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Implementing accessibility settings for people living with dementia in touchscreen apps

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Short Title: Implementing accessibility settings for dementia

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1. Abstract

BACKGROUND: Accessibility options within apps can enable customisation and improve usability. The consideration of accessibility for people living with dementia has not been explored, but is necessary to prevent a 'digital divide' in our society. This study set out to examine whether the introduction of accessibility settings for people with dementia in two mainstream gaming apps (Solitaire and Bubble Explode) could improve the user experience.

OBJECTIVES: To evaluate the effectiveness of tailored accessibility settings for people living with dementia by comparing the gameplay experience with and without the settings, and measure the impact on their ability to initiate gameplay, play independently and experience enjoyment.

METHODS: Thirty participants were recruited to test one of the two apps that had been adapted to include accessibility features. These features were derived from an analysis of gameplay in a previous study, from which the design of the present study was replicated. The results were compared with those from the earlier study (i.e. pre-adapted apps).

RESULTS: The accessibility features significantly improved usability in Solitaire, which had been the more problematic of the two apps when evaluated in its pre-adapted form. Bubble Explode retained the high-level of usability without further improvements. Initiation of gameplay was significantly improved in the adapted version of Solitaire, with no significant differences to progression or enjoyment for either app.

CONCLUSIONS: This study represents the first implementation of accessibility settings for dementia in mainstream apps, whilst demonstrating the feasibility and positive impact of the approach. The findings reveal core principles of touchscreen interaction and design for dementia that can inform future app development.

2. Introduction

Accessibility is a key concept of interactive systems that promotes equal opportunities for all users [1]. Within digital applications (apps), settings menus are commonly used to present accessibility options, enabling the appearance and sounds of the app to be customised to suit the user requirements [2]. Some apps include specific accessibility settings to address the needs of people living with a particular condition, e.g. autism [3] or aphasia [4]. Whilst website accessibility for people living with dementia has received some attention [5,6], there has been no exploration of accessibility settings in apps for this population. A likely explanation as to why people living with dementia have not been considered as beneficiaries of tailored accessibility settings within existing software is due to the widespread approach of creating bespoke solutions [7]. Whilst there are advantages to this method, the potential benefits to adapting existing apps used by the wider population is that there is a vast array of choice already available and the risk of stigma is reduced [8]. Given the omnipresence of apps on technologies such as smartphones and tablet computers, there is a need to explore accessibility settings for people living with dementia to prevent digital exclusion.

The notion of a 'digital divide' led the authors to undertake a project exploring the abilities of people living with dementia to use existing apps on a tablet computer. This project has focused on gaming apps, as the need to address independent leisure activities for people with dementia is known [9,10]. Many examples of technology application in this field have been in the form of 'assistive' devices [11], and often where the person with dementia is not the intended user [8]. Less attention has been paid to the promotion of technology as a source of independent leisure activity with people with dementia, which is surprising given technology's role in this area for other sectors of the population [12]. Stereotypical preconceptions of the needs, requirements and abilities of people living with dementia drive the selection and development of technology for them [8]. Examples of such preconceptions include the notion that people with dementia cannot learn new skills because of their cognitive impairment [13], and that a diagnosis of dementia prevents quality of life and reduces an individual's capacity for pleasure [14]. These negative perceptions may be a consequence of measuring skills and performance against pre-diagnostic levels, which inevitably focus on loss [15]. If technological solutions focus instead on the retained abilities of people living with dementia, the potential for experiences that promote enjoyment and pleasure can be realised [16]. The results from phase one of this research project established this.

An initial study (phase one) conducted in 2015 demonstrated that people with dementia could independently initiate and engage with selected apps [17]. Thirty people with dementia tested two apps – Solitaire, a traditional card game, and Bubble Explode, a tile-matching puzzle game – on three occasions. These games were selected based on an evaluation process that identified a wide range of generic accessibility options in both apps [17]. Phase one reported that 90% of participants independently initiated gameplay, with 88% enjoying playing the games. However, the two games differed in playability with 93% of participants reaching a predetermined checkpoint in Bubble Explode compared with only 17% playing Solitaire. Our analysis of the gameplay identified issues in both apps relating to accessibility that disrupted gameplay for many of the participants, although this was more apparent in Solitaire. For example, Solitaire has two possible control methods: (i) 'drag and drop', where the user touches the card they want to move and slides their finger to the desired location to place it, or (ii) 'tap', where the user simply touches the card they want to move and the computer automatically places it if there is a viable placement. The concurrent presence of both control methods created an accessibility problem as the computer sometimes misinterpreted the user's intention, either by moving the card automatically if the user raised their finger from the screen during a 'drag and drop' attempt, or by not moving the card automatically if the user held their finger down too long during a 'tap' move. This is especially problematic for users with dementia who are at increased risk of being confused when the game does not behave as expected.

These and other disruptions identified during app usage in phase one highlighted the need for accessibility settings designed specifically for people living with dementia. We discussed the problems associated with each game with the respective app developers, and collaboratively agreed adaptations to improve accessibility (see Table 1). To evaluate the effectiveness of these adaptations, we designed the current study (phase two) replicating the methods and experimental design employed in phase one with the adapted apps [17]. The following research question was addressed: Can the implementation of tailored settings improve the accessibility of existing touchscreen apps for people living with dementia?

3. Materials and Methods

This paper will present a summary of the materials and methods; a more detailed description can be accessed in the publication of phase one [17], of which the present study is a replication using the newly adapted apps with dementia-specific accessibility settings. A couple of exceptions to this replication were necessary, both relating to the aforementioned adaptations which were introduced as updates to the existing apps. Firstly, due to the release schedule of the two app updates being several months apart, two waves of data collection took place (see 3.1), which differs from phase one where all participants were recruited at the same time and alternately assigned to the two groups. Secondly, as the update for Bubble Explode on the iOS platform was delayed beyond the timeframe allocated to complete this study, this app was instead presented to participants on the Android platform in phase two, which required a change to the tablet computer (see 3.3).

3.1 Design

Given that the evaluation of digital technology interaction by people living with dementia is still a relatively innovative research topic [11], an exploratory research design was used employing quantitative analysis of video recorded gameplay sessions. For phase two, 30 new participants were recruited to play the updated versions of the apps. Each participant was asked to play the same game at three different time-points over the course of a five-day period, with each gameplay session being video recorded. In the first wave of data collection, 15 participants were recruited to play Solitaire (Group 1), followed by a further 15 participants in the second wave to play Bubble Explode (Group 2). The sample size and number of data collection points was consistent with the design of phase one [17] in order to allow for a comparison of the apps before and after the adaptations had been implemented.

3.2 Participants

Thirty people living with dementia were recruited from residential and specialist dementia services in Sheffield, UK. Twenty-two of the participants were female and eight were male. Their mean age was 84.17 years (range 66-102; SD 8.35). The severity of their cognitive impairment was assessed using the Montreal Cognitive Assessment (MoCA [18]), with a score of <26/30 required to distinguish between dementia and healthy controls. The participants' mean score on the MoCA was 12.97 (range 4-24; SD 4.9).

The study was granted ethical approval by the School of Health and Related Research (ScHARR) Ethics Committee at The University of Sheffield, and the lead author obtained consent directly from each participant. A thorough description of the consent procedure is detailed in the publication of phase one of this study [17], which was replicated exactly for phase two. In addition to the presence of cognitive impairment (verified by the MoCA) and the capacity to consent to participate, participants were also required to have the physical capability to interact with the tablet computer for this study. No other inclusion or exclusion criteria was used.

Of the 30 participants recruited to phase two, 26 engaged at all three time-points and four engaged at two time-points. This resulted in a total of 86 sessions out of a possible 90. The missing data were accounted for by: participants missing a session through ill health (two occasions); participants being judged to having shown signs of discomfort at a previous session (one occasion); or participants declining to participate on the day of the session (one occasion). Due to equipment failure, the video recordings of two gameplay sessions could not be analysed. Therefore, the results relate to 84 recorded gameplay sessions (43 for Solitaire and 41 for Bubble Explode). In comparison with phase one, there were five more sessions attended by participants playing Solitaire in the present phase, but the same number of sessions attended involving Bubble Explode.

3.3 Materials

To improve accessibility, the problems associated with each app, identified in phase one, were discussed with the respective developers, and design adaptations were agreed collaboratively (see Table 1). For Solitaire, once the collaborative discussion phase with the developers was completed, the three agreed adaptations were all implemented as expected in the app update. However, with Bubble Explode, of the four agreed adaptations, three were only partially implemented and the other was a compromised solution. Updates for both apps including the adaptations were released within nine months.

An Apple iPad (fourth generation) running iOS 9 was used for all participants playing the adapted version of Solitaire, and a Samsung Galaxy Tab (S2) running Android 7.0 (Nougat) was used for all participants playing the adapted version of Bubble Explode. Both tablets were presented in a 'Proud to Play' purpose-designed case for people living with dementia (see Fig. 2), created as part of the international 'InTouch' research project [19]. As previously stated, the use of an Android tablet for Bubble Explode was necessary due to the availability of the app update at the time of the research. This specific tablet was selected as it was the closest in specification to the Apple iPad; providing a multi-touch capacitive touchscreen with the same screen size (9.7 inch), resolution (1536 x 2048) and pixels per inch (264). Hardware and software settings were matched as closely to the iPad settings [17], with brightness and volume maximised and all notifications turned off. The Galaxy Tab was compatible with the specially designed case used in all other conditions during phases one and two so continuity of presentation was ensured. A Panasonic HD digital video recorder (model HC-X900) on a tripod was used to record all data collection sessions.

3.4 Procedure

The sessions were conducted in a suitable environment within each care service that ensured privacy and comfort. The video camera was positioned on a tripod in a position allowing a view of the tablet screen over the participant's shoulder (see Fig. 3).

For each participant the following procedure was used at each data collection session. The tablet was presented to the participant with the start of the game ready on the screen. The researcher provided a rehearsed physical demonstration of the game, in combination with verbal instructions describing the process. The researcher then reset the game to the beginning and invited the participant to begin in his or her own time. Participants were given the opportunity to play the game through to completion unless they indicated that they wanted to finish earlier or if their gameplay session exceeded 10 minutes. As the focus of the research was on independent gaming, the researcher retreated out of the participant's line of sight and resisted any initial requests for advice or support from the participant during gameplay by politely encouraging them to try and continue themselves. However, if the participant requested support more than twice, or was deemed to be in any discomfort or distress, the researcher responded to the participant and offered support, thus ending their gameplay session for the purpose of analysis.

3.5 Video coding

After all data had been collected, each video recorded gameplay session was analysed using the coding scheme presented in Table 2. Analysis was conducted using The Observer® XT (version 12.0.825) software by Noldus Information Technology on a Dell Precision T3610 computer running Windows 7 Professional. Videos were first transferred from the recording equipment to an encrypted external hard drive and uploaded to The Observer® software for analysis. The researcher viewed each video at half-speed and entered codes chronologically within the monitored duration of gameplay (from the end of the demonstration until the gameplay session ended).

3.6 Outcome measures

Accessibility and gameplay were measured through analysis of the coded video data.

3.6.1 Accessibility

Three outcomes were measured to assess the effectiveness of the accessibility settings (see Table 2).

1. Game advancing moves.

The percentage of screen interactions coded as advancing the gameplay was calculated from the total number of intentional screen interactions in each gameplay session. In Solitaire, game advancing moves were defined as drawing cards from the deck or placing cards in viable locations, and in Bubble Explode as removing coloured groups of bubbles.

2. Usability problems.

The percentage of screen interactions that were coded as being indicative of an issue relating to usability was calculated from the total number of screen interactions in each gameplay session. Usability problems for both apps were defined as attempted but unsuccessful viable moves, unintentional screen interactions or interactions with on-screen elements not directly related to gameplay (e.g., menu icons).

3. Utilised prompts.

The percentage of prompts to which participants responded was calculated from the total number of displayed prompts in each gameplay session. This included the inactivity prompts found in both apps, as well as the redirection prompt following an invalid move attempt in Bubble Explode. Utilising a prompt was defined as attempting the highlighted move as the next screen touch.

3.6.2 Independent gameplay and enjoyment

With the implementation of new accessibility features designed to improve the gameplay experience for people living with dementia, it was important to repeat the original outcome measures [17] to investigate the impact of the adaptations. Therefore, the following variables were measured through the video coding process (see Table 2), for comparison with phase one.

1. Independent gameplay initiation.

Participants were observed for independent initiation of gameplay, once the rules had been explained to them and they were invited to start.

2. Checkpoint attainment.

Participants were observed for independent advancement through the game to a pre-determined ‘checkpoint’ [17].

3. Enjoyment.

Participants were asked whether or not they had enjoyed their experience at the end of each gameplay session.

3.7 Data analysis

The coded data were analysed using appropriate statistical analyses (independent samples *t*-tests, chi-square tests for homogeneity, Fischer’s exact tests).

4. Results

To assess the effectiveness of the implemented adaptations for both Solitaire and Bubble Explode, the data are compared with the equivalent data from phase one. Participant characteristics from both phases are presented in Table 3. There was no significant difference between the age of the participants in phase one (M = 87.33, SE = 0.97) and phase two (M = 84.17, SE = 1.52; t (58) = 1.75, p = .09, r = .22), and no significant difference between their MoCA scores in phase one (M = 13.4, SE = 0.55) and phase two (M = 12.97, SE = 0.9; t (48.06) = 0.41, p = .68, r = .06). None of the participants recruited to either phase reported having had any experience using tablet computers prior to this research project.

Table 4 presents the total counts of all screen interactions made by participants compared between phases 1 and 2. The outcomes related to accessibility for both phases and both apps are derived from the figures in this table, calculated as proportions according to the definitions described in section 3.6.1.

4.1 Solitaire (Group 1)

Comparisons of accessibility and gameplay (Table 5) were conducted between the original and adapted versions of Solitaire. The proportion of game advancing moves in the adapted version (29.45%; M = 50.1, SE = 6.36) did not differ significantly to the original version (27.96%; M = 36.45, SE

= 8). However, usability problems were significantly reduced in the adapted Solitaire (7,93%; *M* = 12.65*, SE* = 2.41) compared with the original version (53.3%; *M* = 44.05*, SE* = 5.48). There was also a significant increase in the proportion of prompts utilised in the adapted version (60.83%; *M* = 36.41*, SE* = 7.32) compared with the original version (20.45%; *M* = 15.01*, SE* = 7.33; Table 5).

In terms of gameplay, there was a significant increase in independent initiation in the adapted version of Solitaire compared to the original (Table 5). There was no significant change in independent advancement to the checkpoint and enjoyment was not significantly changed.

4.2 Bubble Explode (Group 2)

Accessibility and gameplay (Table 5) were compared between the original and adapted versions of Bubble Explode. There was no significant difference in the proportion of game advancing moves between the adapted version (47.06%; *M* = 69.85*, SE* = 4.28) and the original version (53.06%; *M* = 69.36*, SE* = 4.32), and usability problems remained low in the adapted version (7.61%; *M* = 9.3*, SE* = 2.06) as with the original version (7.83%; *M* = 8.29*, SE* = 1.66). As the prompt feature was newly introduced for the adapted version of Bubble Explode, there is no comparative data from phase one. Descriptive statistics reveal that just over 10% of the prompts that appeared on screen were utilised by participants. This figure is lower than for both designs in the original (20.45%) and adapted (60.83%) versions of Solitaire.

Independent initiation of gameplay remained at ceiling level (100%) for the adapted Bubble Explode, and there were marginal but non-significant increases in both independent advancement and game enjoyment (Table 5).

5. Discussion/Conclusion

Phase two of this research project demonstrated the effectiveness of introducing accessibility settings designed for people with dementia into two mainstream gaming apps; improving gameplay in one (Solitaire) which was originally found to be very difficult, and maintaining the playability of the other (Bubble Explode) which was already quite successful. Independent initiation of gameplay and progression was equal or greater between the adapted versions of both apps and their original counterparts, and despite marginal fluctuations, self-reported enjoyment remained high for participants playing both games, reaffirming the notion that touchscreen apps have the potential to provide enjoyable independent experiences for people living with dementia.

Solitaire was originally difficult for people with dementia to play despite the presence of generic accessibility features such as changing the colours of the game backgrounds, the face of the cards and a next-move prompt feature [9]. The adapted version of Solitaire, with new accessibility features tailored for people with dementia, significantly increased independent initiation of gameplay and reduced the number of usability problems experienced by participants. In addition, redesigning the prompt feature (see Fig. 4a and 4b) significantly increased its utilisation during gameplay. This suggests that the adaptations were effective in improving the accessibility of the app for people living with dementia; removing or at least minimising the barriers identified in phase one. Further examination of the various types of usability problems (unsuccessful moves, unintentional touches and non-game interactions) revealed that the total count of each substantially decreased (see Table 4) in comparison with the results from phase one, despite there being more initiated gameplay sessions and therefore more overall touches. This is important because several of the individual barriers identified from the data in phase one were attributed to specific categories of touch. Consequently, whilst the overall reduction in usability problems indicates improved accessibility generally, the finding that all three of these categories decreased provides evidence that the individual adaptations were effective.

In contrast with the improved accessibility evident in Solitaire, the results from Group 2 of participants assigned to play Bubble Explode in the present phase indicated that the adaptations had less impact. Game advancing touches actually decreased slightly (from 53% to 47%), and there was only a marginal decrease in usability problems (from 7.8% to 7.6%), although both these results were non-significant. Interestingly, the effectiveness of the newly introduced prompt feature was also minimal, with just 10% of all generated prompts being utilised, even though this was identified in the gameplay analysis of phase one as something that could be beneficial. Two possible explanations for the lower impact of the Bubble Explode adaptations are considered. Firstly, the original Bubble Explode was already a highly accessible game, and it is possible that marginal improvements were all that could have been realistically achieved. However, many of the identified problems in phase one (see Table 1), on which the implemented app adaptations were based, were again observed in the present phase. Consequently, the second explanation proposed is that the adaptations that were actually implemented were less consistent with what was proposed as solutions based on the gameplay analysis. For example, the newly introduced prompt feature was very subtle (a glowing light behind the bubbles, similar to the glowing effect used for a prompt in the original version of Solitaire, which had been found to be ineffective in phase one); and there was no audible or animated feedback assigned to an invalid move attempt. Although only speculative, it is conceivable that had it been possible to implement all solutions in full, the effectiveness of the adaptations may have been greater. In concluding this aspect of the discussion, it is felt important to state that it was not the intent to apportion blame or criticise when considering these issues, and to emphasise that the developers were under no obligation to collaborate with this research project and were doing so in an attempt to improve the accessibility of their app for their users.

The ability to customise software has been highlighted as a key benefit of modern touchscreen devices for people with dementia [11]. Consequently, Solitaire and Bubble Explode were selected ahead of other comparable apps for this research largely due to the range of customisation options included in their design [17,20]. Furthermore, the adaptations to Solitaire were all included as customisation options within the existing app (see 1.1), to allow users to select which of them, if any, they want to apply during gameplay. Whilst the Bubble Explode developers did not include the adaptations as options, instead implementing them as design changes for all app users, they still adapted their existing app, as opposed to releasing a separate version specifically for dementia. By including adaptations and customisation options in this format, a blueprint has been laid out that it is hoped other developers will follow in the future. To our knowledge, these are the first examples of accessibility options specifically designed for people with dementia to be incorporated into mainstream apps (see Fig. 5). The benefit to increasing the accessibility of existing apps is that people can tailor the gameplay experience to fit their own needs. Dementia affects each individual uniquely [21], and therefore no combination of settings will suit everybody. However, by including adaptations as a series of options that can be turned on or off, the accessibility of apps can impact a wider audience.

A further benefit to the incorporation of accessibility settings in existing apps relates to the stigmatisation that can arise through the design of technology that is set apart from other products by its association with disability [22]. A separately-released ‘Bubble Explode for Dementia’, for example, would be unnecessarily segregated from the original game based on just a few accessibility features that allow the game to be played by a wider audience. By offering all apps together, people with dementia are able to share the same technology-use experience without risking isolation. This has the potential to encourage intergenerational socialisation and raise awareness of dementia with younger audiences [23].

Finally, whilst the participants in the present project reported having no prior tablet computer experience, it is inevitable that people receiving diagnoses of dementia now, and increasingly in the future, will be existing users. By 2020, it is forecast that 1.4 billion people globally will be tablet users [24]. Whilst focused on gaming apps, the results of this research reveal core principles relating to accessibility for dementia, both in terms of how people interact with apps and devices, and the optimum design of content, which can be generalised to other types of apps (e.g. finance, health management, etc.). If the implementation of accessibility options for people with dementia were to be widely adopted by app developers, existing app users who receive a diagnosis of dementia would have an increased opportunity of continuing to use the same software while only having to adjust the settings to meet their changing needs. This corresponds with continuity theory [25], which emphasises the crucial role that continuity of activity can have on preserving a sense of identity and self-concept, and has also been linked to improved self-esteem [26].

The use of two different samples to test the pre-adapted and adapted versions of these apps is unorthodox but was a necessary decision given the adaptation process which led to a gap of two years between phases one and two. The option to have the second cohort of participants play both pre-adapted and adapted versions for direct comparison was considered, however this could have led to potential biases. For example, if a participant struggled with some of the accessibility issues identified in the pre-adapted version, they may have a negative bias toward the game when asked to play again with the adapted version. Conversely, if they had not been impacted by the accessibility issues of the pre-adapted version, their knowledge of the game might have put them at an advantage when playing the adapted version in comparison with someone who had not played before. In order to mitigate the effects of having two different samples, the same recruitment strategy was used in both phases to recruit a comparable sample of participants. Participant characteristics in both studies were reported (see Results) and the similarity between the samples in terms of gender, age and cognitive score is evident, with no significant differences between the samples in age or cognitive score. However, despite these similarities, it is possible that an unexplored and therefore uncontrolled variable, such as hobbies and interests, may account for some of the variance in the results. As highlighted (see 3.3), due to the unavailability of the updated Bubble Explode app on the iOS platform, participants in Group 2 of the present phase used a Samsung Galaxy Tab as opposed to the Apple iPad tablet used in phase one. Whilst these tablets were closely matched on technical specifications and showed no differences in performance whilst running Bubble Explode either in pre-testing or during the study, in ideal circumstances this change would not have occurred and, again, the potential for this having affected the results is recognised. Due to the exploratory nature of the reported research, a relatively small sample of 30 participants was used in each phase. The authors envision that on the basis of these results, future research that aims to further the development of accessibility settings for people living with dementia should increase in scale.

5.1 Conclusion

Incorporating tailored accessible design within existing apps can improve the experience of using tablet computers for people living with dementia. This highlights the potential of apps to provide opportunities for leisure and engaging activity for people with dementia, just like for the rest of the population. This research demonstrates how the specific needs of this population can be conveyed to app developers to incorporate accessibility features for dementia.

6. Statements

6.1 Acknowledgement

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6.2 Statement of Ethics

This project received a favourable ethical opinion from the School of Health and Related Research (ScHARR) Ethics Committee at The University of Sheffield. Written, informed consent was given by each participant to a member of the research team.

6.3 Disclosure Statement

The authors have no conflicts of interest to declare.

6.4 Funding Sources

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6.5 Author Contributions

PJ designed the study, collected the data, conducted data analysis and drafted the manuscript. AJA critically appraised and revised the manuscript and supervised all aspects of the process in the role of doctoral supervisor.

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8. Figures

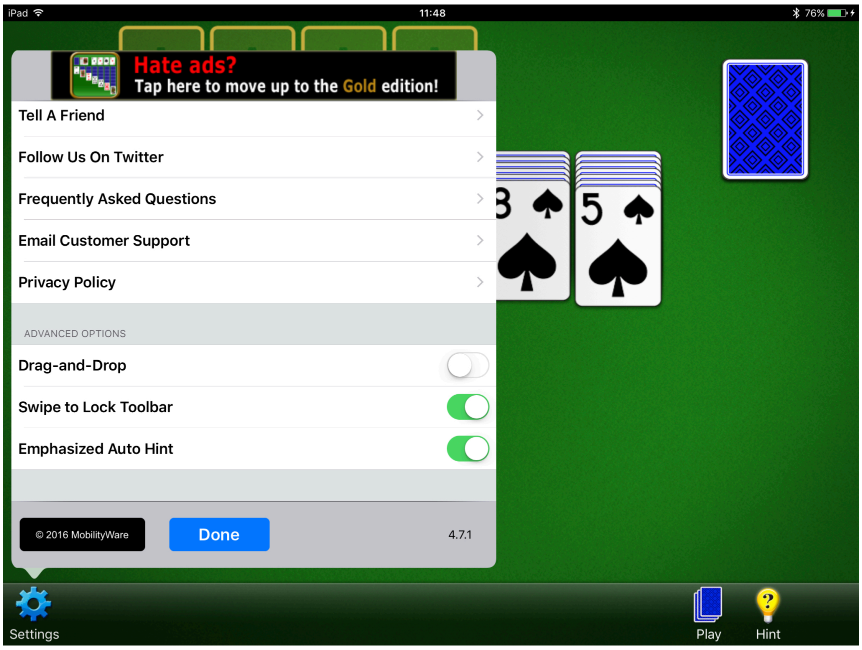

Fig. 1. Accessibility options implemented in Solitaire to address identified barriers to gameplay for people living with dementia

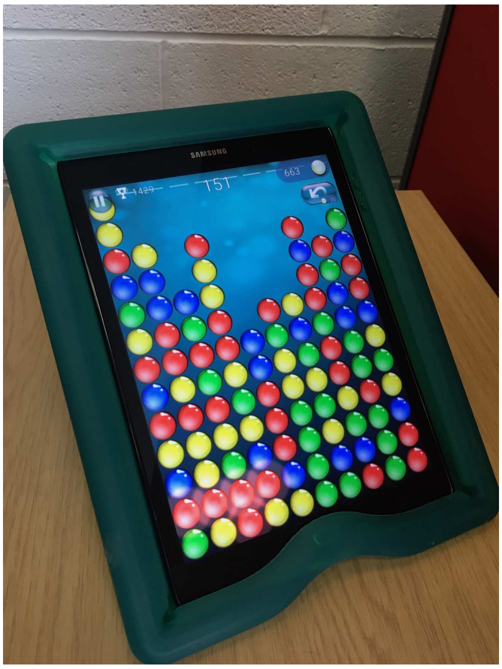

Fig. 2. Samsung Galaxy Tab presented in purpose-designed case

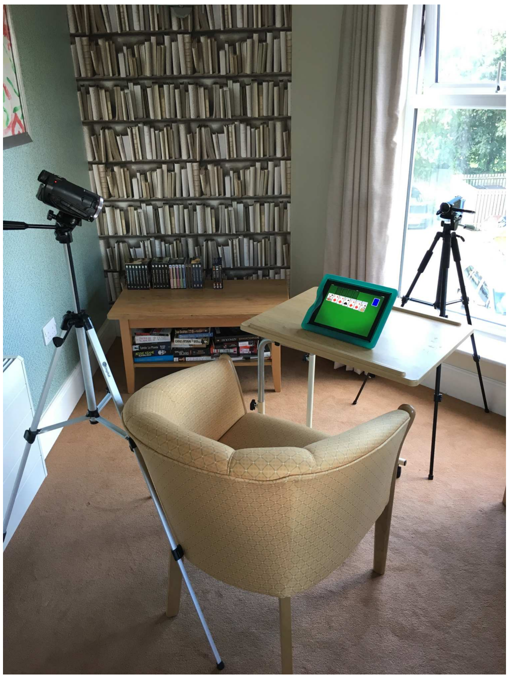

Fig. 3. Example environment used for data collection

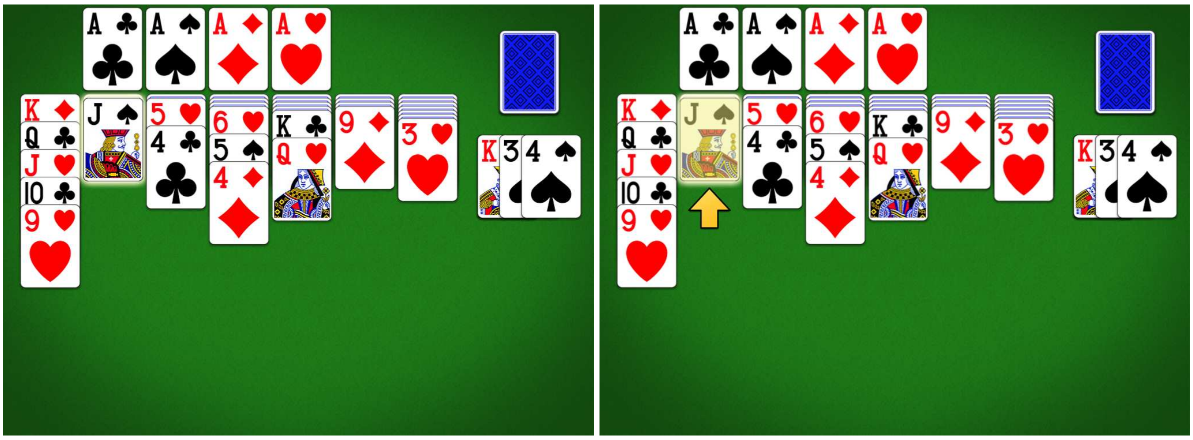

Fig. 4a and 4b. Screenshots of Solitaire illustrating a comparison of the prompt feature prior to (4a) and post (4b) adaptation to make the app more accessible for people living with dementia

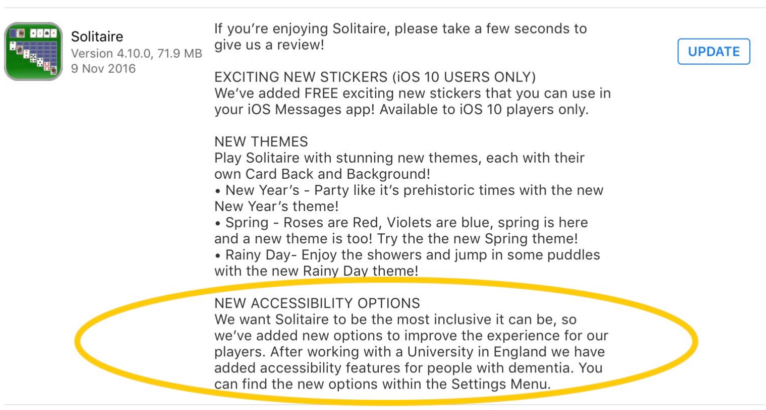

Fig. 5. Screenshot from the Apple App Store of the release notes for version 4.10 of MobilityWare's Solitaire app, which included the accessibility options (highlighted) emanating from the present research

9. Tables

Table 1. Summarised app adaptations

Solitaire (MobilityWare)	
Identified problems	**Collaboratively agreed solutions**
Two user control methods ('drag and drop' and 'tap') functioning concurrently	Added option to select one control method from the menu*
Pop-up toolbar that was frequently triggered unintentionally	Added option to change the input method required to trigger the toolbar*
Auto-prompt feature which proved ineffective during gameplay	Added option to emphasise the visual presentation of the auto-prompt*
Bubble Explode (Spooky House Studios)	
Identified problems	**Collaboratively agreed solutions**
Overlay of menu buttons and interactive elements at the start of gameplay	Adapted layout of opening gameplay screen
Text feedback, in addition to other forms of feedback, that proved distracting	Adapted presentation of text feedback
No auto-prompt feature if users are inactive	Inclusion of auto-prompt feature for inactivity
No feedback given for incorrect moves	Assign audio and visual feedback to an incorrect move attempt

**see Fig. 1.*

Table 2. Summary of coding scheme designed for the purposes of this research project to observe all user-led screen interactions and the presence of certain app features

Screen interactions	**Definition**
Game advancing move	*An intentional game move that is valid and successfully completed*
Unsuccessful move	*An intentional game move that is valid but not successfully completed*
Invalid move	*An intentional game move that is invalid (i.e., does not comply with the rules of the game)*
Unintentional interaction	*An interaction with the screen that was not intended by the participant*
Non-game interaction	*An interaction with the screen that is intentional but not directly related to the game (i.e., a menu item)*
Gameplay	**Definition**
Gameplay initiated	*Player begins gameplay (first screen interaction after demonstration)*
Checkpoint reached	*Checkpoint of the game is reached independently by the player*
Checkpoint not reached	*Checkpoint of the game is not reached by the player*
Prompts	**Definition**
No prompt	*No prompt is displayed on the screen*
Prompt	*Prompt is displayed on the screen*
Prompt utilised	*Next intentional screen interaction attempts highlighted move*
Prompt not utilised	*Next intentional screen interaction does not attempt highlighted move*

Table 3. Characteristics of participants in phases 1 and 2

		Female	Male	Mean age (SD)	Mean MoCA score /30 (SD)	Total no. of sessions
Solitaire (Group 1)	Phase 1	12	3	87.53 (5.89)	13.07 (2.84)	38
	Phase 2	13	2	85.4 (6.61)	12.8 (4.78)	43
Bubble Ex. (Group 2)	Phase 1	13	2	87.13 (4.93)	13.73 (3.22)	43
	Phase 2	9	6	82.93 (9.87)	13.13 (5.18)	43

Table 4. Total counts of screen interactions in original and adapted versions of both apps where gameplay was initiated

	Solitaire		Bubble Explode	
Category of interaction	Original version (N=27 sessions)	Adapted version (N=40 sessions)	Original version (N=42 sessions)	Adapted version (N=41 sessions)
Total touches	2137	2434	1507	1971
Game advancing moves	279	660	737	857
Unsuccessful moves	227	137	71	82
Invalid moves	719	1581	652	964
Unintentional touches	812	38	39	62
Non-game touches	100	18	8	6
Total intentional gameplay moves (*game advancing moves + invalid moves*)	998	2241	1389	1821
Total moves indicative of usability problems (*unsuccessful moves + unintentional touches + non-game touches*)	1139	193	118	150
Prompts generated	44	120	-†	665
Prompts used	9	73	-†	68

†New feature not present in original version of the app

Table 5. Summarised outcomes relating to accessibility, independent gameplay and enjoyment from gameplay sessions involving both original and adapted versions of both apps

Solitaire				
	Total (%)			
Outcome	Original version (N=27 sessions)	Adapted version (N=40 sessions)	Test of independence	Sig.
Game advancing moves (calculated from total intentional gameplay moves)	27.96	29.45	t (65) = 1.34, r = .16	.18
Usability problems (calculated from total touches)	53.3	7.93	t (36.12) = -5.25, r = .66	<.001*
Prompts utilised (calculated from total prompts generated)	20.45	60.83	t (39.01) = 2.07, r = .31	.045*
	Original version (N=38 sessions)	Adapted version (N=43 sessions)	Test of two proportions	Sig.
Independent initiation of gameplay	73.68	93.02	X^2 (1, N = 81) = 5.6	.018*
Independent advancement to checkpoint	15.79	20.93	X^2 (1, N = 81) = .35	.55
Enjoyment	88.89	77.5	-†	.34
Bubble Explode				
	Total (%)			
Outcome	Original version (N=42 sessions)	Adapted version (N=41 sessions)	Test of independence	Sig.
Game advancing moves (calculated from total intentional gameplay moves)	53.06	47.06	t (81) = .08, r = .01	.94
Usability problems (calculated from total touches)	7.83	7.61	t (81) = .38, r = .04	.71
Prompts utilised‡ (calculated from total prompts generated)	-	10.23	-	-
	Original version (N=43 sessions)	Adapted version (N=41 sessions)	Test of two proportions	Sig.
Independent initiation of gameplay	100	100	N/A	N/A
Independent advancement to checkpoint	76.74	87.8	X^2 (1, N = 84) = 1.75	.19
Enjoyment	83.72	95.35	-†	.16

*<.05 significance, †Due to small sample sizes, Fisher's exact test was used, ‡New feature not present in original version of the app