%	+41.32%	+23.02%
Terminology	+18.07%	−4.42%	+17.08%	+32.12
Learning	+15.38%	−22.05%	+33.55%	+20.12%
System capabilities	+15.08%	−5.83%	+6.70%	+15.64%
PSSUQ overall score	+13.77%	−21.89%	+31.22%	+27.71%
System usefulness	+3.97%	−14.97%	+24.18%	+16.29%
Information quality	+17.90%	−28.87%	+45.81%	+42.67%
Interface quality	+19.02%	−26.98%	+16.67%	+14.31%

QUIS: Questionnaire for User Interaction Satisfaction; PSSUQ: Post-Study System Usability Questionnaire.
Increases in task completion times are indicated with bold font. (+) Change in the desired direction for each measure.

DMN tasks: between iteration changes

Table 2 presents changes across iterations on the three categories of DMN tasks. The adding events and navigating the interface task categories both illustrated improvement in time taken to complete the given tasks across Iterations 2–5, with the exception of Iteration 4 where participants took longer on average to complete these types of tasks. For Iteration 2 of the DMN, it took participants an average of 672 s (s) to add tasks and this was reduced by 78.42% to 145 s by the fifth iteration. Similarly, participants averaged 74 s using Iteration 2 to complete the navigating the interface tasks, which decreased by 70.27% to 22 s with the fifth iteration. The adding information task category showed little change over time across iterations, being completed relatively quickly from the start (Iteration 2 = 39 s and Iteration 5 = 41 s).

DMN tasks: across trial changes

A repeated measure ANOVA to determine whether response times improved across repeated trials (i.e., trials 1, 2 and 3) of similar tasks revealed a significant main effect of trial, $F(2,118) = 10.27$, $p < .001$. Participants completed the tasks faster for trial 2 (as measured in seconds) than trial 1, $F(1,59) = 6.08$, $p = .02$, and faster for trial 3 than trial 2, $F(1,59) = 11.07$, $p = .002$. The data showed a 28.89% decrease in amount of time it took to complete the tasks between trial 1 ($M = 114.13$, SD = 158.37) and trial 2 ($M = 81.16$, SD = 91.81), and a further 24.79% decrease in response time between trial 2 and trial 3 ($M = 61.05$, SD = 76.68). This indicates that participants improved in their ability to use the DMN features with practice.

Questionnaires

The user satisfaction questionnaire (i.e., QUIS) overall and subscale scores followed the same pattern across iterations as the average task completion times described above for the DMN app. As seen in Table 2, participants rated Iterations 3 and 5 more favourably than the previous iterations. Iteration 4, however, was rated lower than Iteration 3. The overall change in overall QUIS score from Iterations 2 to 5 was positive, increasing from 6.73 to 7.93 (out of 9.00). All QUIS user satisfaction subscales demonstrated the same pattern of change in scoring from iteration to iteration. By Iteration 5, all QUIS subscales were rated on average at or above an 8.12 out of a possible 9 (Screen = 8.55, Terminology = 8.50, Learning = 8.12, System Capabilities = 8.28), suggesting high user satisfaction.

The system usability (i.e., PSSUQ) scores across iterations also reflected higher scores for Iterations 3 and 5, but not 4 (see Table 2). Overall, participants rated Iteration 5 better (as indicated by lower scores) than Iteration 2, going from 2.82 to 2.04. Iterations 3 and 5 scores were calculated with 3 and 4 participant responses, respectively. PSSUQ subscale scores also illustrated this similar pattern. By Iteration 5, all PSSUQ subscales were rated on average at or below 2.22 out of a possible 7 (System Usefulness = 2.22, Information Quality = 1.86, Interface Quality = 2.00), which is in the Agree to Strongly Agree range.

Correlational analyses

As seen in Table 3, correlational analyses showed that faster completion times for all three categories of DMN tasks were associated with more favourable ratings on the usability questionnaire (i.e., PSSUQ) overall score ($rs > 0.52$). A similar pattern was found between the system satisfaction (i.e., QUIS) overall score and navigating the interface ($rs = 0.51$) and adding information DMN tasks ($rs = –0.46$). These findings suggest that participants' satisfaction and opinion of the DMN increased as they were able to perform the tasks asked of them with greater proficiency. Furthermore, with one exception, correlational analyses suggested that neither ability to complete the three categories of DMN tasks nor participants' self-reported ratings of satisfaction with and usability of the DMN (i.e., QUIS and PSSUQ overall) were associated with self-reported measures assessing comfort with technology and use of scheduling tools, or with cognitive ability (i.e., MoCA), $rs > –0.38$ and $rs < 0.21$ (see Table 3). The one exception was the finding of a significant negative correlation between the MoCA score and Navigating the Interface ($r = –0.47$), suggesting that poorer cognition was associated with longer task performance for this task category.

Table 3. Pearson's correlations of questionnaires and task completion times.

	1	2	3	4	5	6	7	8[a]
1. Adding events	–							
2. Navigating interface	.394	–						
3. Adding information	.600*	.150	–					
4. Technology comfort score	–.086	.059	–.055	–				
5. Scheduling tool use score	.072	.017	–.014	–.102	–			
6. MoCA total score	–.019	–.470*	–.140	–.407	–.117	–		
7. QUIS overall score	–.318	–.505*	–.463*	–.047	–.194	.207	–	
8. PSSUQ overall score[a]	.521*	.685*	.591*	.166	–.384	–.235	–.836*	–

*Significant correlation.
[a]Correlations computed with 17 participants.

Results: qualitative changes based on participant feedback

Here, we outline the major changes to each DMN feature that occurred between each iteration of usability testing. Figure 1 shows side-by-side images of the Today, Add New Task, Calendar, Profile and Notes features comparing Iteration 2 to Iteration 5. Table 4 outlines the technical specifications of each iteration. Each change was motivated by participant feedback and clinician observations. Each change was made with the purpose of bettering the user's experience and the ease of use of the interface.

Across iterations, the font, button size and text contrast were gradually increased to improve visibility to address participant feedback that text was difficult to read, and buttons were too small to efficiently touch. After every iteration, there were suggestions from both participants and examiners to add features to improve the utility of the DMN to better support retrospective and prospective memory as well as guide participants through interactions with the DMN. New features that were added included: cues to enter specific types of text to help lead users through textual information entry, various icons such as check marks and red flags as well as alarms and notifications to help users more easily keep track of their daily activities, and verbiage was simplified to clarify instructions and improve understanding. New components that were added as a result of participant feedback included a journaling component in the Notes section and a physical keyboard for typing (as opposed to touch screen). Some features that adhered to iOS standards were replaced with simplified versions of these features that did not require complex motion. For example, standard iOS date and time pickers were exchanged with click to select date and time pickers to reduce issues with scrolling and swiping.

Post-Iteration 5, the DMN application was completely rebuilt according to the specifications learned by usability testing to

Table 4. List of cosmetic and technical changes from iteration to iteration.

	System and cosmetics	Today page	Add new task	Profile	Notes
Iteration 2	1. Switched to iOS platform 2. Increased font size and target size of checkboxes 3. Increased spacing of time blocks in visual time schedule	1. Weekly calendar added to select dates easily (instead of swiping) 2. "Tap Here to Add a New Task" button text added 3. Black text colour in To Do List	1. Buttons to bring up text entry for Title and other entry fields 2. Who, What, Where and Notes fields to add more detail for tasks 3. iOS standard date/time selection		1. New added feature (not available in Iteration 1)
Iteration 3	1. Decluttered interface to simplify 2. Increased font size	1. Removed weekly calendar navigation; trained participants to use Calendar[a] page to navigate to new dates 2. Enlarged "Add a New Task" button and added "+" icon 3. Current date displayed at the top	1. Buttons replaced with large text fields and text hints (i.e., "Tap Here") 2. Description box to add details (Who, What, Where) 3. Green check marks appear next to successfully filled text fields		
Iteration 4	1. Physical keyboard option 2. Changed "Confirm" to "Okay" when prompted for Smart Home task completion confirmation 3. Higher colour contrast	1. Moved Notes button from bottom to top of page (next to other buttons) 2. Borders around event blocks in visual time schedule 3. Black text for majority of buttons (except when highlighted)	1. Pop-up notifications for time conflicts when adding a new task 2. High importance marker (red flag icon) available to denote tasks/events 3. Task alarm available (15, 30, 60-minute reminders)		1. "Start typing here" in entry field 2. Increased size of Save button
Iteration 5	1. Changed "Okay" to "Click to Confirm" when prompted for Smart Home task completion confirmation 2. Voice to Text feature 3. Changed to clicking time selection (instead of iOS scrolling)	1. Return to Today page from Calendar[a] by double-clicking "Go to Today" button 2. "Click to Confirm" button moved to top of check boxes in To Do List	1. Option to repeat tasks when adding them (i.e., daily, weekly, monthly) 2. Task alarm available (10, 15, 30-minute reminders)	1. "Tap Here to Type" text added to all text entry fields 2. Green check marks appear next to successfully filled text fields	

Each row lists the characteristics/technical specifications of that iteration.
[a]Minimal changes to feature. Calendar changes were larger font size and switching blue font colour to black in Iteration 5.

make the application more stable, as well as to add a few new features. Among these changes/additions were increased text size and colour contrast between buttons and surrounding elements, and modified text prompts to communicate more clearly what belongs in the text field (e.g., "Tape Here to Type" was changed to "Tap Here to Fill In Information"). A Help page was also added, accessed via a button with a question mark inside a circle on the Today page. The Help page includes text explanations and informational videos for users needing a resource to look up answers to application use questions (e.g., how to access a feature). The application was also reprogrammed such that viewing, editing and deleting current task details opened a separate window to minimize the chance of unintentional alterations to other tasks. The rebuilt application has enhanced security features, requiring a simple username and password to login. In addition to being able to set recurring events (incorporated in Iteration 5), these recurring events are marked with a circle of arrows in the To Do list on the Today page. Several improvements were also made to simplify and improve usability and organization of the Notes section. For example, pictures can easily be taken with the tablet and attached to Notes or Journal entries to enhance the entries. To increase ease of use, a Search feature allows participants to quickly access a specific Note or Journal entry they may be looking for; this will be especially helpful after participants have been using the DMN for some time and have accumulated a lot of Notes or Journal entries. Motivational features were also incorporated to support DMN use. At random intervals, the DMN provides participants with a motivational quote and prompt encouraging them to record a recent achieved accomplishment in a specific Note created for this purpose.

In addition to information that is manually entered into the application, the DMN is also capable of incorporating live activity data that is produced by an existing smart home infrastructure consisting in part, of several ambient sensors placed around the home. As the resident moves around the home performing their normal routine the smart home system automatically records patterns of sensor events that are activated, such as motion and door sensors. These patterns of sensor events are then fed to an algorithm that can interpret them as activities. The goal of this feature is to automatically add activities the smart home has recognized as completed by the resident to support retrospective memory for individuals that may forget to enter certain activities into the DMN consistently. These smart home-recognized activities show up in the To Do List on the DMN's home alongside their manually entered tasks.

All these changes taken together became the sixth iteration, which will be deployed in a pilot clinical trial. To support the clinical trial and participant acquisition of consistent DMN use, the Settings page allows clinicians to adjust components within the DMN (e.g., turning on or off the hourly training alarms used during early stages of DMN intervention training sessions; use of pictures).

It is also important to note that it is possible to create a product that individuals highly regard but would not use, illustrating a gap between evaluation of the product and interest in using the product. To assess whether participants with MCI would be willing to use a technology like the DMN to assist with everyday memory difficulties, we asked Iterations 4 and 5 participants whether they would be interested in using the DMN application once it was complete. Participants with MCI in both Iterations 4 and 5 expressed positive interest in the DMN. One Iteration 4 participant responded that they would use the DMN application after some changes were made (e.g., "the option to see the week too instead of just [the] day"), with the remainder responding "most likely" or "yes". All participants in Iteration 5 replied "yes" or "yes, probably", with one participant asking "When would this be available?". These responses suggest that participants with MCI not only rated the design features of the DMN highly but also recognized the possible benefits of the DMN, given their interest in using the DMN application.

Discussion

Our goal was to develop a user-friendly mobile DMN application using an iterative user-centred development process. We expected that each iteration of the DMN would become increasingly easier to interact with and use. Improvements were operationalized as faster completion times for tasks using the DMN app, and increased satisfaction and usability ratings as measured by the QUIS and PSSUQ questionnaires, respectively. Our goal was to reduce task completion times and to have participants rate all questionnaire items for the final tested iteration in the upper range of the QUIS (i.e., 7–9 range) and the Agree to Strongly Agree range of the PSSUQ (i.e., 1–2 range).

Consistent with expectations, participants showed marked reductions in task completion times from Iteration 2 to Iteration 5 for two of the three task categories: adding events (672–145 s) and navigating the interface (74–22 s). The third task category, adding information, showed no change (39–41 s). This could be due to the fact that adding information to the Profile page was functioning well to begin with and did not need major improvements. That is, in comparison to the approximately ten changes the DMN interface underwent for the adding events and navigating the interface tasks, the Profile page underwent only two changes. In addition, the adding information tasks also required fewer task completion steps.

Consistent with our goal, participants in the final iteration (Iteration 5) on average rated all subscales of both the satisfaction questionnaire (i.e., above 8 on a nine-point scale) and usability questionnaire (i.e., 2 or below on a seven-point scale) very highly. This indicates that we were successful in meeting a threshold indicative of a strong level of DMN usability and satisfaction. The lack of correlations between questionnaire ratings of DMN satisfaction and usability with measures of cognition, scheduling tools use, and comfort with technology further suggests that the application is broadly user-friendly. This fulfils our goal of making the DMN user friendly for individuals with MCI regardless of cognitive abilities, familiarity with technology or prior use of scheduling tools.

Correlational analyses also revealed that faster task completion times for all three categories of DMN tasks were associated with more favourable system interface usability ratings (PSSUQ). Similarly, more favourable satisfaction ratings (QUIS) were associated with both faster task completion times for navigating the interface tasks and adding tasks. These findings indicate that participants' satisfaction with and opinion of the DMN increased as they performed the tasks quicker. These findings are consistent with prior work [31], which has found that participant's perception of the likeability and usability of technology appear to be partly related to their ability to quickly and easily use the features.

Although still high, the lowest rated attributes of Iteration 5 for system usability were System Capabilities (8.28 out of 9) and Learning (the system) (8.12 out of 9). The next step is a pilot clinical trial to teach individuals with MCI how to use and incorporate the DMN into their daily routine. In the current study, we did not provide participants with formal training in the application, as the goal was to improve usability and design of the DMN. We did find, however, that when the data were combined across iterations, participants became faster at completing similar tasks across trials. This suggests that practice with a task improved participants' speed and efficiency when interacting with the DMN. Participants in the clinical trial will receive a standardized flexible five to six-session training protocol guided by a clinician and a user training workbook. We expect these changes will improve ratings for system Learning. In addition, we used participant feedback to further build out features for the DMN application that will be used in the pilot clinical trial, including adding a Help page, search function, security features, picture capabilities for Notes and recurrent event settings. We expect that these added features will further increase participant satisfaction ratings in the areas of System Capabilities.

Participants rated Iteration 3 higher than Iteration 2 in both self-reported satisfaction and usability (7.82 and 2.43 compared to 6.73 and 2.82, respectively) and task completion times were faster in Iteration 3. Compared to Iteration 2, Iteration 3 featured a decluttered interface, enlarged font and button size, the current date on the Today page, and check marks next to successfully entered text fields on the add new task page. These changes both simplified the user's experience and helped guide them through each interaction, likely contributing to the significant decrease in task completion time for the adding events and navigating the interface task categories. In contrast, Iteration 4 was rated lower than Iteration 3 in satisfaction and usability. Response times for all three DMN task category performances also increased for Iteration 4 compared to Iteration 3. Taken together, this data may suggest that the changes made to the DMN following Iteration 3 led to worse reception. In contrast to Iteration 3, Iteration 4 featured a physical keyboard, task alarms, borders around event blocks, pop up notifications and red flags – all elements that could have complicated the interface, leading to lower ratings and longer completion times. It is also important to consider possible differences in participant demographics. Iteration 4 consisted of four individuals with MCI and one with TBI, which was two more cognitively impaired individuals than the two caregivers and three individuals with MCI who served as participants for Iteration 3. Also of note, two of the participants that tested Iteration 4 were married and experimenter notes indicated that they appeared to present with a negative mood state the day of testing. Their subsequent lower ratings of the application could have reflected their negative mood state and skewed Iteration 4's ratings.

Iteration 5 of the DMN was tested with five individuals with MCI and received uniformly favourable reviews (QUIS: 7.93; PSSUQ: 2.04) and improved DMN task response times. Iteration 5 featured specific text prompts and a more user-friendly time and date selector that featured simple single tap selections as opposed to a scrolling element. It also featured a way to streamline interaction with the add new task page; smaller increment task alarms and the ability to create repeating tasks facilitated adding multiple tasks quicker. Of importance, participants with MCI in both Iterations 4 and 5 indicated that they would be interested in using the DMN application if it were made available. This suggests that in addition to creating an application that received high satisfaction and usability ratings, participants with MCI recognized the potential benefits of the technology for assisting with everyday memory difficulties. Given the positive user feedback and the subsequent modifications to further enhance the application, we expect that the current iteration being used in the pilot clinical trial will receive equally favourable reviews, if not better reviews.

This iterative design study also illuminated several aspects of iterative design development. First, our study underscored the importance of intentionally designing for older adults and those with memory impairment when creating any type of external, technological memory aid. Technology aids as they are on the market are not made to cater to older adults, who have different needs given the sensory and motor changes that occur as part of the normal aging process. When we created the first iterations, we did so with the principles for designing for older adults set forth in previous studies [32] (e.g., appropriate illumination, large text size, increased distance between objects on screen). As iterations progressed, we continued to make cosmetic changes to better serve our target population such as larger buttons, better contrast between colours of different elements and increased text size. One such specific example of catering to older adults and those with MCI involved the time and date selection mechanisms. Existing literature advises to avoid scrolling movements, yet the standard iOS platform featured exactly that when choosing a date or time. As experimenters observed participants struggle and voice their dislike for the feature, we replaced the scroll selector with a touch-to-pick selector standard for Android platforms.

Second, the success of this iterative design process as shown by user feedback and ratings speaks to the benefits of usability testing and designing not only for but with users when developing this application. By testing the DMN application iterations (i.e., Iterations 2 through 5) with potential users (i.e., older adults with varying levels of cognitive abilities), we were able to not only receive feedback we may not have learned from younger or cognitively intact participants but also integrate it and then test the changes with a new sample of older adults with memory impairment. Thus, with the feedback of memory impaired older adults we were able to create an application that was made-to-order for the targeted user population and should therefore be usable and useful for individuals with MCI.

We also allowed three participants to take Iteration 5 home to use it for one week. This allowed for examination of real-life situations that would better emulate the intended use of the application (integrated into a normal, daily routine), and discovery of necessary changes that participants may not have been able to uncover during one supervised session in the laboratory. For example, we discovered that individuals with MCI would forget how to operate features of the DMN after leaving the laboratory (e.g., how to add or modify a task). This led us to change the colour of the “Add New Task” button to make it stand out in the interface, due to participants forgetting where the button was located. Furthermore, it became more salient that we needed to design a Help function for users. We also learned that participants would appreciate a reward system that encouraged and motivated users to continue to use the application. Accordingly, we added pop-up notifications with motivational messages and prompts to record achievement milestones into the final application. Therefore, testing in a real-world environment is also very important so that we can generalize our findings to the environment in which the DMN will be used and make our product usable and desired by our target population. There are shortcomings of this study that should be addressed and improved upon in future research. As we conducted testing sessions in a controlled environment (i.e., our laboratory) with an experimenter observing, it is possible participants felt undue pressure to compensate for any design flaws and rate the application favourably, holding back honest feedback. We also had among our participants cognitively intact individuals (i.e., caregivers), in addition to cognitively-impaired individuals. This could have skewed the iterations’ ratings, resulting in a less-than-accurate picture of how our target population (cognitively impaired users) regards the DMN. Importantly, all Iteration 5 participants had MCI and the DMN application was rated uniformly high across all aspects of usability and satisfaction by this group of participants. Subjective ratings and performance of tasks could also both have been skewed due to our sample of participants being well-educated. With only five participants per iteration, it is possible that other factors such as affective state or fatigue could have played a more significant role in influencing DMN ratings that were less likely to be averaged out as would happen with a larger sample size. Future work might benefit from utilizing the “thinking aloud” testing method during usability testing sessions. While we recorded participants’ comments we did not instruct them to share their thoughts during interaction with the DMN, which could have illuminated misconceptions of design elements and the reasons for these misinterpretations that the participant may not have articulated during follow-up questionnaires [33].

Future research could also explore a voice interface to augment natural interaction between user and application, as with Google Home or Amazon’s Alexa devices. Additional studies of the same nature with commercial technologies such as applications already available on standard smartphones would be beneficial. For example, if the completion times of similar tasks are faster and feedback more positive for the DMN than that of another application, it will further validate the DMN as more usable and preferable than other options.

By combining various features of validated external compensatory aids into a user-friendly technological tool, we created an application that can be used to increase functional independence as well as support retrospective and prospective memory difficulties for individuals with cognitive impairment. Compared to current paper-pencil methods that are traditionally used in rehabilitation, the DMN is an interactive and integrative application with adjustable font size and contrasting colours that prompts users to utilize it with alarms and notifications. This technology combines these features with elements of existing memory notebooks (e.g., scheduling and journaling capabilities), which go beyond available digital devices without being too cumbersome to carry. Preliminary data from three pilot case studies also showed that participants experiencing memory difficulties were able to learn to quickly learn to use the elements of the DMN and were successful in consistently integrating it into their daily routine [34]. These users subsequently also reported increased satisfaction with life and decreased everyday memory difficulties [34]. With the pilot clinical trial as the next step, we expect the DMN will be further validated to improve functional independence and quality of life for users.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Disclosure statement

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ORCID

Nisha Raghunath https://orcid.org/0000-0001-5154-8613
Diane Cook https://orcid.org/0000-0002-4441-7508
Maureen Schmitter-Edgecombe https://orcid.org/0000-0002-5304-2146

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