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Supporting people with Acquired Brain Injury to use a Reminding app; Narrow-deep vs. Broad-shallow User Interfaces

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People with memory impairments following an acquired brain injury stand to benefit from smartphone apps as memory aids. Due, in part, to usability issues they use smartphone-based reminding less than the general population. Evidence suggests this group may benefit from user interface (UI) designs with more screens with less information per screen (narrow-deep UI) rather than fewer screens with more information per screen (broad-shallow UI). This study compared the difference in speed, accuracy, guidance needed and task load for 32 people with acquired brain injury when setting reminders using narrow-deep and broad-shallow UI. They were also given cognitive assessments (measuring selective attention, executive functioning and overall executive and memory ability) and interviewed about their UI preference. There was a significant difference in accuracy; participants were less accurate (they made two more errors on average for every three reminders set) using a broad-shallow compared to narrow-deep UI. The reason for this difference was that participants omitted more information when using broad-shallow UI. There were no differences in speed, guidance required and overall task-load. Participants with better selective attention and more experience with smartphones benefited the most from narrow-deep UI compared to broad-shallow UI. Most participants preferred one UI over the other. Those who preferred narrow-deep found it easier to use, that they missed less information and liked having one piece of information at a time. Those who preferred broad-shallow found it easier to review the information and felt less likely to lose track. The findings can inform that implementation of UI choices to make apps more accessible for those with cognitive impairments.

- **Human-centered computing ~ Accessibility ~ Accessibility technologies**
- **Human-centered computing ~ Accessibility ~ Empirical studies in accessibility**
- Human-centered computing ~ Interaction design ~ Empirical studies in interaction design

Additional Keywords and Phrases: Assistive technology for cognition, Acquired brain injury, Neuropsychological rehabilitation

INTRODUCTION

By 2030, around 4.9% of the estimated worldwide population (387 million people) will have a neurological impairment due to a degenerative disease or acquired brain injury (ABI) (including stroke) [42]. In the UK (population 66 million) there were 480,652 hospital admissions for brain injury and stroke in 2016/17 [1]. Cognitive impairments such as prospective memory impairment are a common and extremely debilitating consequence of neurological damage after ABI.

Prospective memory (PM) refers to the ability to remember to carry out future intentions [7, 33]. These delayed intentions need to be remembered over time while unrelated tasks are completed. PM also involves planning, initiating tasks, self-monitoring and inhibiting distraction [33]. As well as PM difficulties, people with ABI can often experience impaired concentration, attention and judgement [33, 45]. Such impairments can limit the ability to carry out everyday tasks effectively, prevent employment, as well as negatively impacting health, wellbeing and social functioning.

Reminding technologies that prompt the user at a set time can support people to carry out future intentions. [4, 18, 20]. Technology that actively prompts the user about an event at the right time improves memory for intended tasks compared to non-technological methods [8, 18]. Smartphone software that sends reminders is ideal for this support because users are likely to keep their phone nearby. By prompting, supporting scheduling and communicating with care providers, this technology can increase the cost-effectiveness of care by reducing the time spent in costly intensive rehabilitation and reducing the likelihood that people receiving community based care will require or return to more intensive rehabilitation [25].

Although memory aids can be particularly important for people with ABI, this population uses smartphone based memory aids less than the general population. A 2014 survey study found that while 79% of people with ABI (n=81) used paper calendars, only 38% used reminders on a mobile phone [17]. This use could have increased in the time since this study was carried out; two 2017 studies found similar smartphone use between people with TBI and control participants [43] but lower uptake by people with stroke compared to control participants without stroke [44]. A recent study highlighted that there are more barriers to the use of assistive technology to support cognition than other types of assistive technology (e.g. mobility devices) [40]. A systematic review and meta-analysis found a large effect size (d=1.27) over seven studies (n=147) comparing memory aid technology to pencil and paper methods or practice as usual [18]. This research highlights the importance of the user interface design in helping more people who may currently use non-technological memory strategies to also use technology.

1.1 Background

Potential explanations for the low uptake and long-term use of assistive technology include them being challenging to learn/use, people forgetting or not feeling motivated to use them, and lack of support from caregivers [16, 17, 19]. Education and training have been shown to be vital to overcome the barriers to uptake and subsequent use of assistive technology for cognition [36, 37]. Recommending and training use of reminding technologies is a common part of neuropsychological rehabilitation delivered by rehabilitation workers and clinicians to help people with memory impairment after an acquired brain injury [34, 45]. In the absence of purpose-built technologies clinicians turn to widely available reminding apps such as Google Calendar [18, 23]. It is also the case that people often use commercially available smartphone apps and do not receive support from clinicians. Two studies investigating smartphone use by people with traumatic brain injury (n=29) and stroke (n= 29) found that very few participants (4 in total, 2 with TBI and 1 with stroke) had received any formal guidance from a clinician to help them use the technologies [43, 44].

Within this rehabilitation context it has been noted that interaction with devices and apps can be challenging due to cognitive impairments common after brain injury [15, 21, 34, 35]. This is especially true if people with ABI are using the technologies without guidance from clinicians [43, 44]. Users with ABI might not be aware that they need to enter reminders or may forget to enter them in the first place [15] and learning to use reminding technology may be difficult [34, 36]. In these cases, carers or family members may enter reminders on behalf of the individual. The efficacy of reminders set by a third party to support memory has been demonstrated [7, 17]. However, most people with ABI would want or need to independently set reminders. Indeed, learningto independently support memory using memory aids is often an important rehabilitation goal [45].

HCI research can help to improve device accessibility for people with cognitive impairments [6, 12, 13]. HCI researchers have developed web interface design guidelines for people with cognitive impairment. For example, the Web Accessibility Initiative has outlined features people with cognitive disabilities often rely on such as clearly structured content, consistent labelling and predictable interactions [14]. Recent WCAG2.1 guidelines are also relevant such as guideline 1.3; 'Creating content that can be displayed in different ways without losing information or structure' [14].

1.2 Narrow-deep and Broad-shallow UI Design

In the context of setting reminders on a smartphone, there are different ways the information required to set the reminder can be shown (e.g. title, date, time of event, time of notification, notes, repetition, duration). All the information could be shown on a single screen, or a small number of screens. If the information requires more space than the phone screen allows then it could be made smaller or scrolling could be used. On the other hand, there could be many screens each with a small amount of information. This would require the user to navigate between different screens but reduce the need for scrolling or reducing the size of the display. These design choices are described by Hochheiser, Feng and Lazar [12] as 'broad-shallow' (lots of information, few screens) and 'narrow-deep' (lots of screens with less information on each) structures. Most reminding apps use a broad-shallow user interface and do not use or offer a narrow-deep alternative. The first 20 apps that can be found on the iOS App Store when searching 'reminders' (searched February 2021) have broad-shallow designs; all the information that can be entered tends to be on one screen. If there is too much information to fit the mobile screen then scrolling is used. Google Calendar, which has over 1 billion installs, also has a broad-shallow design. Google Calendar has been investigated as a memory aid technology in neuropsychological rehabilitation in several studies [10, 16, 22, 23].

User interface style has rarely been explored in the context of assistive technology to help with ABI rehabilitation. A 2019 review [3] highlighted the lack of research into the impact of user interface design on technology use by people with ABI. This review only mentioned one paper that had investigated an information search user interface by people with cognitive impairment following an acquired brain injury [24]. This paper involved a group of six participants with different types of cognitive impairment, one of which was traumatic brain injury, which limited the findings. There has been no study that has compared different user interface styles in mobile phone reminding apps for people with ABI.

There is evidence that a narrow-deep user interface may be better at supporting technology use for people with cognitive impairments than a broad-shallow one. Hu and Feng [13] investigated the use of broad and deep web content search structure by people with cognitive disabilities (n=23). They found that search failure rates were higher when using the broad structure than when using the deep. Furthermore, neuropsychology researchers who have investigated the use of assistive technology have found that people with ABI have difficulty processing a large amount of information at once. Sutcliffe and colleagues [35] investigated use of an email client on a PC by people with ABI (n=8) and recommended an interface that supports continuous engagement by making the current task object (e.g. text box or send button) salient compared to other distracting objects on the screen. In another study 15 people with ABI receiving rehabilitation and 15 control participants were asked to complete tasks using a PC calendar [22]. Participants with ABI made the same types of errors as control participants but made them more often and experienced a higher workload. They concluded that appropriate software for people with ABI would have an interface that presents a small amount of information and has step-wise data entry to minimise the working memory burden [22].

Micro-prompting technology that aims to guide people with ABI through daily tasks with several sub-steps (e.g., making breakfast) that utilizes narrow-deep UI on a smartphone has been investigated [9, 18]. For example, Gómez and colleagues [9] developed adaptive manuals on a smartphone using QR codes to help people with ABI complete everyday tasks. This system split the task into several sub-steps which was each presented on a single screen to help the user complete them in order. This is a style similar to the set-up ‘wizard’ interfaces often encountered on personal computers when setting up software. Other micro-prompting technology that splits tasks into their individual steps to guide people through them have been shown to improve task performance for people with ABI and dementia [18]. Setting a reminder is also an everyday task with several sub-steps and narrow-deep UI splits it into these component parts to help guide the user.

In the context of setting reminders using a mobile app, a narrow-deep UI has several potential advantages over broad-shallow. There is evidence that a narrow-deep UI might reduce the amount of navigation and text on one page and so help prevent people with cognitive impairments experiencing cognitive overload. Buehler *et al.* 2016 found that obstacles in navigation and information architecture, for example navigating through menu options, could undermine the use of educational aid technologies by students with intellectual disabilities [5]. One study [3] reviewed the technology-based information searching literature that involved people with cognitive impairment. They concluded that users should be supported through text heavy pages. Citing papers investigating internet navigation by people with learning disabilities [13, 41], they suggest that horizontal navigation may be more useful for those with cognitive impairment than vertical which requires users to scroll.

A narrow-deep UI might be easier for people with selective attention difficulties who may miss details if many are presented on one small screen. Feedback from focus groups with five people with ABI who were shown Google Calendar (with a broad-shallow UI) was that there was too much information and people may skip parts of the reminder setting process, missing important details [16]. Showing only one piece of information on each screen may make it easier to attend to each aspect of setting a reminder. The memory and attention processes that underpin working memory or executive functioning involved in carrying out a series of steps in a task to achieve a desired goal may be impaired for people with ABI. People with impaired executive functioning could have their use of smartphone apps supported by a narrow-deep user interface. Technologies to support executive functioning have generally involved timely prompts to support the completion of several sub-tasks involved in an overall task; for example, to help with remembering each component of a morning routine, preparing a meal, or doing a vocational task [2, 18, 27]. In a narrow-deep UI, each screen could be considered a prompt about each component of the task of setting a reminder and therefore support the user's executive functioning to help them carry out the sub-tasks required to complete the overall task of setting a reminder.

By supporting attention and executive functioning and preventing cognitive overload, accuracy of information entered is likely to be better using narrow-deep UI than using broad-shallow UI. However, speed may be compromised because the user has to go through a larger number of screens and cannot quickly scroll to the bottom and save the reminder before attending to each piece of information that needs to be entered. While this could potentially be beneficial (as it requires the user to attend to everything they are setting so they will be less likely to miss things), it could lead to frustration and negatively impact user experience. It is also possible that people would need less guidance from others to set a reminder because each screen in narrow-deep explicitly asks for the next part of the reminder.

In terms of user experience, a narrow-deep UI may be preferred to a broad-shallow UI if it makes it easier to use. Alternatively, it is possible that people will be frustrated by the narrow-deep UI if it means taking longer to enter reminders. Experience with smartphones may also impact preference between narrow-deep and broad-shallow UIs because those with experience of using calendar apps will likely use ones with broad-shallow user interfaces and so prefer a UI style they are more used to.

1.3 Contribution and Aims

This paper addresses a gap in the literature by comparing two contrasting user interface choices within a smartphone reminder app for people with acquired brain injury. The Broad-Shallow UI has a small number of screens with a large amount of information per screen and the Narrow-Deep UI has many screens each with a small amount of information. There is evidence that the use of reminding apps supports memory for people with memory impairments following ABI. However, accurate reminders need to be set by the users for these technologies to benefit them. The reminding apps that people with ABI can currently access on app stores use broad-shallow UI. Therefore, it is an important contribution to assess how this UI choice compares to an alternative option (narrow-deep UI) when it comes to facilitating the accurate entry of reminders. The results can inform future design choices of developers creating apps for people with ABI or those wishing to make apps that have universal accessibility.

In this counterbalanced, within subject study, participants with memory impairments following acquired brain injury set reminders using both UI's on the ApplTree app which was developed by the research team as part this research. The impact of this UI choice on four domains of reminder setting ability and preference was assessed; 1) how accurately participants set reminders; 2) how quickly participants set the reminders; 3) how much guidance they requested from the experimenter and; 4) their self-reported user experience (NASA Task load index). We subsequently investigated whether level of previous experience with smartphone calendars and cognitive ability (overall cognitive ability, executive functioning, and a test that involves selective attention) impacted reminder setting performance differences between the Broad-Shallow and Narrow-Deep UI conditions. A detailed break-down of the different omissions and mistakes made in each condition was also reported. Finally, an analysis of the reasons for participants' preference for Narrow-Deep or Broad-Shallow UI (when a preference was stated) was completed by using a brief feedback interview after participants used the app with both UI conditions.

2 METHOD

2.1 Participants and setting

Adults (18 years old or over) with self- or other-reported memory impairments (e.g. reported by staff) following an acquired brain injury (n=32) were recruited from two community brain injury rehabilitation services and one brain injury support charity. Exclusion criteria were a) the inability to provide informed consent for research participation, b) inadequate writing or reading (English) which would impair comprehension and performance of experimental tasks and/or answering of questionnaires, c) inability to verbally communicate adequately in an experimental setting and d) severe physical or sensory disability which would prevent any attempt at using a typical smartphone device (e.g. paralysis of both upper limbs). These exclusion criteria were assessed by the service and charity staff when identifying people to approach for the study. The exclusion criteria were added because a) our recruitment pathway through a community charity support group and people receiving community support meant we would not be able to initially contact caregivers or family members to consent on behalf of individuals who were unable to provide informed consent; b) the app use assignments and app could only be presented with written English (due to time and budget limitations and the fact that the researcher and developer only spoke English) and because alternatives like reading out the app assignments or typing the information for the participant would have compromised the experimental consistency of the study; c) because of an inability of the research team to provide alternative communication methods during the study and; d) because using an app on a touchscreen phone was key to the running of the study – alternatives such as spoken interfaces would have compromised the experimental consistency of the study. Participants were not compensated for their time taking part in the study. Travel costs to arrive at the session were reimbursed. Ethical approvals to carry out the study were obtained from relevant health boards (reference information not disclosed to protect author anonymisation).

A convenience sampling method was used. Service and charity staff were asked to identify people who they believed met the inclusion criteria and would not meet any of the exclusion criteria. They were initially approached either by a staff member or volunteer, or by a member of the research team. The study took place in the location of the service or charity meeting. The study session took around 90 minutes including a break of up to 10 minutes.

The participants were 16 males and 16 females with a mean age of 49.16 years (SD = 12.57). Participants were a median of 4 years post injury (range = 0.36 to 19 years) and the majority owned smartphones (5 owned non-smartphone mobiles).

2.2 Materials

2.2.1 ApplTree app

ApplTree is a reminding app developed by the research team. It is a reminding app that has features that match those available in most freely available reminding apps. ApplTree was developed with feedback from people with ABI and caregivers in order to develop in-app features that could overcome difficulties described by people with ABI when they use smartphone reminder apps [16, 22]. The app is intended to be a platform for research into the impact of different features that could be implemented to improve the uptake and usefulness of reminding technologies for this user group. Previous research has investigated the impact of push notifications on the number of reminders participants with ABI enter into the app [reference retracted to preserve author anonymization]. Alternative user interface design is another feature that could impact use by influencing the accuracy of reminder setting.

The opening screen is shown in Figure 1. The user can freely toggle between reminder setting (where reminder information can be added) and the calendar screen (where events can be viewed, edited or deleted). The app allows a user with administrator privileges to toggle between narrow-deep and broad-shallow UI. The opening screen is the same for both UI conditions. The Broad-shallow UI and Narrow-deep UI interfaces are shown in Figure 2. The reminder setting functionality of the app is the same for both UI conditions. Name, date, time, duration, notification, notes, repetition and loudness (how loud the prompt is) can be set for each reminder.

On both versions there was an error prevention mechanism to stop a reminder being set in the past; the date/time widget automatically moved back to the current date and time when a time in the past was selected. No omission error prevention method was used. This is in line with other reminding apps that can be downloaded from the app stores (e.g. Google Calendar). Not having omission error prevention is intentional because, when setting a reminder, omissions are made very often and are often not errors. For example, you do not always need to set repetition or duration and it would be frustrating to be asked to do so every time. Not entering or selecting any title, time/date, duration, notification, notes, repetition or loudness and pressing sets a reminder defaulted to no title, at the current time and date, with no set duration, notification set at the time of the event, no notes, no repetition and level 2 loudness (vibration and sound when firing).

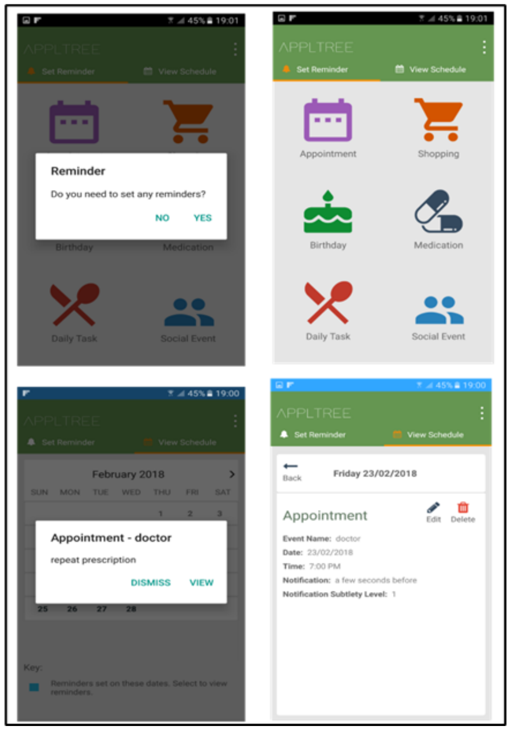

Figure 1: ApplTree UP (top left), opening screen (top right), a reminder notification (bottom left) and reminder information (bottom right).

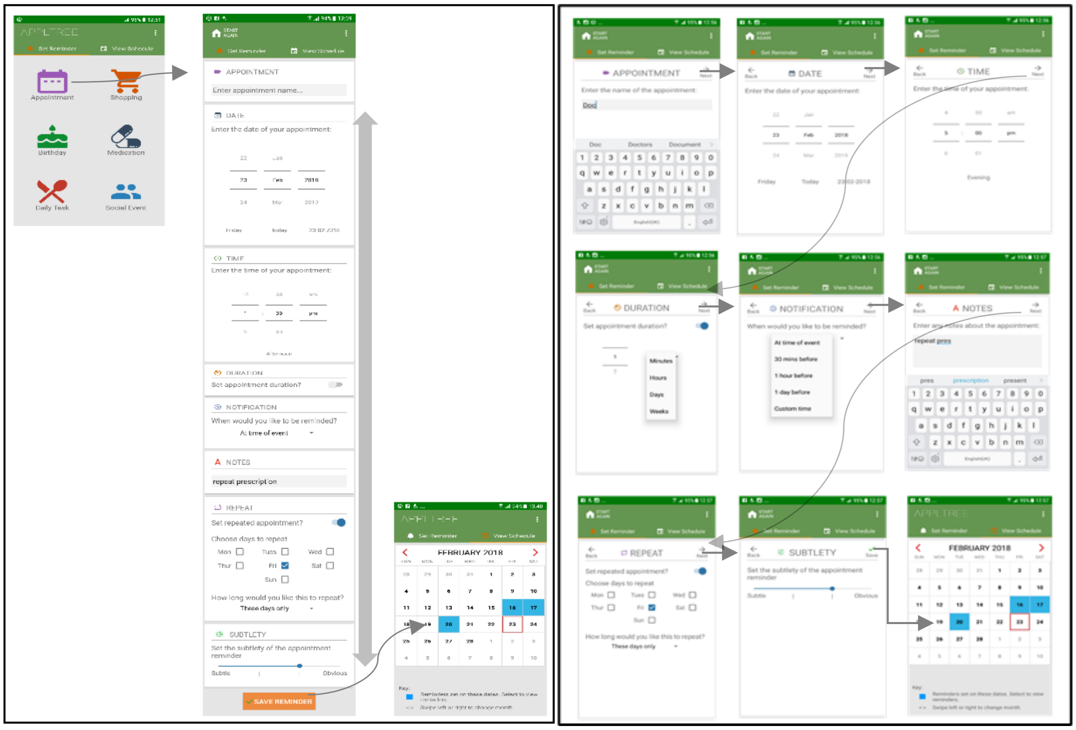

Figure 2. Left; Broad-shallow UI in ApplTree. Scrolling is needed to see all of the information. Right; Narrow-deep UI in ApplTree. Each piece of information has its own screen.

2.2.2 Reminding Assignments

Participants used ApplTree to set six reminders that were written on two A4 assignment sheets (three assignments per sheet). ApplTree UI was set to broad-shallow for one of the assignment sheets and narrow-deep for the other. The reminders assigned were similar to real events that may need to be scheduled into a reminder app such as medication, doctors' appointments, attending classes or meeting a friend. The assignments were piloted with five people with acquired brain injury (who did not take part in this study). Verbal feedback was gathered from pilot participants, and a note was made of how long it took participants to complete the first draft of the two assignment sheets. The assignments were amended based on their feedback and the two assignment sheets altered to make them equivalent in difficulty. The assignment sheets and scoring sheet used by the experimenter are available as supplementary documents.

2.2.3 Neuropsychological Tests

Standardized neuropsychological tests were given to participants to characterise their cognitive profile. The tests cover the domains of memory (Rivermead Behavioural Memory Test (RBMT)), and executive functioning (Delis-Kaplan Executive Function System (D-KEFS) trails and verbal fluency sub-tests). The D-KEFS trails visual scanning, letter sequencing and number sequencing sub-test scores also involve selective attention. These test scores were summarised and used in the analysis investigating the impact of cognitive abilities on app use in each condition. For this analysis the scaled scores on each sub-test of the RBMT and D-KEFS were combined to create an overall cognitive ability score (Cronbach's Alpha = 0.83). D-KEFS sub-test scaled scores were combined to create an executive functioning score (Cronbach's Alpha = 0.84). D-KEFS trails visual scanning, letter sequencing and number sequencing sub-test scaled scores were combined to create a measure of selective attention ability (Cronbach's Alpha = 0.9). Sets of scores were combined by creating the average of the scaled scores for each sub-test.

2.2.4 Procedure

The study was conducted between November 2017 and December 2019. All participants were guided through the information sheet by the experimenter and given an opportunity to ask questions about the study. At this stage the researcher carrying out the study verified that the person met the study criteria by ensuring they were over 18, had an acquired brain injury and that they reported memory difficulties following their ABI. The researcher used their judgement to discern whether or not the participants met any exclusion criteria (e.g. inability to provide informed consent or verbally communicate adequately to take part). All participants who had sessions arranged were judged to be eligible to take part. Participants then signed consent forms. After this they completed a demographic questionnaire (gender, age, employment status) and were asked for information about their acquired brain injury (cause and time since injury) and phone and reminder use. If they used them, the extent of their smartphone, smartphone calendar, and non-electronic reminder use was rated on a 5 point scale (1=extremely rarely, 2=rarely, 3=sometimes, 4=often, 5=very often).

Next the participants completed the reminder setting assignments using ApplTree. ApplTree was provided on the same Android Galaxy S7 phone for all participants. Participants completed one assignment sheet (with 3 reminders per sheet) with broad-shallow UI and one assignment sheet (3 reminders per sheet) with narrow-deep UI. To ensure that the order of both the assignments and user interface type was counterbalanced, a 2x2 latin square was randomly generated for each set of four participants (with eight sets in total as n=32). For example, the participants 1 to 4 were assigned to receive one of the four possible combinations of assignments and UI type (narrow-deep with assignments 1, narrow-deep with assignments 2, broad-shallow with assignments 1 and broad-shallow with assignments 2). Latin squares were generated from https://hamsterandwheel.com/grids/index2d.php. A visualization of the randomized counterbalancing process is shown in figure 3.

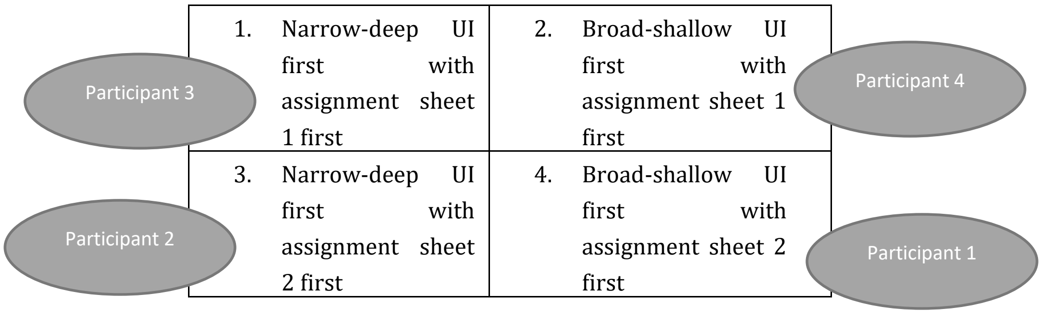

Figure 3. A cluster of the first 4 consecutive participants (e.g. participants 1-4) randomized to one of the four possible UI and assignment sheet orders shown using randomly generated 2x2 latin squares.

Prior to the assignments

Prior to attempting the assignments participants were given a tutorial by the experimenter showing them how to use the app to set an example appointment. This tutorial took 3 minutes. This involved the researcher setting an example appointment reminder and describing each step while the participant watched. This included how to navigate between setting the reminder and viewing the calendar, where to enter the title, the date, the time, repetition, notes, notification time, loudness, how to return to the home screen, and amending a reminder using the edit and delete functions. This tutorial was the same for all participants. At the end of the tutorial participants were given the opportunity to ask questions to clarify any aspect of the use of the app. Each participant was given this tutorial before both the assignment sheets for the broad-shallow and narrow-deep UI type conditions. Participants were asked to complete the assignments as quickly and accurately as they could. They were asked to try to complete the assignments on their own. However, if needed, they could ask the experimenter for help. They were given the assignments to read through before starting, and the assignment sheet was in front of them while they were setting the reminders. The timer was started as soon as the participant started using the app.

During the assignments

While the participants were doing the assignments, a tally was kept by the researcher every time they were asked a question about use of the app. A request for guidance was counted every time they asked a question unless it was an issue with the app crashing, a hardware issue, or an issue with the assignments that was not relevant to the participant's use of the app (e.g. to clear a notification or to clear up confusion with the assignments).

If a participant did not complete an assignment sheet (with all three reminders) in 25 minutes, then that assignment was discontinued, and the experimenter would move on to the next step in the experiment. Any reminders they fully completed were scored. This cut-off of 25 minutes per reminder, was to ensure some reminder entry data could be gathered from both UI conditions even for participants who found it difficult to complete the reminder tasks. This limit was set based on previous experience running a similar study [reference retracted to preserve author anonymization] where it was noted that some of participants took a long time on the first reminder sheet and then left the study before attempting the second assignment. The research team decided setting a time limit would improve the participants experience in the study and make it more likely that both reminder sheets would be attempted allowing comparison between the conditions for any of the three reminders that were completed.

After the assignments

The NASA Task Load Index (TLX) is a quick measure of perceived task load (in the domains of Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration) when completing a task with technology [11]. Each domain is measured on a 20 point scale. The TLX was provided on an A4 sheet of paper for the participants after each of the UI type conditions was completed. The same A4 TLX sheet was used for both the first and second assignments, so the participant could directly compare their experience using the second UI condition with the first UI condition. Participants were given a different colour of pen to mark the TLX sheet after the second set of assignments. After each UI assignment the experimenter scored the participants' app entries using the score sheet, noting which parts of the reminder were entered wrongly or omitted. After the first set of assignments the reminders set were deleted to avoid confusion during the second set of assignments.

After both sets of assignments were finished, they were asked about their thoughts on the difference between using the app during the first and second assignments; 'What did you think about the difference between the app the first time you used it compared to the second time?' If they asked any follow up questions to the experimenter or required anything clarified about the conditions, the experimenter described the broad-shallow and narrow-deep conditions. The experimenter asked a follow up question if necessary to ask why they preferred one over the other if a preference was stated. The responses were audio recorded and transcribed by the experimenter.
Participants were given a 10-minute break if needed. After this the neuropsychological tests were administered. The D-KEFS trails test was administered first, followed by the verbal fluency test then the RBMT. A further break was offered between the D-KEFS and RBMT. There was occasionally not enough time in the session (1 - 1.5 hours) for the D-KEFS and RBMT assessments to be fully completed. If this was the case the participant was invited to a further study session to complete these tests.

The experimenter who conducted the study session scored the assignments, TLX and neuropsychological tests. Reminder setting accuracy was scored as mistakes per reminder. A mistake was defined as information missed that should have been entered, or information entered incorrectly. Speed was average time taken to complete one reminder. This was calculated as the average of the time for each of the three reminders in an assignment sheet. Amount of guidance needed was calculated as the average number of times people asked the experimenter for help during each of the three reminders in an assignment sheet.

Not all participants completed all three reminders on each assignment sheet. Participants were included in the analysis if they completed at least one of the three reminders on each assignment sheet. For example, if a participant only completed reminder 1 and 2 in the broad-shallow UI condition then their average accuracy, speed and guidance required would be compared to reminder 1 and 2 from the narrow-deep UI condition. This step was taken to ensure that people were not excluded from analysis if they found the reminder setting task difficult or were very slow to set reminders.

2.3 Statistical Analysis

Parametric analysis (t-test or Pearson's correlation) was used where data was interval continuous and assumptions required for the parametric analyses were met. Non-parametric analyses (Wilcoxon Signed-Rank test or

Spearman's correlations) were used if data was non-interval continuous or assumptions for parametric statistics were not met.

To analyse participants' preference between UI conditions feedback from each study session was transcribed and the transcript was coded by the experimenter who did the interviews. Descriptive thematic codes (for detail and specific experiences) were developed. Coded phrases were then discussed in meetings with the research team and a common code-set was agreed. Focused Coding using thematic analysis (no prior framework was used to categorise the themes) identified the important issues by virtue of the number of comments that covered each sub-theme [32].

3 HYPOTHESES

3.1 Primary Analyses

Hypothesis 1: More accurate reminders (fewer mistakes per reminder) will be set with narrow-deep UI than with broad-shallow UI because people are less likely to miss aspects of the reminder.
Hypothesis 2: Reminders set with narrow-deep UI will take longer to set than with B/S UI because there are more screens to navigate.
Hypothesis 3: When setting reminders using the broad-shallow UI, participants will make more guidance requests than when setting reminders using the narrow-deep UI because narrow-deep is more of a guided navigation through the app
Hypothesis 4: Participants would rate their experience using the narrow-deep UI (measured by the Task Load Index (TLX)) as preferable compared to the broad-shallow UI because narrow-deep UI is easier to use.

3.2 Secondary Analyses

SA1. Factors influencing reminder setting mistakes

SA1.1: Experience with smartphone reminders (smartphone calendar use on 6 point scale – higher equals more use) will have a significant negative correlation with reminder setting mistakes (higher = more mistakes per reminder).
SA1.2: Executive functioning (calculated by combining the DKEFS sub-test scores; higher scores = better executive functioning) will have a significant negative correlation with reminder setting mistakes (higher = more mistakes per reminder).
SA1.3 Selective attention (captured by the visual scanning, letter sequencing and number sequencing in DKEFS; higher scores = better selective attention) will have a significant negative correlation with reminder setting mistakes (higher = more mistakes per reminder).
SA1.4: Age (years) will have a significant positive correlation with reminder setting mistakes (higher = more mistakes per reminder).

SA2. Factors associated with the disparity between narrow-deep and broad-shallow UI reminder setting performance

SA2.1: Those with less experience setting reminders will have more benefit of narrow-deep vs. broad-shallow; fewer mistakes, increased independence and better user experience
SA2.2: Those with lower cognitive functioning will have more benefit of narrow-deep vs. broad-shallow; fewer mistakes, increased independence and better user experience
SA2.3: Those with a profile of poor executive functioning will have more benefit of narrow-deep vs. broad-shallow; fewer mistakes, increased independence and better user experience
SA2.4: Those with a profile of poor selective attention will have more benefit of narrow-deep vs. broad-shallow; fewer mistakes, increased independence and better user experience

4 RESULTS

The RBMT was completed by 26 of the participants; six participants did not complete this test because they did not have time during the initial study session and they could not be contacted for, or did not wish to complete, a subsequent session. One participant did not complete the D-KEFS due to lack of time and because they could not be contacted for a follow-up session.

The median percentile rank on the RBMT was 17% (range = 0.6% - 77%). This indicates that the median memory ability of the participants in the study was lower than over 83% of the general population. The switching sub-tests of the D-KEFS can give an indication of the executive functioning ability of the participants because they require following of set task rules, and switching between mental sets (e.g. switching between naming fruits and furniture). The mean scaled score on the letter number switching sub-test of the D-KEFS was 6.84 (SD = 4.09). The mean scaled score on the verbal category switching sub-test of the D-KEFS was 6.74 (SD = 3.32). These are considerably below the average scaled score of 10 that would be expected in the general population.

D-KEFS visual scanning, letter sequencing and number sequencing sub-test scores measure selective attention ability. The mean scaled scores on these sub-tests (visual scanning scaled score = 5.48, SD = 3.45; letter sequencing scaled score = 6.65, SD = 4.26; number sequencing scaled score = 6.61, SD = 4.1) indicate that the sample had a reduced selective attention ability compared to the general population for which the average scaled score is 10.

4.1 Primary analyses – Narrow-deep vs. broad-shallow

The primary research question investigated the differences in reminder setting (mistakes, time taken, guidance asked for and task load) when participants used the broad-shallow and narrow-deep UIs. Two participants completed one reminder from each assignment sheet, with all the others completed all 3 reminders in both assignment sheets.

4.1.1 Mistakes

Participants made 2.29 mistakes per reminder (SD = 1.43) using the narrow-deep UI and made 2.96 (SD = 1.82) mistakes per reminder when using the broad-shallow UI. Hypothesis 1 was supported as participants set significantly more accurate reminders (with fewer mistakes per reminder) with narrow-deep UI than with broad shallow UI. The mean difference was -0.67 reminders (SD=1.09, CI = -1.06 to -0.27) (t(df=31), p=0.002). For every 3 reminders set, people make 2 more mistakes when using the broad-shallow user interface.

4.1.2 Time taken

On average, participants did take slightly longer to set a reminder (mean difference = 21.22 seconds, SD = 117.18) with narrow-deep UI (mean time = 278.06 seconds, SD = 137.08) than with broad-shallow UI (mean time = 256.84 seconds, SD = 104.92). However this difference was not significant and hypothesis 2 was not supported (t(df=31)= 1.024, (95%CI = -21.03 to 63.47) p=0.314).

4.1.3 Guidance

Contrary to our expectations, participants made fewer guidance requests when setting reminders using the broad-shallow UI (0.78 queries, SD= 0.8) than when setting reminders using the narrow-deep UI (1.01 queries, SD=1.07). On average people made 0.23 (SD = 1) more queries during the narrow-deep UI condition than they did during the broad-shallow UI condition. There were large variations in both how often people asked for help and the extent to which this differed when using the two UI types. This difference was not significant (t(df=31)= 1.287 (95%CI = -0.13 to 0.59) p=0.207) and hypothesis 3 was not supported.

4.1.4 Perceived Task Load

We predicted that participants would rate their task load as lower after using the narrow-deep UI than after using the broad-shallow UI. The median score for the 6 TLX items was 8.34 (out of 20) (range = 0.67 to 16.17, Q1=4.63, Q3=8.34) after using the narrow-deep UI and 9 (range = 1 to 16.4, Q1=5.05, Q3=9) after using the broad-shallow UI. The median difference in this score (broad-shallow score minus narrow-deep score) was 0.17 (range = -10.67 to 4.35, Q1=-2.5, Q3=-0.63). This difference was not significant and hypothesis 4 was not supported (W = 170.5, z = -1.02, p=0.31)

4.2 Secondary analyses

Secondary analyses were carried out to explore factors that may influence reminder setting and the disparity in reminder setting performance between UI conditions.

4.2.1 SA1. Factors influencing reminder setting mistakes

None of the four hypotheses regarding the factors that influence mistakes when setting reminders were supported (SA1.1 to SA1.4) as there were no significant correlations found. Experience with smartphone reminders did not have a significant negative correlation with reminder setting mistakes (Spearman's rho = -0.240 (n=32), p=0.186). Executive functioning did not have a significant negative correlation with reminder setting mistakes (Pearson's r = -0.288 (n=31), p=0.116). Selective attention did not have a significant negative correlation with reminder setting mistakes (Pearson's r = -0.264 (n=31), p=0.152). Age did not have a significant positive correlation with reminder setting mistakes (Pearson's r = 0.159 (n=32), p=0.386).

4.2.2 SA2. Factors associated with the disparity between N/D and B/S UI reminder setting performance

None of the twelve hypotheses regarding the factors (smartphone experience, cognitive ability, executive ability and selective attention) that may influence the disparity between narrow-deep and broad-shallow UI on mistakes, guidance and task load when setting reminders were supported (SA2.1 to SA2.4). Two significant correlations were found (when testing hypotheses (SA2.1b and SA2.4b). However, these were in the opposite direction to what was hypothesised.

Experience with smartphone reminders did not have a significant positive correlation with narrow-deep vs broad-shallow mistakes disparity (Spearman's rho = 0.097 (n=32), p=0.599). Experience did not have a significant positive correlation with narrow-deep vs broad-shallow task load disparity (Spearman's rho = -0.088 (n=32), p=0.632). However, experience with smartphone reminders did have a significant negative correlation with narrow-deep vs broad-shallow guidance disparity (Spearman's rho = -0.383 (n=32), p=0.03). This was the opposite finding to what was predicted. People with less experience with smartphones tended to ask for more guidance when setting reminders using the narrow-deep UI and people with more experience tended to ask for more guidance when setting reminders using the broad-shallow UI.

Cognitive functioning did not have a significant positive correlation with narrow-deep vs broad-shallow mistakes disparity (Pearson's r = 0.209 (n=31), p=0.259). Nor did cognitive functioning have significant positive correlations with guidance (Pearson's r = -0.207 (n=31), p=0.264) or task load (Pearson's r = 0.196 (n=31), p=0.290) disparity between narrow-deep and broad-shallow UI conditions.

Similarly, the executive functioning measure did not have a significant positive correlation with narrow-deep vs broad-shallow mistakes disparity (Pearson's r = 0.227 (n=31), p=0.220). Executive functioning also did not have significant positive correlations with guidance (Pearson's r = -0.225 (n=31), p=0.224) nor task load (Pearson's r = 0.236 (n=31), p=0.202) disparity between narrow-deep and broad-shallow UI conditions.

The measure of selective attention - calculated from the D-KEFS visual scanning, letter sequencing and number sequencing sub-test scores - did not have a significant positive correlation with narrow-deep vs broad-shallow mistakes disparity (Pearson's r = 0.246 (n=31), p=0.184). Nor did the selective attention measure have a significant positive correlation with narrow-deep vs broad-shallow task load disparity (Pearson's r = 0.128 (n=31), p=0.493). However, this selective attention measure did have a significant negative correlation with narrow-deep vs broad-shallow guidance disparity (Pearson's r = -0.399 (n=31), p=0.026). This was the opposite finding to what was predicted. People with poorer selective attention tended to ask for more guidance during the narrow deep UI condition and people with better selective attention tended to ask for more guidance during the broad shallow UI condition.

4.3 Types of errors made

The types of errors made were documented on the assignments score sheets completed by the experimenter. To help understand what differences there may be in type of error between the two UI conditions, the errors were categorized as either omissions (where required information was missed) or wrong information (where the wrong information was entered). Table 1 shows the total number of times each type of error occurred for each aspect of the reminders (e.g. date, time, repetition) for both narrow-deep and broad-shallow UI. For wrong information, examples of the kind of wrong information entered are given.

Table 1. The frequency of occurrences of omissions and wrong information entered for the reminders when using broad-shallow and narrow-deep UI.

Event information required in our examples	Omissions (accumulative total; n=32)		Wrong information (accumulative total; n=32)		
	Narrow/Deep	Broad/Shallow	Narrow/Deep	Broad/Shallow	Examples of common wrong information
Title	4	16	2	5	Title wrong or not clear enough (e.g. ‘tel call’ instead of ‘GP appointment’)
Date	4	10	5	4	Wrong date added
Time	3	11	11	14	Wrong time added (e.g. AM selected instead of PM)
Repetition – days	5	8	10	11	Repeated days left out when required or added when not required
Repetition – number of weeks	6	6	3	3	Wrong number of weeks of repetition selected (e.g. 1 week instead of 3)
Loudness	12	16	4	4	Wrong loudness level selected(e.g. loudest when quietest asked for)
Notes or linked reminders	12	26	2	4	Note wrong or unclear (e.g. medication to be taken ‘at meal’ instead of ‘after lunch’)
Notification time (before event)	10	15	4	3	Wrong notification time set (e.g. 30 mins before when 1 hour before was asked for)
Duration	12	17	9	4	Wrong duration set (e.g. 30 mins instead of 2 hours)
Amending reminders	11	22	4	0	Reminder was edited or deleted wrongly (e.g. only 1 event deleted when two should have been deleted)
TOTAL	78	147	54	52	

4.4 Participant feedback

When asked which user interface they preferred, 12 indicated narrow-deep, 10 indicated broad-shallow and 4 did not state whether they had a preference or not. Four participants who took part in the study did not complete the feedback questions after the second user interface was used as there was not enough time in the session, and two were not audio recorded during the session, or the audio file was corrupted. Thematic analysis of the reasons for the preferences resulted in four major themes for preferring narrow-deep UI and two major themes for preferring broad-shallow UI. Table 2 outlines the themes.

Table 2. Summary of reasons why participants preferred one UI condition over the other.

Preferred Narrow-Deep	**Preferred Broad-Shallow**
‘One thing at a time’	‘Easier to review information’
‘Missed less information’	‘Less likely to lose track’
‘It felt easier’	
‘Pressing better than scrolling’	

4.4.1 Narrow-deep - ‘One thing at a time’

These participants preferred having one piece of information at a time to review and enter (e.g. the title or the time of the event). For example, this feedback was given by one participant who used broad-shallow second and preferred narrow-deep:
Participant: *“Eh for me it was a wee bit more confusing. I think I did have to scroll back up. But easier to use maybe… but na I preferred the first one. Just for me, the first one.“*
Experimenter: *“And is that because it set it all out one at a time?”*
Participant: *“Aye definitely. That is how it is. Just cos it was… easier doing it one bit at a time instead of all at once.”*

Another participant described narrow-deep UI as an alternative to broad-shallow UI that could be better for people with acquired brain injury:
“…if you’re filling in something – especially if you’ve got brain damage – you may forget what part of the notification or what part of the app you’re at. So for example if you’re starting off with an appointment at the University. So, appointment the first thing you do is put the name of the appointment, then it will come up the time of the appointment, then it’ll come up the duration of the appointment. Rather than you having to scroll up because you may forget you’ve already done it. I think it would be easier because em. That’s where I was getting stuck. I would maybe see the next thing but I haven’t scrolled it up.”

4.4.2 Narrow-deep - ‘Missed less information’

Another reason participants preferred narrow-deep was that they felt they missed less information when using narrow-deep compared to broad-shallow UI. For example one participant who made 4.33 mistakes per reminder with broad-shallow compared to 1.83 mistakes per reminder with narrow-deep said:

"I thought the second one (broad-shallow UI) was going fine until I had to cancel and wasn't sure the best way to go about that. You know… and I started to go… well I started doing something and [thought] that doesn't feel right. So then I just why don't you just go back to the main screen and just cancel it – delete it for the two days on the screen itself. It's just trying to figure out the best way to work it."

This participant was not sure what mistakes they had made with broad-shallow but they did think something was wrong. They then went on to say they tended to try to go quickly through tasks like setting reminders. This highlights the potential benefit of narrow-deep as a user interface that prevents the user from rushing through setting reminder and potentially missing entering important information:
"It's quite straight forward I think. Um I get quite - that's why I kind of stick to routines. Once I'm used to it you know I kind of fly through it. I'm used to doing things very quickly – the job I used to do was always rush rush rush rush rush. And I'm used to doing things quite snappy and whatever. So it's a learning curve for me to be able to… you know look don't get frustrated, take your time, think it through. Em that it, it's always just come naturally I suppose."

4.4.3 Narrow-deep - 'It felt easier'

Three participants preferred narrow-deep and simply stated that it felt easier to use without being able to explain why. For example, one participant who struggled with the assignments and made 4 mistakes per reminder with narrow-deep and 6 with broad-shallow UI said:
"See the first time (using narrow-deep UI), for me, went no too bad. But see the second time was a bit more difficult. I don't know I just seemed to understand it better. There was just something about the second time that made it harder. The first time seemed to go plain sailing. But the second time it was a wee bit more difficult for some reason. I don't know if it was a bit more difficult, but I just seemed to not do it as easy."

4.4.4 Narrow-deep - 'Pressing better than scrolling'

There were also three participants who stated that the interaction required in narrow-deep UI (pressing the next button) was easier for them than the scrolling required in broad shallow UI. For example one participant said:
"I found that one (narrow-deep UI) a lot easier. You know when you're scrolling across it's an easier set up because you're just clicking, and it just comes up rather than having to go through the whole thing."

4.4.5 Broad-shallow - 'Easier to review information'

For participants who preferred broad-shallow UI most of them stated that this preference was because it was easier to review the information they were entering quickly by scrolling up and down. For example, the following conversation was recorded between the experimenter and a participant who made 3 mistakes per reminder with narrow-deep and 1.33 mistakes per reminder when using broad-shallow:
Participant: *"First one (broad-shallow UI) was easier because you had multiple things you could do in it. But the second one (narrow-deep UI) was just – one thing you could do (at a time). I found that a little bit more difficult to just comprehend or to work out."*
Experimenter: *"And was that because you couldn't see everything at the same time?"*

Participant: *"Yeah. The other one (broad-shallow UI) you could. You would just scroll through it and it gave you everything that you needed. Whereas the other one was just one thing on the screen which I found a bit harder to use."*

4.4.6 Broad-shallow - 'Less likely to lose track'

Feedback from four participants who preferred broad-shallow UI discussed feeling less likely to lose track with broad-shallow due to the number of screens in the narrow-deep UI. For example, one participant stated that they found assignment harder when using narrow-deep even though they completed it without making a mistake:

Participant: *"That one (narrow-deep UI) was. I'm not sure if the app was harder… but the assignment was. I found it, I just found that one harder. I'm not sure if (it was down to the assignment or down to the app). This one was a bit more bitty, I don't know if bitty makes sense*."
Experimenter: "*There were more bits of information to take in?"*
Participant: "*Yeah with the other one you could see it was em. this one was more complicated I suppose. With a lot more little bits in it. So em… and eh there is a lot more pressing of buttons with this one. Almost too much. What I find is I'm getting half way through it and I'm forgetting what I'm put in the… what I'm writing the assignment for. Just cos there are too many buttons. It's almost taking too not too long – I'm not stressed, I'm not rushed, I'm just doing it nice and calm but it's - I'm forgetting what is going in."*

Another participants described a similar problem with narrow-deep UI if they needed to go back and review the information they were entering:
Experimenter: *"What did you think about the differences between app conditions?"*
Participant: *"Depends, you might be pressing next or. The only thing I would have with pressing next all the time is if the information you want to put into it is not in that order then you're in a whole world of trouble – did I do it on that page and how many pages do I have to go back?..."*

5 DISCUSSION

We found that altering the user interface type from broad-shallow to narrow-deep meant that people with acquired brain injury made significantly fewer mistakes; approximately two fewer omissions or errors for every three reminders set. The difference in mistakes was mainly due to omissions: that is, less of the necessary information to set a reminder was omitted in the narrow-deep condition. Broad-shallow is the interface design used by the most popular apps on both the iOS App Store and Google Play Store. These results indicate that a narrow-deep design or a design that allowed the user to toggle between the two interface designs may be more accessible for people with acquired brain injury. Our results also indicate that altering the design to narrow-deep would not reduce reminder entry speed, increase task load or reduce the ability to independently set reminders.

As Table 1 highlights, there were more omissions in each of the different parts of the reminder setting process when broad-shallow was used rather than narrow-deep. Much of the information being missed was critical; if a real reminder were being set, the omissions would seriously impact its chances of prompting the user to do the task.

For example, failing to set the reminder time or date (which happened 11 and 10 times respectively in broad-shallow vs. 3 and 4 times in narrow-deep) would mean the time or date would default to the current date or time meaning it would not fire at the correct moment to prompt the user about the event. An alternative method to reduce omission errors would be omission error prevention. For example, the app could force the user to enter each aspect of the reminder before the reminder can be set. However, in reminder apps that can be downloaded from the app store, omissions error prevention is rare. Omissions are not prevented because they are common when setting reminders and are not always errors (e.g. not having repetition or a specified duration). The finding that omission errors are common for people with ABI when entering reminders using the broad-shallow UI that most reminder apps use suggests that some omission error prevention (e.g. alerting the user if they did not interact with the date or time widgets) could be a useful feature in these apps to make them more accessible.

The participants had never used this app before and were asked to set reminders after only a small amount of training. Therefore, the study investigates the impact of user interface design on the first few times a person with acquired brain injury uses a newly acquired smartphone reminding app. These first few uses are likely to be very important; the UTAUT model highlights that usefulness and self-efficacy predicts future use [39]. If someone uses the app but finds it difficult then it may put them off using it in the future. If they set a reminder but unintentionally miss information or add it incorrectly then they will not receive the prompt to remind them about the task or event at the correct time. This may mean they stop using the app as they did not find it useful or did not feel able to use it correctly. Experiences when using an app for the first time may be even more crucial for people with cognitive impairments. People with acquired brain injury and those with learning difficulties both experience the same types of problems when using software as the general population, but with greater severity [22]. Furthermore, lack of confidence using technology and a lack of support are reasons these groups have given for not using assistive technology [16, 17]. This highlights the importance of accessible software design to improve the likelihood of a positive first experience with an app.

Setting a reminder using an app is a task with several sub-steps and there is evidence that technology that guides people with ABI through each step can improve their performance [9, 18]. This may be particularly important when a task is unfamiliar. Compared to broad-shallow UI, narrow-deep UI may be closer to this micro-prompting or 'wizard' style where the steps are described and followed in order, one at a time.

Most participants did have a preference between narrow-deep and broad-shallow UI styles and this preference was evenly split. The difference in preference did not match the difference in accurate reminder setting. This indicates that in some instances participants had their performance supported by narrow-deep but either they did not realize the interface made a difference, or the difference it made did not influence their preference. People who preferred narrow-deep tended to prefer it because it was easier to understand the process involved in setting the reminder and because they missed less than they did when they used scrolling. People who preferred broad-shallow tended to prefer it because it made it easier to quickly review what they were entering and because they lost track of what they were entering when using narrow-deep (there was no overarching information showing them their progress setting a reminder). These findings suggest that an option in narrow-deep to quickly review the reminder while setting it could be a useful way to combine benefits of both narrow-deep and broad-shallow. Alternatively, broad-shallow may be the better option once a user has developed the expertise to enter a reminder quickly and accurately. Therefore, having the option to toggle between, or move from, narrow-deep to broad-shallow with increasing expertise or practice could be useful and improve user acceptance.

5.1 Factors that may influence use

The secondary analysis explored the relationship between user interface condition and factors that may influence use such as experience using smartphones, cognitive ability and age. This analysis aimed to provide indications for future research rather than conclusive findings. It is limited by the lack of power and multiple analyses that raise the chance of false positive findings. Most of the selected correlations were found to be in the direction hypothesized. However, most were in the small-medium effect size range and none of the correlations that were in the direction hypothesized were significant. Participants with less experience with smartphone calendars and those with lower cognitive abilities did not find narrow-deep UI less demanding to use (less task load) relative to those with more experience and those with better cognitive abilities. There is no indication that participants with more experience with smartphones and participants with better cognitive ability found narrow-deep easier to use (lower task load) than broad-shallow relative to people with less experience and people with poorer cognitive ability. It also does not appear that people with more experience and people with better cognitive ability had better accuracy in narrow-deep than broad-shallow UI relative to those with less experience or poorer cognitive ability.

Two significant negative correlations were found. These were between experience using a smartphone and the disparity in guidance asked for between narrow-deep and broad-shallow UI, and between our combined measures of selective attention on the D-KEFS and the disparity in guidance asked for between narrow-deep and broad-shallow UI. Both were the opposite direction to our hypothesis: People with more experience with smartphones asked for less help when using narrow-deep UI relative to the broad-shallow UI than people with less experience with smartphones. People with better scores on the D-KEFS sub-tests that tap into selective attention ability asked for less help when using narrow-deep UI relative to the broad-shallow UI than people with lower scores on those D-KEFS measures. These were both the opposite direction to our hypotheses. We expected that people with less smartphone experience and those with poorer selective attention would be more supported by the narrow-deep UI relative to the broad-shallow UI than people with more smartphone experience and those with better selective attention.

The findings suggest that people with less experience with smartphones and people with poorer cognitive abilities are not supported more by the narrow/deep user interface than people with more experience and better cognitive abilities to set reminders more accurately and independently. This finding contradicts the idea that narrow-deep UI offers more guidance and should require people who need more help generally (i.e. those with less experience and more cognitive difficulties) to ask for it less. However, because this is a correlation it may also indicate that people with more smartphone experience or better cognitive ability are able to benefit from narrow-deep UI compared to broad-shallow UI while those with less experience or poorer cognitive ability are not.

These results might also be explained by the fact that the narrow-deep UI draws people's attention to aspects of reminder setting that they would otherwise miss, particularly for those with less experience with smartphones and poorer selective attention. In this situation we would expect better accuracy (which we see from the whole sample in narrow-deep reminder setting accuracy compared to broad-shallow accuracy) and more questions about what to set (because people who would otherwise miss a piece of information out are attending to what needs to be set).

5.2 Limitations and Future Research

Any differences in outcome variables between the conditions, while not insignificant on a practical level, were statistically small. This is not surprising considering the app had the same features in both conditions, the reminder setting tasks were piloted to ensure comparable difficulty and the conditions were counterbalanced to negate order effects. The only difference between the two conditions was the way the information was presented (narrow-deep vs. broad-shallow). The highly controlled nature of this study was necessary to pinpoint the differences between the two UI conditions. Outside of this controlled environment there are other design differences that may be associated with the two UI choices. Reminder apps that use a broad-shallow also often present the calendar as the first screen. This can contain a lot of information so may put people off). Narrow-deep UI makes it possible to increase the size of text and widgets which may make them easier to use for people with motor or visual impairments.

It is difficult to replicate real life reminder setting in a controlled research context. It is unlikely that a user would have all the relevant information for setting a reminder written like the assignments given to participants. Different reminders would be relayed in various ways. An appointment may be hastily written on paper when on the phone to a healthcare provider. A social event may be arranged through one or several text messages, or in person. How the reminder information is delivered to the person presents varying challenges to memory and attention - for example, having to keep an appointment time in mind before writing it or entering it into a phone. This study aimed to reduce the attention and memory demand by presenting all the information on one sheet. The purpose was to investigate the demands presented by entering this information into the phone rather than the demands of attending to and remembering that information.

It is possible that the differences seen between the two user interfaces in both errors made (number of omissions) and participant preference reflected in their feedback could have been influenced by the way the reminder information was communicated. For example, a benefit of the broad-shallow UI which is not present in narrow-deep UI is having all the information you are entering contained on one (scrollable) screen. This difference might be more important when setting a reminder from memory or without all the information available. It may be that the issue with people losing track of what they had set using narrow-deep becomes more problematic when the user cannot check a written account of the information they are entering. Alternatively, people may be even more susceptible to missing information when using broad-shallow when setting a reminder from memory; and narrow-deep UI may prompt them to recall and enter more aspects of the reminder (e.g. duration or notification time) that they would otherwise have missed out. Further research could investigate how different reminder information delivery methods influence reminder setting with different user interfaces.

Some participants in the study did say they found the assignments difficult to follow, especially when a task depended on the completion of an earlier task (e.g. deleting medication reminders or appointments that were to be entered previously). Omissions may have therefore been due to not fully following the assignment information. However, the two assignments were piloted with five people with acquired brain injury prior to beginning recruitment and the assignments were amended to make the assignment sheets 1 and 2 as equal as possible in difficulty. There was no mention of one assignment being more difficult than the other, Furthermore, both effects of any differences between the assignments and practice effects would be mitigated by the counterbalancing of assignment order and condition order.

The design of the narrow-deep and broad-shallow user interfaces in the ApplTree app was developed to be representative of the scrolling broad-shallow interface usually used by reminding apps that are currently available and widely used (e.g. Google Calendar) and a narrow-deep alternative to this with no scrolling. Broad-shallow could be designed to have all the information on one screen without scroll. However, on a phone screen this would mean the information would need to be very small so many apps (and websites when viewed on a mobile phone) use scrolling to maintain a large enough text size. Future research could investigate different versions of these user interface types, for example a version of broad-shallow UI with all the information on a single screen and no scroll.

This study was primarily concerned with the first few uses of a reminder app by people with ABI, rather than the issues that appear during long term use. As mentioned above, the first few times somebody uses a reminding app are important and may be especially important for people with ABI. The results highlight the utility of the narrow-deep UI (which is not currently used) for improving reminder entry for this group during these first few uses. However, the results cannot speak to the long-term use or acceptability of narrow-deep or broad-shallow UI in the long term. While we did not find any difference in user preference, nor time taken to enter a reminder, between the conditions during our study, it may be the case that the narrow-deep UI becomes less acceptable over time when users are more familiar with using the app. The broad-hallow UI that allows quicker reminder entry might be better once reminder entry is more habitual and once the user is more experienced. Future studies could investigate the impact of narrow-deep and broad-shallow use over time.

Participants who were unfamiliar with Android phones may have found it more difficult to use ApplTree on an Android phone than those familiar with Android operating systems. While both user interfaces were presented on the same device in counterbalanced order allowing for a direct within-subject comparison, participants less used to the phone type may have experienced more barriers generally when learning to use the app on an unfamiliar device. If it is the case that narrow-deep is better for those less familiar with setting reminders on smartphones, and broad-shallow better for people more familiar with the process, then having some participants using both software and hardware for the first time may have influenced the results of the UI accuracy comparison and user feedback. However, it should be noted that when giving feedback no participants mentioned finding the hardware difficult to use because they were familiar with different hardware. Future studies should note what make of phones participants had (which we did not) and, ideally, would present the app on the persons own phone or have both the most commonly used hardware (iOS and Android) available for the participant to choose.

Participants in this study did not receive any prolonged training with the app. There is research outlining different training courses and evidence-based training strategies to help people learn how to use memory aid technology. For example researchers have evaluated training sessions given as part of rehabilitation for durations of weeks and months [23, 36, 38]. Future research could investigate the impact of the user interface design on the amount of time it requires for people to learn to use assistive technology. It may be that altering the user interface of the software can reduce the amount of training required in rehabilitation.

Different training strategies have also been tested including error-free or errorless learning where mistakes made are reduced as much as possible while learning to use the technology [36]. This has been found to be effective for people with impaired memory after ABI to learn new skills [26, 36]. However, it is unclear what the best training strategy is for learning to use assistive technology in brain injury rehabilitation. There is evidence that error-based learning leads to improved skill generalization and self-awareness compared to errorless learning for tasks such as meal preparation [26]. A three-armed randomized controlled trial study was recently completed comparing systematic instruction, error-based and trial and error learning approaches when training the use of smartphone based memory aids in brain injury rehabilitation [28, 29, 30]. Trial and error learning led to higher proficiency immediately after training compared to a highly structured systematic instruction, and led to better proficiency with the app one week later compared to an error-based learning method. There were no differences between the groups that received different training methods at 6-week follow up [30]. Qualitative findings indicate different advantages of the different training. For example, people may find the highly structured sessions easier so experience reduced training burden, while error-based methods may be more challenging during the session but could lead to a real or perceive improvement in their expertise with using the app and phone [29]. When learning to use software in brain injury rehabilitation, the user interface may influence the effectiveness of a training strategy. For example, it may be easier to implement an error-free learning method using a narrow-deep user interface that, compared to a broad-shallow UI, reduces the amount of errors that can be made while learning the process of entering reminders.

The researcher scoring the reminder setting tasks (accuracy, speed and noting the guidance requested) was not blind to the app UI condition the participants were using and were aware of the study hypotheses. This was a potential source of bias. This was mitigated by the scoring sheets which had a checklist for the scoring method to remove as much subjectivity from the scoring as possible (see supplemental materials).

6 CONCLUSION

People with prospective memory difficulties following ABI can benefit from the use of smartphone reminding apps. However, cognitive difficulties may make it difficult to use such apps. This study has demonstrated that narrow-deep UI type might reduce omission errors and therefore help people with cognitive impairments after ABI use a smartphone reminding app. This has not previously been formally assessed in reminding technology in the context of ABI rehabilitation. Most reminding apps use a broad-shallow UI which led to significantly less accurate reminder setting than narrow-deep UI with no difference in reminder setting time, guidance required or perceived task load. This result informs clinicians about the design of apps that are likely to be useable for their clients and about the mistakes they are likely to make. It also has implications for developers of accessible technologies given that broad/shallow is currently the user interface choice for most reminding apps and other software such as searching websites for information and emailing software.

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