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Joddrell, P. orcid.org/0000-0002-8210-6508 and Astell, A.J. (2019) Implementing accessibility settings in touchscreen apps for people living with dementia. *Gerontology*, 65 (5). pp. 560-570. ISSN 0304-324X

<https://doi.org/10.1159/000498885>

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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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Keywords: Dementia; Technology; Accessibility; Leisure

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.

23

24 2. Introduction

25 Accessibility is a key concept of interactive systems that promotes equal opportunities for all users
26 [1]. Within digital applications (apps), settings menus are commonly used to present accessibility
27 options, enabling the appearance and sounds of the app to be customised to suit the user
28 requirements [2]. Some apps include specific accessibility settings to address the needs of people
29 living with a particular condition, e.g. autism [3] or aphasia [4]. Whilst website accessibility for people
30 living with dementia has received some attention [5,6], there has been no exploration of accessibility
31 settings in apps for this population. A likely explanation as to why people living with dementia have
32 not been considered as beneficiaries of tailored accessibility settings within existing software is due
33 to the widespread approach of creating bespoke solutions [7]. Whilst there are advantages to this
34 method, the potential benefits to adapting existing apps used by the wider population is that there is
35 a vast array of choice already available and the risk of stigma is reduced [8]. Given the omnipresence
36 of apps on technologies such as smartphones and tablet computers, there is a need to explore
37 accessibility settings for people living with dementia to prevent digital exclusion.

38 The notion of a 'digital divide' led the authors to undertake a project exploring the abilities of people
39 living with dementia to use existing apps on a tablet computer. This project has focused on gaming
40 apps, as the need to address independent leisure activities for people with dementia is known [9,10].
41 Many examples of technology application in this field have been in the form of 'assistive' devices
42 [11], and often where the person with dementia is not the intended user [8]. Less attention has been
43 paid to the promotion of technology as a source of independent leisure activity with people with
44 dementia, which is surprising given technology's role in this area for other sectors of the population
45 [12]. Stereotypical preconceptions of the needs, requirements and abilities of people living with
46 dementia drive the selection and development of technology for them [8]. Examples of such
47 preconceptions include the notion that people with dementia cannot learn new skills because of
48 their cognitive impairment [13], and that a diagnosis of dementia prevents quality of life and reduces
49 an individual's capacity for pleasure [14]. These negative perceptions may be a consequence of
50 measuring skills and performance against pre-diagnostic levels, which inevitably focus on loss [15]. If
51 technological solutions focus instead on the retained abilities of people living with dementia, the
52 potential for experiences that promote enjoyment and pleasure can be realised [16]. The results
53 from phase one of this research project established this.

54 An initial study (phase one) conducted in 2015 demonstrated that people with dementia could
55 independently initiate and engage with selected apps [17]. Thirty people with dementia tested two
56 apps – Solitaire, a traditional card game, and Bubble Explode, a tile-matching puzzle game – on three
57 occasions. These games were selected based on an evaluation process that identified a wide range of
58 generic accessibility options in both apps [17]. Phase one reported that 90% of participants
59 independently initiated gameplay, with 88% enjoying playing the games. However, the two games
60 differed in playability with 93% of participants reaching a predetermined checkpoint in Bubble
61 Explode compared with only 17% playing Solitaire. Our analysis of the gameplay identified issues in
62 both apps relating to accessibility that disrupted gameplay for many of the participants, although this
63 was more apparent in Solitaire. For example, Solitaire has two possible control methods: (i) 'drag and
64 drop', where the user touches the card they want to move and slides their finger to the desired
65 location to place it, or (ii) 'tap', where the user simply touches the card they want to move and the
66 computer automatically places it if there is a viable placement. The concurrent presence of both

67 control methods created an accessibility problem as the computer sometimes misinterpreted the
68 user's intention, either by moving the card automatically if the user raised their finger from the
69 screen during a 'drag and drop' attempt, or by not moving the card automatically if the user held
70 their finger down too long during a 'tap' move. This is especially problematic for users with dementia
71 who are at increased risk of being confused when the game does not behave as expected.

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

80 **3. Materials and Methods**

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

91 **3.1 Design**

92 Given that the evaluation of digital technology interaction by people living with dementia is still a
93 relatively innovative research topic [11], an exploratory research design was used employing
94 quantitative analysis of video recorded gameplay sessions. For phase two, 30 new participants were
95 recruited to play the updated versions of the apps. Each participant was asked to play the same game
96 at three different time-points over the course of a five-day period, with each gameplay session being
97 video recorded. In the first wave of data collection, 15 participants were recruited to play Solitaire
98 (Group 1), followed by a further 15 participants in the second wave to play Bubble Explode (Group 2).
99 The sample size and number of data collection points was consistent with the design of phase one
100 [17] in order to allow for a comparison of the apps before and after the adaptations had been
101 implemented.

102 **3.2 Participants**

103 Thirty people living with dementia were recruited from residential and specialist dementia services in
104 Sheffield, UK. Twenty-two of the participants were female and eight were male. Their mean age was
105 84.17 years (range 66-102; SD 8.35). The severity of their cognitive impairment was assessed using
106 the Montreal Cognitive Assessment (MoCA [18]), with a score of <26/30 required to distinguish

107 between dementia and healthy controls. The participants' mean score on the MoCA was 12.97
108 (range 4-24; SD 4.9).

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

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

125 **3.3 Materials**

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

133 An Apple iPad (fourth generation) running iOS 9 was used for all participants playing the adapted
134 version of Solitaire, and a Samsung Galaxy Tab (S2) running Android 7.0 (Nougat) was used for all
135 participants playing the adapted version of Bubble Explode. Both tablets were presented in a 'Proud
136 to Play' purpose-designed case for people living with dementia (see Fig. 2), created as part of the
137 international 'InTouch' research project [19]. As previously stated, the use of an Android tablet for
138 Bubble Explode was necessary due to the availability of the app update at the time of the research.
139 This specific tablet was selected as it was the closest in specification to the Apple iPad; providing a
140 multi-touch capacitive touchscreen with the same screen size (9.7 inch), resolution (1536 x 2048) and
141 pixels per inch (264). Hardware and software settings were matched as closely to the iPad settings
142 [17], with brightness and volume maximised and all notifications turned off. The Galaxy Tab was
143 compatible with the specially designed case used in all other conditions during phases one and two
144 so continuity of presentation was ensured. A Panasonic HD digital video recorder (model HC-X900)
145 on a tripod was used to record all data collection sessions.

146 **3.4 Procedure**

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

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

162 **3.5 Video coding**

163 After all data had been collected, each video recorded gameplay session was analysed using the
164 coding scheme presented in Table 2. Analysis was conducted using The Observer[®] XT (version
165 12.0.825) software by Noldus Information Technology on a Dell Precision T3610 computer running
166 Windows 7 Professional. Videos were first transferred from the recording equipment to an encrypted
167 external hard drive and uploaded to The Observer[®] software for analysis. The researcher viewed
168 each video at half-speed and entered codes chronologically within the monitored duration of
169 gameplay (from the end of the demonstration until the gameplay session ended).

170 **3.6 Outcome measures**

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

172 **3.6.1 Accessibility**

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

174 **1. Game advancing moves.**

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

179 **2. Usability problems.**

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

185 **3. Utilised prompts.**

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

190 3.6.2 Independent gameplay and enjoyment

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

195 1. Independent gameplay initiation.

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

198 2. Checkpoint attainment.

199 Participants were observed for independent advancement through the game to a pre-determined
200 'checkpoint' [17].

201 3. Enjoyment.

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

204 3.7 Data analysis

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

207 4. Results

208 To assess the effectiveness of the implemented adaptations for both Solitaire and Bubble Explode,
209 the data are compared with the equivalent data from phase one. Participant characteristics from
210 both phases are presented in Table 3. There was no significant difference between the age of the
211 participants in phase one ($M = 87.33$, $SE = 0.97$) and phase two ($M = 84.17$, $SE = 1.52$; $t(58) = 1.75$, p
212 $= .09$, $r = .22$), and no significant difference between their MoCA scores in phase one ($M = 13.4$, $SE =$
213 0.55) and phase two ($M = 12.97$, $SE = 0.9$; $t(48.06) = 0.41$, $p = .68$, $r = .06$). None of the participants
214 recruited to either phase reported having had any experience using tablet computers prior to this
215 research project.

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

220 4.1 Solitaire (Group 1)

221 Comparisons of accessibility and gameplay (Table 5) were conducted between the original and
222 adapted versions of Solitaire. The proportion of game advancing moves in the adapted version
223 (29.45%; $M = 50.1$, $SE = 6.36$) did not differ significantly to the original version (27.96%; $M = 36.45$, SE

224 = 8). However, usability problems were significantly reduced in the adapted Solitaire (7.93%; $M =$
225 12.65, $SE = 2.41$) compared with the original version (53.3%; $M = 44.05$, $SE = 5.48$). There was also a
226 significant increase in the proportion of prompts utilised in the adapted version (60.83%; $M = 36.41$,
227 $SE = 7.32$) compared with the original version (20.45%; $M = 15.01$, $SE = 7.33$; Table 5).

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

231 4.2 Bubble Explode (Group 2)

232 Accessibility and gameplay (Table 5) were compared between the original and adapted versions of
233 Bubble Explode. There was no significant difference in the proportion of game advancing moves
234 between the adapted version (47.06%; $M = 69.85$, $SE = 4.28$) and the original version (53.06%; $M =$
235 69.36, $SE = 4.32$), and usability problems remained low in the adapted version (7.61%; $M = 9.3$, $SE =$
236 2.06) as with the original version (7.83%; $M = 8.29$, $SE = 1.66$). As the prompt feature was newly
237 introduced for the adapted version of Bubble Explode, there is no comparative data from phase one.
238 Descriptive statistics reveal that just over 10% of the prompts that appeared on screen were utilised
239 by participants. This figure is lower than for both designs in the original (20.45%) and adapted
240 (60.83%) versions of Solitaire.

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

244 5. Discussion/Conclusion

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

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

265 barriers identified from the data in phase one were attributed to specific categories of touch.
266 Consequently, whilst the overall reduction in usability problems indicates improved accessibility
267 generally, the finding that all three of these categories decreased provides evidence that the
268 individual adaptations were effective.

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

291 The ability to customise software has been highlighted as a key benefit of modern touchscreen
292 devices for people with dementia [11]. Consequently, Solitaire and Bubble Explode were selected
293 ahead of other comparable apps for this research largely due to the range of customisation options
294 included in their design [17,20]. Furthermore, the adaptations to Solitaire were all included as
295 customisation options within the existing app (see 1.1), to allow users to select which of them, if any,
296 they want to apply during gameplay. Whilst the Bubble Explode developers did not include the
297 adaptations as options, instead implementing them as design changes for all app users, they still
298 adapted their existing app, as opposed to releasing a separate version specifically for dementia. By
299 including adaptations and customisation options in this format, a blueprint has been laid out that it is
300 hoped other developers will follow in the future. To our knowledge, these are the first examples of
301 accessibility options specifically designed for people with dementia to be incorporated into
302 mainstream apps (see Fig. 5). The benefit to increasing the accessibility of existing apps is that people
303 can tailor the gameplay experience to fit their own needs. Dementia affects each individual uniquely
304 [21], and therefore no combination of settings will suit everybody. However, by including adaptations
305 as a series of options that can be turned on or off, the accessibility of apps can impact a wider
306 audience.

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

315 Finally, whilst the participants in the present project reported having no prior tablet computer
316 experience, it is inevitable that people receiving diagnoses of dementia now, and increasingly in the
317 future, will be existing users. By 2020, it is forecast that 1.4 billion people globally will be tablet users
318 [24]. Whilst focused on gaming apps, the results of this research reveal core principles relating to
319 accessibility for dementia, both in terms of how people interact with apps and devices, and the
320 optimum design of content, which can be generalised to other types of apps (e.g. finance, health
321 management, etc.). If the implementation of accessibility options for people with dementia were to
322 be widely adopted by app developers, existing app users who receive a diagnosis of dementia would
323 have an increased opportunity of continuing to use the same software while only having to adjust the
324 settings to meet their changing needs. This corresponds with continuity theory [25], which
325 emphasises the crucial role that continuity of activity can have on preserving a sense of identity and
326 self-concept, and has also been linked to improved self-esteem [26].

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

349 authors envision that on the basis of these results, future research that aims to further the
350 development of accessibility settings for people living with dementia should increase in scale.

351 **5.1 Conclusion**

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

357

358 **6. Statements**

359 **6.1 Acknowledgement**

360 The authors wish to express their gratitude to the managers, staff and service users of Sheffcare,
361 Anchor, Country Court Care and Roseberry Care, as well as the app developers MobilityWare
362 (Solitaire) and Spooky House Studios (Bubble Explode), without whom this research would not have
363 been possible.

364 **6.2 Statement of Ethics**

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

368 **6.3 Disclosure Statement**

369 The authors have no conflicts of interest to declare.

370 **6.4 Funding Sources**

371 This research was conducted as part of a doctoral thesis funded by the Centre for Assistive
372 Technology and Connected Healthcare (CATCH) at the University of Sheffield.

373 **6.5 Author Contributions**

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

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8. Figures

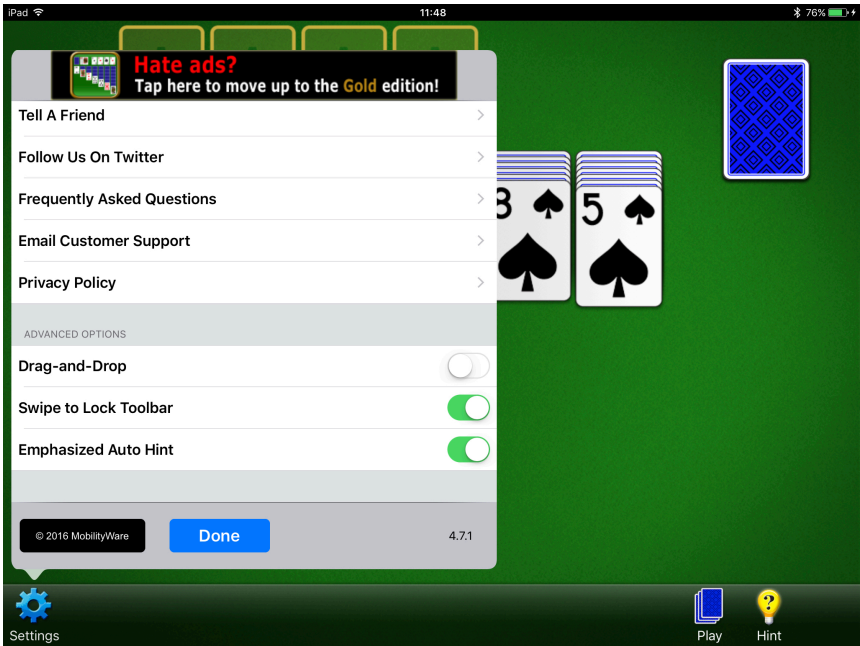


Fig. 1. Accessibility options implemented in Solitaire to address identified barriers to gameplay for people living with dementia

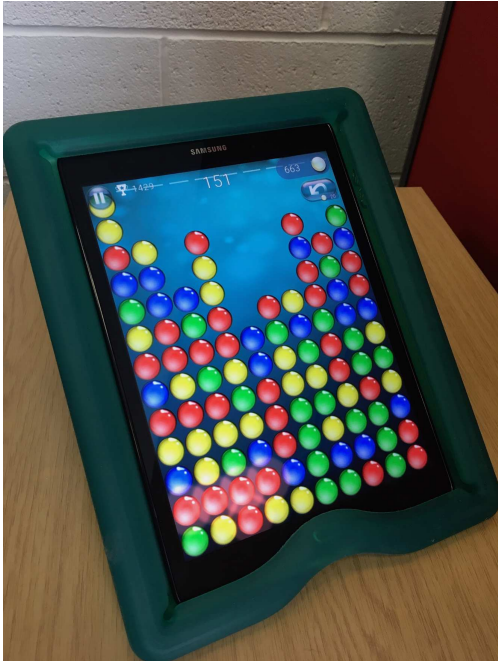


Fig. 2. Samsung Galaxy Tab presented in purpose-designed case



Fig. 3. Example environment used for data collection

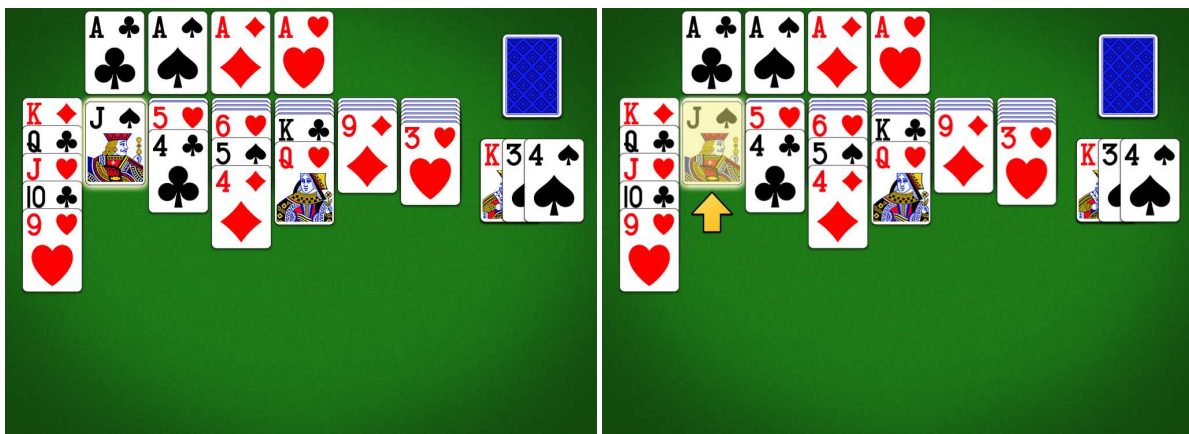


Fig. 4a and 4b. Screenshots of Solitaire illustrating a comparison of the prompt feature prior to (4a) and post (4b) adaptation to make the app more accessible for people living with dementia

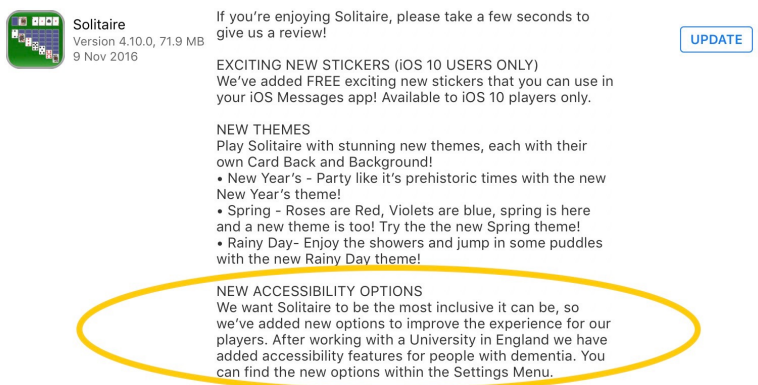


Fig. 5. Screenshot from the Apple App Store of the release notes for version 4.10 of MobilityWare's Solitaire app, which included the accessibility options (highlighted) emanating from the present research

9. Tables

Table 1. Summarised app adaptations

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

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

Category of interaction	Solitaire		Bubble Explode	
	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