

# Administering Cognitive Tests Through Touch Screen Tablet Devices: Potential Issues

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**Abstract.** Mobile technologies, such as tablet devices, open up new possibilities for health-related diagnosis, monitoring, and intervention for older adults and healthcare practitioners. Current evaluations of cognitive integrity typically occur within clinical settings, such as memory clinics, using pen and paper or computer-based tests. In the present study, we investigate the challenges associated with transferring such tests to touch-based, mobile technology platforms from an older adult perspective. Problems may include individual variability in technical familiarity and acceptance; various factors influencing usability; acceptability; response characteristics and thus validity *per se* of a given test. For the results of mobile technology-based tests of reaction time to be valid and related to disease status rather than extraneous variables, it is imperative the whole test process is investigated in order to determine potential effects before the test is fully developed. Researchers have emphasized the importance of including the ‘user’ in the evaluation of such devices; thus we performed a focus group-based qualitative assessment of the processes involved in the administration and performance of a tablet-based version of a typical test of attention and information processing speed (a multi-item localization task), to younger and older adults. We report that although the test was regarded positively, indicating that using a tablet for the delivery of such tests is feasible, it is important for developers to consider factors surrounding user expectations, performance feedback, and physical response requirements and to use this information to inform further research into such applications.

**Keywords:** Aging, attention, cognition, focus groups, qualitative research, tablet computers

## INTRODUCTION

The past five years have seen a rapid growth in the number of people over the age of 65 using mobile devices. Almost one in five older adults in the United States possess a smart phone with increased usage driven by factors such as the advanced capabilities of smart devices, the value placed on the ability to communicate with relatives, and the perceived usability

of touch screen technology [1, 2]. The trend opens new avenues for adjuncts to health-related diagnosis, monitoring, and intervention and thus the delivery of healthcare to a population that typically find it harder to access such services. This is of particular relevance for older adults who are increasingly at risk of developing dementia and associated disorders, and an often-corresponding reduction in both mobility and the ability to access healthcare services. As a result of increased engagement with digital technology devices such as tablets and smart phones, mass healthcare monitoring in older adulthood is a real possibility. Furthermore, healthcare solutions

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45 that economically scale up for a large number of users  
46 are increasingly in demand.

47 Mobile healthcare technology (mHealth) has been  
48 applied to many different healthcare challenges to  
49 help individuals living with chronic conditions such  
50 as diabetes [3]. Due to the ‘connected’ nature of  
51 these devices and the growing availability of broad-  
52 band internet, the idea of ‘information to support the  
53 user’ has been expanded beyond traditional medical  
54 sources and now provides a platform for community-  
55 based solutions where users share experiences and  
56 advice on managing a condition [4]. More advanced  
57 mHealth concepts include the idea of using on-body  
58 biometric sensors to monitor people’s health and to  
59 communicate these readings to their mobile device  
60 using wireless body area networks [5, 6]. Data gath-  
61 ered and disseminated through these means can be  
62 used to augment diagnosis and monitoring processes  
63 [7]. In addition to their use in physical conditions  
64 [8], mHealth may also be applied to the management  
65 of cognitive health [9]. However, although research  
66 examining the use of various health-related apps by  
67 older adults is helping to indicate what factors affect  
68 the use of such apps by this population [2, 8–10],  
69 there is a paucity of research investigating the use of  
70 touch screen tablets in assessing information or cog-  
71 nitive processing in older adults. This is especially  
72 so in relation to individuals living with cognitive  
73 impairment and dementia. Although it sounds sim-  
74 ple in theory to move away from testing on PCs by  
75 adapting cognitive tests for use with touch screen  
76 technology, using this platform can introduce new  
77 biases or effects, related to the technology per se  
78 or the technology/human interface. Biases may, for  
79 example, detrimentally affect the accuracy, validity,  
80 sensitivity, and specificity of the test and the robust-  
81 ness and clinical relevance of the results, when used  
82 either in a home or clinical setting and whether  
83 self-administered or given by another person. An  
84 individual’s test score/results must be indicative of  
85 the integrity of a given function and not be contam-  
86 inated by extraneous factors arising from physical,  
87 e.g., stimulus-related effects, related to the test itself,  
88 the procedure, the platform it is administered from,  
89 the test environment, and any administrator/patient  
90 interaction [11, 12].

91 Such factors are particularly pertinent to the test-  
92 ing of an individual’s reaction speed and variability.  
93 Reaction time (RT) speed and its intra-individual  
94 variability (IIV<sub>RT</sub>) are measures regularly employed  
95 as behavioral indicators of the speed of informa-  
96 tion processing and the integrity of cognitive and

97 attention-related function in older adulthood, in both  
98 research and clinical arenas, with disproportionate  
99 slowing and raised variability associated with mild  
100 cognitive impairment, Alzheimer’s disease, and vas-  
101 cular dementia [13–16]. As RT speed and variability  
102 appear to be behavioral indicators of the integrity (at  
103 least in part) of white and grey matter [17] in older  
104 adulthood and neurodegenerative dementia processes  
105 such as Alzheimer’s disease, such measures may be  
106 of use clinically.

107 Arguably, RT and IIV<sub>RT</sub> testing appear particu-  
108 larly suited to delivery or presentation via a touch  
109 screen tablet as they tend to be cheaper and simpler  
110 to use than laptops or desktop computers and can  
111 have multiple advantages over computers for test-  
112 ing information processing in older adults [9, 18,  
113 19]. However, it is also increasingly clear that fac-  
114 tors unrelated to brain structure and function and a  
115 disease process can influence RT and IIV<sub>RT</sub> and that  
116 it is vital to determine, investigate, and ameliorate  
117 such effects with respect to the touch screen tablet  
118 platform, in order to ensure test validity.

119 Evidence already reveals that there are a number  
120 of challenges to be aware of when digital technolo-  
121 gies are used by older adults including physical issues  
122 such as decline in manual dexterity and eyesight  
123 and decreasing cognitive capabilities, frustration, the  
124 need for specific training, age, gender, dry finger skin,  
125 and age-related cognitive motor skills [2, 18–22], all  
126 factors likely to affect the performance of RT and  
127 IIV<sub>RT</sub> tests using a touch screen platform and thus  
128 their clinical validity, usefulness, and robustness. Fur-  
129 thermore, RT research has revealed many participant  
130 and methodology-related factors capable of signif-  
131 icantly affecting RT study outcome including: the  
132 test item, the environment, response requirements,  
133 participant and tester, feedback, concurrent disease,  
134 medication, abnormal visual and attention-related  
135 processes, caffeine, depression, personality, and gen-  
136 der [11–13, 23–27].

137 Factors specific to the use of a touch screen tablet  
138 may also affect performance on such tasks. In a  
139 first step to investigating such factors, we took a  
140 novel approach, using a simple, focus group-based  
141 paradigm. We [28] examined the experience of a  
142 group of younger and older adults while performing  
143 the Multi-Item Localization (MILO) task—a typical,  
144 but touch screen tablet-based, RT test typical of those  
145 contributing to the clinical determination of cognitive  
146 integrity.

147 MILO has been used in previous objective research  
148 studies, to explore the speed and accuracy with which

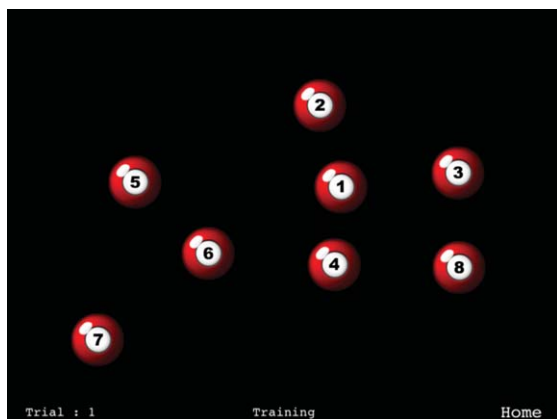


Fig. 1. A screen shot of the iPad MILO task used in the current study.

participants can perform sequences of actions [29, 30]. It is similar to other well-established paper-and-pencil (e.g., The Trail Making Task [31]) and computer-based cancellation tests [32] in requiring a sequence of items to be identified in a specific order. Figure 1 presents a typical trial from the tablet implementation of MILO that was used in the current study [33]. The task for the participant would be to touch each virtual pool ball in sequence, from one to eight.

The general advantages of computer-based presentation as compared to paper-and-pencil task include the recording of RTs for each item, rather than simply overall completion time (e.g., [32]) and the ability to easily explore spatial patterns of search organization (e.g., [34]). In addition to these, the MILO task makes it possible to easily manipulate the sequence type (e.g., letters, digits, or both) and sequence behavior (e.g., items vanishing or remaining, sequence position remaining fixed or shuffling between responses), to explore the temporal context of visual search [29]. Such a task therefore represents the type that might be considered for use in a clinical situation, providing information about RT speed and variability, and attention processing and other aspects of higher level, cognitive processing.

## MATERIALS AND METHODS

For the purpose of the current study, we used a fixed sequence of the digits one to eight, and configured the display so that items vanished when touched. Although this MILO configuration was not initially designed specifically for use with older adults, we chose the task specifically because the display layout and physical response demands were appropriate for

use with this population [35–37]. For example, there are a number of challenges to be aware of when digital technologies are used by older adults including physical issues such as decline in manual dexterity and eyesight and decreasing cognitive capabilities, both potentially hindering interaction with mobile platforms, which are not adapted to their needs [18, 19, 22]. In the MILO task, the target object size and spacing were well within these suggested limits and responses could be self-paced. More specifically, when the iPad was placed on a table 50 cm in front of participants, each 1.9 cm item subtended approximately  $2^\circ$  visual angle, with gaps between items varying between  $0.8^\circ$  and  $8^\circ$  visual angle. To successfully complete a trial, participants were required to touch each object following the numeric sequence one to eight as quickly as possible, but there were no specific time limits, so participants could calibrate their responses taking into account any motor limitations.

When an item was touched, it vanished from the screen, so that the set size, and search difficulty was reduced with each response. Touching an item out of sequence (i.e., a mistake) resulted in the termination of the trial and visual feedback in the form of a schematic sad face. There was a two second inter-trial interval and no feedback on speed or accuracy was provided for correct trials. Each participant completed 10 training and up to 10 experimental trials and at the start of each trial the position of all target items was randomized within the constraints of a virtual grid that was programmed to ensure items did not overlap. As our goal was to explore factors related to presenting a RT task using a touch screen tablet format *per se*, we did not record actual RT performance as participants were allowed to comment upon any aspects the task while they were doing it. Instead, as detailed below, we used a focus-group design to make a qualitative assessment of individuals' experiences and device usability.

In an approach that is interdisciplinary and draws from Human Computer Interaction (HCI) and User Experience (UX) research traditions, a focus group approach was adopted in order to determine from the individuals themselves potential issues relating to the use of mobile technology for cognitive testing that may influence the RT results. To provide information of relevance to real life test scenarios, as it is common in MILO and similar computer-based tests of attention and cognition to provide on-screen feedback using a visual or auditory warning indicative of incorrect response, we also investigated the potential

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influence of this real-time feedback upon task acceptability and performance. Furthermore, the researcher or clinician administering the test typically sits close to the individual taking the test; anecdotally this has been reported to be off-putting to the person taking the test in research situations, but it may also be reassuring for some. We therefore also examined this factor with respect to task acceptability and performance.

We, Jenkins et al. [28], recruited eleven younger adults (18–30 years) and twelve older adults (65+ years) for a one and a half hour focus group. The younger adults were recruited via University block-emails, electronic notices, and word of mouth. The older adults were recruited via the Older People and Ageing Research and Development Network (OPAN) and the local 50+ Networks. Poor general health and visual and dexterity limitations and participation in similar research studies formed exclusion criteria. Two members of the research team were present, one leading and the other observing and taking notes. A semi-structured schedule was followed. Our research method is discussed in full in Jenkins et al. [28], but to reiterate; there are of course limitations associated with this qualitative technique, which we acknowledged and addressed in order to ensure, as far as possible, that they did not introduce bias. For instance, the knowledge, skills, and experience of the researcher leading the focus group can have an unfavorable bias on the generation of information from the participants. In order to avoid such an impact, the research team ensured there were two members of the research team present, one leading and the other observing and taking notes. A semi-structured schedule was followed but also encouraged expansion of discussed areas. Qualitative analysis is rarely employed in the field of computer science therefore this research is novel, rich, and pushes the boundaries of what is already known in the research community.

The focus group was split into three parts. The first part of the focus group was based on discussions around the participants' understanding of attention, the importance of attention, and changes in attention [28]. In the second part, the participants performed the tablet-based MILO task in a separate room with another member of the research team sitting beside them. In the third part, all participants reformed the focus group to discuss their experience of taking the tablet-based test. This paper specifically focuses on the participants' experience of using the tablet in the context of a RT test and the participants were made aware that their actual RT was not looked at during the debriefing session.

Table 1  
Focus group schedule (iPad test experience)

| Focus group section          | Questions and prompts  |
|------------------------------|--|
| iPad test feedback questions | -Has anyone used an iPad/similar device before?<br>-How would you describe your experiences of using the test?<br>-Prompt – was it enjoyable or not?<br>-How well did you think you have done?<br>-What parts of the tests did you find challenging?<br>-Prompt - was it too fast? Hard to pay attention to, etc.?<br>-Was the iPad easy to use? |

The focus groups were audio-recorded, and a member of the research team took notes. A semi-structured predetermined framework of open-ended questions was used to ensure all aspects relating to the topic area were explored (Table 1). The focus group recordings were transcribed verbatim, and all identifiable information was either removed or consistently anonymized. Thematic analysis was employed on the interview data, which was realist driven, inductive, and bottom-up [38]. Two members of the research team read and re-read the transcripts making initial comments and codes. The process was repeated twice more until individual codes were identified. Subsequently these were grouped into three major themes that emerged across both younger and older participant groups, namely 'views of test experience', 'testing situation and materials', and 'test performance'. [Please contact researchers for full transcriptions and analysis].

## RESULTS

A number of themes and sub-themes have been identified highlighting categories rather than prevalence. The three major themes that emerged across both younger and older participant groups were 'views of test experience', 'testing situation and materials', and 'test performance'. In the results section, we will describe each of these themes and contrast the attitudes of younger and older groups before presenting an amalgamated discussion of the results.

### *Views of test experience*

This theme represents the view both the older and younger participants had of the iPad-based attention-related RT task experience. Six sub-themes have been identified, three unique to the older participants, one unique to the younger participants, and two which both age groups contributed to (Fig. 2).

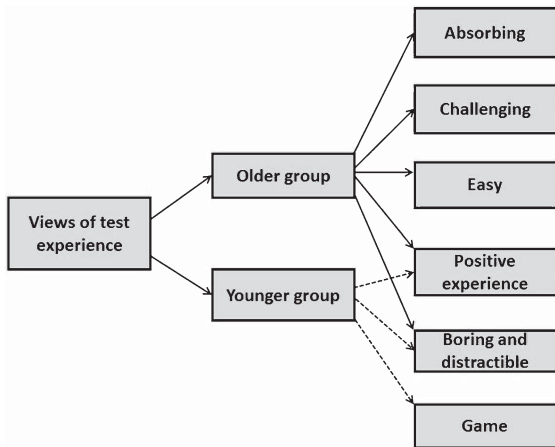


Fig. 2. Views of test experience.

First is the sub-theme ‘absorbing’ which represents the view that some of the older participants said they were absorbed into the iPad test experience. For instance:

“[W]: I found it quite absorbing myself because you had to concentrate on what was in front of you and you have to pin point what the next number was. I have to say it occupied all my thoughts I was just trying to do it as quickly as I could, and as accurately as I could. I was totally absorbed by those 1–8 numbers. Which is strange for me because my mind does tend to wander and it didn’t wander on that occasion”.

The second sub-theme reflects the older participants competing views that the test was a ‘challenge’, and the third sub-theme that it was ‘easy’. For instance:

Challenge: “[J]: I found it absolutely entertaining. I found it quite a challenge [mumbling]. I was sort of trying to do it quite quickly, I failed a couple of times but I think that was these [pointing out his fingers]”.

Easy: “[RA]: I thought it was easier than I thought it would be. I thought ‘I have never used an iPad before!’ And sometimes when I go onto the computer I press something and it goes off, I have done that a few times actually. The iPad I made a few mistakes”

The sub-theme ‘positive experience’ was a shared view of both the older and younger groups. For instance:

Positive experience (older): “[P]: it was quite enjoyable. [W]: and I think the more you did it the more you wanted to do it somehow”.

Positive experience (younger): “[R]: fab, thank you. Did you enjoy doing the test? [A]: it makes me want one [iPad]. [P]: it was interesting but I wouldn’t use the word ‘enjoy’ [laughter] I was just counting dots but it was a little more engaging that some can be. [S]: it made me wonder if they were dots or pool balls [laughter] I think it was nice that it changed on each trial. Like in a paper pencil version of a trail making there is only one set way of doing it and I like having the variation that it is new every time you do it, maybe it is more accurate that way”.

The sub-theme ‘boring and distractible’ is also a shared view in opposition to the test being a positive experience. For instance:

Boring and distractible (older): “[R]: so how did you find the test? [G]: a bit boring I found it, sorry. Repetitively boring there was obviously a sequence for that. I said that to [researcher] I said ‘is this um could you memorise these if you had a good memory and numerative memory?’ The problem is going too fast and then thinking something more interesting may come up next time. It was the same numbers just in a different location. Yeah I found it boring towards the end. [R]: yes and that is perfectly fine, I want you to be as honest as you can. Thank you [G]”.

Boring and distractible (younger): “[R]: ok, so would you say then something like that could be used on a regular basis or would you say no? [L]: I think it was boring”.

The final sub-theme is unique to the younger group and represents the view that the test was like a ‘game’. For instance:

“[B]: it was like many games that you can get on the iPad already, like I have a few already that are similar. [R]: are there any that you think are similar to it? [S]: I wouldn’t know. [A]: not sure. [P]: when she was initially explaining it to me it did kind of remind me almost of like a word search type thing because you are obviously looking for like a 1 and then linking it. [B]: I have quite a few games where you have to link patterns between things and there is ummm well I have about 5 on here and there are millions available as well like [famous game]. [R]: yeah it is a similar thing

402 isn't it. [S]: see I was thinking well what the pur-  
 403 pose of the game is, what it is going to be used as.  
 404 For example, if it is something to do with cognitive  
 405 training then I wondered what well if it would be  
 406 of any use to have like a kind of positive feedback  
 407 mechanism put in because I made a mistake and  
 408 there was a little sad face and that was feedback  
 409 too but you know to get people to play it maybe  
 410 more regularly maybe it would have like increas-  
 411 ing difficulty and a score. That would make them  
 412 go back to it. I don't know if I would play it regu-  
 413 larly just for the sake of doing it as it is now  
 414 because it is just like tapping the numbers and  
 415 I want to know that I am doing good. [A]: yeah  
 416 like in games you want to improve and beat your  
 417 score. [S]: yeah like progression or how well I am  
 418 doing. [B]: or different levels, like the next level  
 419 could have like 10 numbers”.

#### 420 Testing situation and materials

421 This second theme has three sub-themes devel-  
 422 oped from the findings of both the older and younger  
 423 groups (Fig. 3). The first sub-theme reflects the views  
 424 of both groups regarding the experience they had of  
 425 using the iPad. For instance:

426 Device experience (older): “[R]: yes but she  
 427 won't be giving scores, what's more important  
 428 to us is your feedback from the tests. Did you find  
 429 the iPad easy to use? [A]: yeah. [G]: well I did  
 430 and I don't see very well but it was fine. [J]: I  
 431 made two mistakes the same as you; as soon as I  
 432 slowed down a bit I was more accurate. And these  
 433 would slip down all the time [glasses], but it was  
 434 ok once I pushed them back up. [R]: yeah ok so  
 435 that was a challenge you found with your glasses.  
 436 [J]: yeah. [G]: well if you have a problem with  
 437 your sight it affects your mobility doesn't it. [A]:  
 438 yes I have to agree with you and varifocals; you  
 439 have got to look over them. [G]: yes, I have to use  
 440 my reading glasses so that I could see properly.”

441 Also: “[R]: does anyone have any experience of  
 442 using a device like an iPad? [A]: yes I do. [Oth-  
 443 ers]: no. [R]: do you think then that having that  
 444 device and using it previously made an impact  
 445 on it? [A]: yes I think so. I think when I first got  
 446 my iPad I was very tentative. But now I sit there  
 447 with my iPad and go 'large then small' [actions],  
 448 that was news to me at first, I never knew you  
 449 could do that [laughter]. [M]: so do you have  
 450 any idea whether or not someone who either type

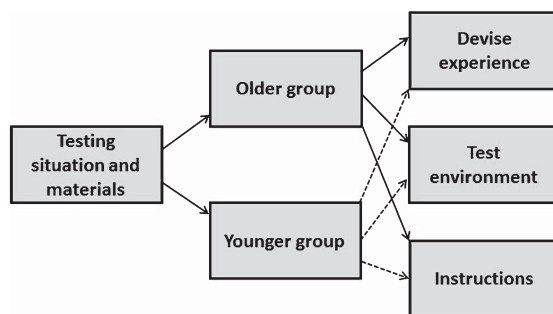


Fig. 3. Testing situation and materials.

451 or play the piano are quicker at that than people  
 452 who are not? [R2]: at the moment we don't for  
 453 that test but from what we know of other things  
 454 we wouldn't be surprised if they were, absolutely.  
 455 [A]: I think you're right though, it's like kids  
 456 on mobile phones, they are so fast. Like when I  
 457 text...well I am faster than I used to be but not as  
 458 fast as they are. [J]: when using a keyboard I do  
 459 try and type properly. My granddaughter goes so  
 460 fast when typing but then has to go back to attend  
 461 to her mistakes, where as I go slower but have  
 462 less mistakes”.

463 Device experience (younger): “[R]: ok, thank  
 464 you. How about the positioning of the iPad? [L]:  
 465 fine. [P]: I moved it. [R]: where did you move it  
 466 to? [P]: I just moved it closer. The angle was a  
 467 bit well I didn't move the angle. For me it would  
 468 have been better flat but maybe because it was  
 469 quite far into the table. [RB]: it would have been  
 470 helpful to have one of those holders, what are they  
 471 called? [P]: like a copy holder? [RB]: yeah, just  
 472 to have it in front of you, I wonder what that would  
 473 have been like. [P]: oh I know I like pushing down  
 474 instead of forwards. [R]: yeah it's so interesting  
 475 that the position of it, where it is, the lighting, you  
 476 have got to think of all these things when it comes  
 477 to testing situations”

478 The second sub-theme is the shared collection of  
 479 views regarding the 'test environment' of both age  
 480 groups. For instance:

481 Test environment (older group): “[N]: I was very  
 482 conscious that [researcher] was watching me.  
 483 [J]: yes and me. [N]: so I wasn't quite relaxed  
 484 doing it from that point of view. I was still  
 485 conscious that someone is watching me doing  
 486 this and you think 'what are they thinking? Are  
 487 they taking a note on how I am approaching this?'



488 so I was very conscious of that as well. [S]: yes  
489 that crossed my mind as well. [N]: I think it might  
490 have been slightly different if she had said 'right  
491 just go in and do this. This is what you have got  
492 to do, sit down and do it and I am going out of the  
493 room' I think I would have approached it slightly  
494 differently mentally".

495 Test environment (younger group): "[L]: yeah so  
496 maybe that unhappy face could spur someone on  
497 to do better and faster but then other people will  
498 see that unhappy face and think 'oh no!'. [P]: it  
499 put me off completely. [RB]: same [laughter]. I  
500 knew [researcher] was sat next to me and I didn't  
501 want her to see the faces. [R]: do you think it  
502 would have made a difference if [researcher] was  
503 not in the room? [RB]: yeah, I didn't want her to  
504 see it so I kept well at that angle she couldn't have.  
505 [B]: it does show that the unhappy face does mean  
506 more".

507 The final sub-theme relating to testing situation  
508 and materials is regarding the 'instructions' that were  
509 given to the participants to complete the iPad test. For  
510 instance:

511 Instructions (older group): "[M]: yes I am with  
512 him, I found it quite interesting and I am not a  
513 trained typist but I do use all my fingers on the  
514 keyboard and so I had all my right hand out. And  
515 at one point I though ahhh maybe I could use  
516 my left hand too but I didn't because I thought it  
517 may get confusing. I learned to look at the pattern  
518 before I started, but I wondered if you ever con-  
519 sidered having one of these clever gadgets that  
520 they can put on your glasses or on your head or  
521 something now so that they can see where you are  
522 looking. Did you know that they are doing these  
523 things in supermarkets now to see where you look  
524 on the shelves? I don't think the object of them  
525 doing it is a very good object but the technol-  
526 ogy is interesting, I didn't know because she was  
527 sitting beside me I couldn't tell if she could see  
528 where I was looking. But I thought that might be  
529 interesting because her introduction about look-  
530 ing for someone in the crowd, you know your first  
531 reaction is look at the whole thing first and before  
532 doing the numbers"

533 Instructions (younger group): "[S]: yeah I was  
534 going to say that because initially it was not right  
535 in front of me it was over there [pointing further  
536 away] and I felt I needed to pull it in front of  
537 me and I think maybe if you have it on your lap it

538 would be different. So I don't know, again in terms  
539 of the instructions of the set way of doing the task  
540 maybe there has to be a certain distance from the  
541 screen or uh I don't know, something that would  
542 make sure it is standardised for everyone".

#### 543 Test performance

544 This theme has six sub-themes, four of which are  
545 shared between the two age groups, and one unique  
546 to each (Fig. 4). The theme relates to how the par-  
547 ticipants felt they performed at the iPad test. The  
548 first sub-theme 'accuracy' is based only on the older  
549 participants. For instance:

550 "[R]: so what did you think? Was it due to more  
551 accuracy or speed? [N]: a combination of both I  
552 think. [P]: yeah it is no good going fast if you're  
553 going to get it all wrong is there. [J]: I was disap-  
554 pointed with the number of mistakes I did make,  
555 obviously trying to go too fast. [P]: I made one but  
556 I think it was because I didn't press hard enough  
557 on the screen. The face came up [showing sad  
558 face]".

559 The second sub-theme is the 'use of hands' whilst  
560 using the iPad. For instance:

561 Use of hands (older group): "[A]: the only prob-  
562 lem I had with the touch screen is my nails. I  
563 have this problem at home, and that's why I use  
564 a [brand name] pen because I find you have to  
565 develop a certain technique of touching. You can't  
566 just go like that [action] because your nail would  
567 touch it and that doesn't work so you have to slide  
568 off rather than...and I found that at home. But as I  
569 said I do find it easier to just use a [brand name]  
570 pen".

571 Also: "[J]: I found it absolutely entertaining. I  
572 found it quite a challenge [mumbling]. I was sort  
573 of trying to do it quite quickly, I failed a couple of  
574 times but I think that was these [pointing out his  
575 wide fingers]".

576 Use of hands (younger group): "[R]: ok, that's  
577 interesting. How did you use it? [RB]: oh just  
578 the one for me. [C]: two fingers. [L]: just one  
579 finger. [B]: one hand. [C]: one hand. [P]: that  
580 was one of the first questions I asked was 'can  
581 I use both hands?' [R]: did you just use the one  
582 finger? [RB]: yeah my index finger. [L]: yeah me  
583 too".

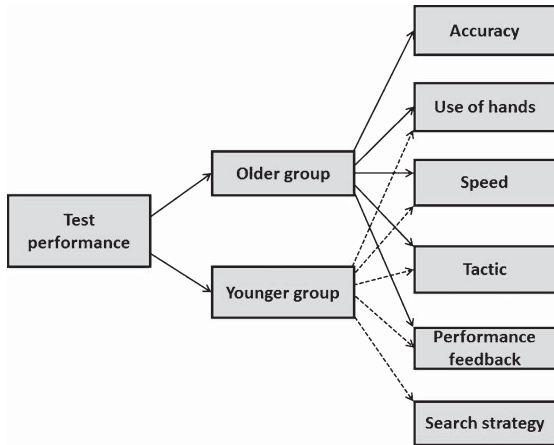


Fig. 4. Test performance.

The third sub-theme ‘speed’ is also shared by the older and younger groups. It reflects the speed participants thought they were supposed to go, or did go when using the iPad. For instance:

Speed (older): “[G]: we know ultimately what the tests are about and that’s cognitive impairment. [A]: or is it speed. [G]: I don’t think speed matters; it’s a balance between speed and accuracy. [M]: I think accuracy. [R]: there are lots of factors, there’s speed and accuracy. [R]: so how do you feel (J)? [J]: I would say about 85%, I think it was ok”.

Speed (younger): “[R]: so did you find the test enjoyable? [L]: in the beginning. [C]: yeah with my competitive edge to it. [L]: yeah I was a bit competitive, I wish we was being timed and we could find out how we done. I get really competitive, I was thinking ‘I need to do this the quickest out of everybody’, I was going for it. [C]: it’s not all about rewards because a reward is obviously a motivator to do well but for me thinking that someone could see a bad kind of response, that would make me want to do even better because I would like ‘I don’t want to be the slow one’ [P]: I work better with positive reinforcement so something to say ‘that you’re doing well’ because if you show well you performed in the worst quartile well I would be like oh I cannot be bothered now, but that’s just me I don’t work very well with punishment. [L]: I am the same. [RB]: yeah like it kind of deflates you a little bit so maybe performance goes down with that as well maybe. [L]: yeah so maybe that unhappy face could spur

someone on to do better and faster but then other people will see that unhappy face and think ‘oh no!’. [P]: it put me off completely. [RB]: same [laughter]. I knew [researcher] was sat next to me and I didn’t want her to see the faces. [R]: do you think it would have made a difference if [researcher] was not in the room? [RB]: yeah, I didn’t want her to see it so I kept well at that angle she couldn’t have. [B]: it does show that the unhappy face does mean more”.

The sub-theme ‘tactic’ refers to the tactics both the older and younger groups had when completing the iPad test. For instance:

Tactic (older): “[J]: I used the one finger all the time, I think I intuitively was picking out the first four numbers and then the other four. Also, I am very competitive, I was trying to go faster and faster so not much focus on being accurate so I had two errors.”

Tactic (younger): “[C]: yeah and also like how I went about it, like at the start I was just like looking 1, 2, 3, 4, as opposed to once I had an unhappy face it changed how I did it, like I was looking at groups so I would find 1, 2, then 3 and 4, then 5 and 6, and I found that I was quicker because it would take me an extra second to look but I tap quicker then because I already knew where the other one was. So I changed how I attended to it. [L]: changed your strategy. [C]: yeah”.

The final shared sub-theme is ‘performance feedback’ which relates to how much feedback they would ideally like to have had from performing the iPad test. For instance:

Performance feedback (older): “[N]: I have to say I would love to know how well I did. I would like to have some feedback on it. I think most of us who have done a test would like that. And what I assume is looking at how many mistakes someone makes is information I would like to have in feedback you know”.

Performance feedback (younger): “[R]: fab ok, how did you find it? [B]: same here yeah and then I got an unhappy face then all of a sudden I was like “wow slow down”. [RB]: I didn’t get an unhappy face. [B]: I got two. [L]: I got two. [C]: I got two. [L]: but I think my finger accidentally went too far next to the other ball, basically I shouldn’t have had the second unhappy face. [P]: do you want to appeal the judgement? [Laughter]. [L]:



666 *I do yes [laughter]. [P]: see you have got no*  
 667 *excuse, I have, I have to hit the keys with my podgy*  
 668 *fingers [laughter]. [C]: yeah it was like 6 and 8*  
 669 *for me that looked similar, that was the two that I*  
 670 *noticed I got wrong. I went for an 8 instead of a 6*  
 671 *because they look so similar, but I knew straight*  
 672 *away that I got it wrong”.*

673 The final sub-theme ‘search strategy’ is unique to  
 674 the younger group. It reflects the strategies employed  
 675 by some of the younger participants to perform the  
 676 iPad test. For instance:

677 *“[P]: I suppose it depends on how you attend to*  
 678 *the whole task whether you’re a linear searcher*  
 679 *or whether you look at the holistic picture and*  
 680 *I could generally sit back and look at the whole*  
 681 *thing. And at that point you’re more susceptible to*  
 682 *different shapes because I could just sit there with*  
 683 *both hands and then if they were split between left*  
 684 *and right I found it easier to go from one side of*  
 685 *the screen to the other using two hands rather*  
 686 *than if they were grouped around one area”.*

## 687 DISCUSSION

688 To reiterate, the main aim of this study was to pro-  
 689 vide a focus group-based qualitative evaluation of  
 690 administering a cognitive test on a mobile device and  
 691 to gauge levels of acceptability with both younger and  
 692 older adults, particularly related to the participant’s  
 693 familiarity with tablet technology. The potential influ-  
 694 ence of real-time feedback and researcher presence  
 695 upon task performance was also examined.

### 696 *Engagement level*

697 Our results suggest that use of a mobile device-  
 698 based cognitive test was both engaging and enjoyable  
 699 for some older and younger adults but that for many  
 700 others it was not. For instance, for some older adults it  
 701 was deemed to be a ‘positive experience’, thus some  
 702 said “[P]: it was quite enjoyable. [W]: and I think the  
 703 more you did it the more you wanted to do it some-  
 704 how”. However, for other older adults it was believed  
 705 to be ‘boring and distractible’, thus one said “[R]: so  
 706 how did you find the test? [G]: a bit boring I found  
 707 it, sorry. Repetitively boring there was obviously a  
 708 sequence for that. I said that to [researcher] I said  
 709 ‘is this um could you memorise these if you had a  
 710 good memory and numerative memory?’ The problem  
 711 is going too fast and then thinking something more  
 712 interesting may come up next time. It was the same

713 *numbers just in a different location. Yeah I found it*  
 714 *boring towards the end. [R]: yes and that is perfectly*  
 715 *fine, I want you to be as honest as you can. Thank you*  
 716 *[G]”. The younger participants also expressed the test*  
 717 *experience as positive, for instance, “[R]: fab, thank*  
 718 *you. Did you enjoy doing the test? [A]: it makes me*  
 719 *want one [iPad]. [P]: it was interesting but I wouldn’t*  
 720 *use the word ‘enjoy’ [laughter] I was just counting*  
 721 *dots but it was a little more engaging that some can*  
 722 *be. However, others also deemed it to be ‘boring and*  
 723 *distractible’, thus “[R]: ok, so would you say then*  
 724 *something like that could be used on a regular basis*  
 725 *or would you say no? [L]: I think it was boring”.*

### 726 *Feedback*

727 In the MILO test, performance feedback was given  
 728 in the form of an unhappy face icon when a mis-  
 729 take was made. However, we see from the comments  
 730 made in this study that in real life, rather than pro-  
 731 viding a potential learning opportunity, via feedback,  
 732 such an icon can have a demoralizing effect, with  
 733 evidence that an individual experiences embarrass-  
 734 ment if an observer can see the unhappy faces, i.e.,  
 735 their poor performance. These factors may detrimen-  
 736 tally affect test results and render the individual less  
 737 likely to want to do the task again. Related to this was  
 738 the finding that people could feel very self-conscious  
 739 when being watched; again the presence or not of an  
 740 observer may affect an individual’s test performance.  
 741 A number of participants were embarrassed at the  
 742 thought that the researcher present could see if they  
 743 had an unhappy face pop up. Although this might not  
 744 be of importance if the tests are self-administered,  
 745 it is a pertinent consideration when administered by  
 746 another individual.

747 A suggestion from the participants wanting feed-  
 748 back on their performance was the implementation  
 749 of a score count, or differing test levels. Test levels  
 750 could be signified by a change in the color of the  
 751 balls. An addition of subtle performance feedback  
 752 to the test design could be what facilitates further  
 753 interest and engagement. One has to consider that  
 754 this may, however, affect performance; some people  
 755 may rise to it and see it as a challenge and be more  
 756 motivated to do well while others may feel demor-  
 757 alized and give up trying; individual differences are  
 758 then likely to play an important part in such consid-  
 759 erations. A potential limitation to our study is that  
 760 we did not have happy feedback; instead lack of a  
 761 sad face meant that performance was acceptable. It is  
 762 likely therefore that developers will need to take into

763 account that feedback *per se* and how it is presented  
764 may influence performance. It is certainly the case  
765 that individuals in our focus groups certainly noticed  
766 and talked about this issue.

#### 767 *Time of day*

768 The time of day that one would best engage with the  
769 task is highly individualistic. Some said they would  
770 be most alert and attentive early in the morning, oth-  
771 ers later at night. Using this test in a clinical setting  
772 would also struggle to take into account the test users'  
773 preferred time of day and the actual time of day. Real-  
774 istically, only in exceptional circumstances where the  
775 test user is especially tired could allowances be made.  
776 In the context of the test being used regularly as a cog-  
777 nitive monitoring tool, they would be advised to use it  
778 at their preferred time of day and the times tests were  
779 taken could be recorded if the impact was severe.

#### 780 *Test design and associated instructions*

781 The participants in this study have highlighted sev-  
782 eral issues pertinent to the development of tablet or  
783 mobile-based tests of attention and reaction time tests  
784 typical of those used in the assessment of cognitive  
785 impairment.

786 One factor that may introduce bias, variability and  
787 low validity, in test outcome is the reported hetero-  
788 geneity in response strategy, e.g., the use of one or two  
789 fingers on one or both hands. It is important therefore  
790 to realize that unless highly specific instructions are  
791 provided, study outcome (e.g., speed and accuracy)  
792 can be related to an individual's choice and execution  
793 of a particular search strategy. This is also a factor to  
794 consider when the same test is repeated, i.e., does  
795 the individual adopt the same search and response  
796 strategy each time?, a factor which may detrimentally  
797 affect task validity. It was also apparent that individ-  
798 ual differences in hand and finger mobility, related to  
799 factors such as arthritis or long fingernails may also  
800 influence performance.

801 The focus group analysis indicated that the instruc-  
802 tions provided need to be very specific in relation to  
803 what the test user understands to be most important,  
804 i.e., speed or accuracy of their performance/fingers  
805 to use/strategy, etc. There was much disparity regard-  
806 ing what the participants felt was most important (in  
807 terms of strategy/technique) despite clear instructions  
808 given prior to the start of the test. Furthermore, the  
809 test's validity could be hindered if instructions regard-  
810 ing what is most important of their performance are

811 not made clear. For instance, the level of education  
812 about the systems purpose, i.e., is it the speed or the  
813 accuracy of their performance which is most impor-  
814 tant? There was much disparity regarding what the  
815 participants thought was most important despite clear  
816 instructions given prior to the start of the test. Their  
817 lack of clarity could have been due to their preoccu-  
818 pation with the testing situation. If so, then it should  
819 be made a priority that they fully engage with the  
820 instruction process prior to the start of the test. The  
821 inclusion of a practice trial could be implemented in  
822 the future.

823 These issues seem to suggest that participants  
824 might have treated the test more like it was a video  
825 game as opposed to a cognitive test with an approach  
826 that involves strategizing to maximize the score they  
827 receive and possibly an increased sense of motiva-  
828 tion or competitiveness with other players to get a  
829 "high score". Researchers have not examined the atti-  
830 tudes and motivations of people who engage with  
831 cognitive testing, however, the motivations for video  
832 game play are quite well understood. Engagement  
833 with video games can be intrinsically motivating with  
834 reward derived from simple actions and immersion  
835 in game [39] or motivation can be derived from a  
836 sense of challenge or competition in the game and  
837 the accomplishment that come with it [40]. In con-  
838 ventional video games, these motivators can drive  
839 people to practice/play more and become extremely  
840 skilled with the games, improving their scores and  
841 their visuospatial awareness [41]. The questions this  
842 raises for the digital tests are first, whether the test  
843 motivates practice in the same way a game does,  
844 and second, whether this practice invalidates the test.  
845 For example, if one becomes too practiced, then test-  
846 performance ceiling effects can be induced.

#### 847 *Physical challenges*

848 Several people also indicated physical challenges  
849 that affected their performance, such as wearing  
850 glasses (slipping down their nose) and difficulty with  
851 varifocals because of the iPad being positioned flat  
852 on the desk and the individual having to lean over it.  
853 Therefore, the ergonomics of the iPad positioning in  
854 relation to the required use of visual aids is of great  
855 importance when developing such tests. A suggestion  
856 from some of the participants was that the iPad is posi-  
857 tioned on a tilted stand in front of them. This position  
858 would ameliorate the physical difficulties reported in  
859 this study but could affect test score and might not  
860 be consistently used. The positioning of the iPad in

861 relation to lighting in the room could also interfere  
862 with the ability to see the stimuli. Again, the tilting  
863 of the iPad on a stand could assist in reducing the  
864 light disruption but also the researcher should take  
865 lighting into account when selecting an appropriate  
866 environment.

867 Furthermore, having long finger nails physically  
868 interfered with users and affected their responses as  
869 did having large fingers, and having arthritis in their  
870 wrists, hands, or fingers (see above). Some of the par-  
871 ticipants suggested the use of a pen/pointer instead of  
872 relying on the skin conductance of their fingers. This  
873 would also alleviate the need for too much empha-  
874 sis on how many hands or fingers should be used,  
875 they would only use the pen/pointer. This indicates  
876 the importance of considering when developing such  
877 tests that manual dexterity and concurrent illnesses  
878 may also affect the physical ability to respond appro-  
879 priately. As such, allowances need to be put in place  
880 in order for researchers and clinicians to control for  
881 physical disability affecting their results.

882 The physical challenges reported above are consis-  
883 tent with findings in Weilenmann [42] in the context  
884 of texting on mobile phones. The senior informants  
885 in this paper entered text on the mobile phone, which  
886 relied on sequential pressing of keys within certain  
887 time-frame. Participants reported issues regarding  
888 timing and the rhythm of key-pressing: (1) Doing  
889 a sequential key-pressing was not a straightforward  
890 task, (2) they tended to press too slowly or pressing  
891 one longer period of time than the other, (3) slow  
892 rhythm of their hand movements.

893 Although it has been argued that touch-displays  
894 are easier and more intuitive to use for older adults  
895 [43], there is no robust evidence in the HCI litera-  
896 ture supporting this commonly believed argument.  
897 For example, Culén and Bratteteig [44] argue touch-  
898 displays are not an optimal choice. However, they  
899 conclude that with customization and adaptation  
900 strategies, they may become a better match.

901 In a multi-directional tapping task on an Android  
902 tablet, Burkhard and Koch [45] asked 30 older adults  
903 (65+) to perform eleven single taps (eleven targets)  
904 around a circle starting from target one and finish-  
905 ing at target eleven, all targets located in a random  
906 order around the table. The authors used Fitts' Law  
907 to compare the measurements on different Android  
908 tablet sizes. Their initial findings show that fac-  
909 tors such as age and gender as well as dry-finger  
910 skin and different age-related cognitive-motor skills  
911 should be considered in design of interfaces on touch-  
912 displays. In particular, their observations indicated

913 that elderly people with dry or wrinkled fingertips  
914 had a significantly higher touch recognition error rate  
915 on some tablets. This could also be related with the  
916 layer types of the resistive touch-screen technology.  
917 Harada et al.'s [46] study also support dry-finger and  
918 users' frustrations with unresponsive taps.

## 919 CONCLUSION

920 Arguably iPad-based tests may be an ideal base for  
921 home testing, with subsequent increased compliance  
922 in clinical trials, longitudinal clinical and research  
923 follow up, and the ability to signal deterioration and  
924 thus to facilitate intervention, but many factors need  
925 to be considered in their development if such tests are  
926 to be reliable, valid, and objective. The participants in  
927 this study highlighted several issues pertinent to the  
928 development of tablet or mobile-based tests typical  
929 of those used in the assessment of cognitive func-  
930 tion in older adults, which can then be used to inform  
931 more specific development for testing in individuals  
932 with cognitive impairment and dementia. In order to  
933 inform those considering developing tasks of RT and  
934 other aspects of cognitive function on touch screen  
935 based tablets, we summarize the information gained  
936 from our focus groups in the following section in a  
937 series of bullet points. It is clear from this informa-  
938 tion that many factors, which may not be currently  
939 taken into account when designing such tasks for  
940 use on touch screen tablets, but which, without being  
941 addressed could significantly influence task perfor-  
942 mance and thus adversely affect the clinical validity  
943 of such a test.

- 944 • Without highly specific instructions, response  
945 strategy to test components and stimuli can vary  
946 between individuals, despite clear instructions given  
947 prior to the start of the test. Variability in the use  
948 of one finger, or several fingers on the same or dif-  
949 ferent hands, was common when participants were  
950 requested to touch the stimuli upon the screen. The  
951 instructions provided therefore need to be highly spe-  
952 cific in order to preserve test validity and consistency  
953 of administration.

- 954 • Arthritis, long fingernails, and dry skin appeared  
955 to adversely affect performance leading to some par-  
956 ticipants suggesting the use of a pen/pointer instead  
957 of relying on the skin conductance of their fingers.  
958 Arguably, this would also alleviate concerns about the  
959 potential variability in finger and hand use. This indi-  
960 cates the importance of considering when developing  
961 such tests that manual dexterity and concurrent ill-

nesses may also affect the physical ability to respond appropriately. As such, allowances need to be put in place in order for researchers and clinicians to control for changes in physical ability affecting results.

- Some participants treated the test more like a video game as opposed to a cognitive test and thus appeared to adopt an approach that involves strategies to maximize their score, and possibly an increased sense of motivation or competitiveness with other ‘players’ (members of the focus group) to get a “high score”. Motivation related to videogame play is relatively well understood. For example, engagement with video games can be intrinsically motivating with reward derived from simple actions and immersion in game [39] or motivation can be derived from a sense of challenge or competition in the game and the accomplishment that come with it [40]. In conventional video games, these motivators can drive people to practice/play more and become extremely skilled with the games, improving their scores and their visuospatial awareness [41]. The questions this raises for touch screen-based cognitive tests are whether the test motivates practice in the same way a game does (because of its similarity with a given game or the fact that tablets are commonly used for gaming) and that fact that motivation can affect RT speed performance [47] and whether this practice invalidates the test. For example, if one becomes too practiced then test-performance ceiling effects can be induced, or indeed such factors may help to improve or stabilize performance in those with cognitive decline.

- Feedback. In the MILO test, performance feedback was given in the form of an unhappy face icon when a mistake was made. However, we see from the comments made in this study that in real life, rather than providing a potential learning opportunity, via feedback, such an icon can have a demoralizing effect, with evidence that an individual experiences embarrassment if an observer can see the unhappy faces, i.e., that their performance is poor. Some individuals clearly felt self-conscious when being watched; thus the presence or not, of a test administrator may affect an individual’s test performance. Although this might not be of importance if the tests are self-administered (e.g., take home cognitive monitoring tests), it is a pertinent consideration if administered by others. A limitation to our study, however, is that our lack of ‘happy feedback’; instead lack of a sad face meant that performance was acceptable. It is likely therefore that developers will need to take into account that feedback *per se* and how it is presented may influence performance.

- Physical challenges that affected test performance included the wearing of glasses (e.g., slipping down their nose when their head was bent over the tablet which was positioned flat upon a table), particularly with varifocals. Therefore, the ergonomics of the tablet positioning in relation to the required use of visual aids is of great importance when developing such tests, see also [42]. A suggestion from some of the participants was that the tablet should be placed in a tilted stand, and indeed spontaneous tried to hold it in this position so they could see the stimuli. However, although this position may ameliorate some physical difficulties, it is possible that it may affect performance in other ways as yet investigated and thus once again consistency of positioning would be highly important. The positioning of the tablet in relation to lighting in the room can also interfere with the ability to see the stimuli, thus lighting becomes an important consideration when selecting the testing environment.

There are of course limitations with our focus group study. For example, individuals living with dementia or cognitive impairment were not included, and it is possible that test administration, reaction to it, and performance varies with the integrity of cognitive function. Future studies should include a wider range of tests and their validation with other forms of computerized testing, groups representative of a wider range of age-related changes such those found in relation to vision (such as cataracts, wearing glasses, color blindness), hearing, mobility and dexterity, memory function (what happens if individuals forget the instructions?), and levels of motivation and response confidence (e.g., examining the potential for guessing the response). Other pertinent factors for developers to consider in the future relate to the minimum time for each test (to ensure that the time taken to perform the test is short so as not to induce fatigue, especially when a number of tests are presented in a battery) but reliable, practical usage and efficiency (both time and economic) within a diagnostic workflow, test anxiety in relation to using the iPads and how this may affect performance, potential influence of practice effects (which may be minimized through dynamic item generation or randomization), whether or not to build in checks that reactions are valid with respect to test instructions and how might negative effects of psychometric testing, such as those induced by performance feedback, demotivate and possibly even disclose a diagnosis to impaired participants. Response strategies also need to be considered in greater detail; for example in

terms of verbalization, whether individuals always use the same response strategy throughout the test and whether different people use different strategies. Methodological considerations regarding the optimal viewing and performance such as fixed viewing distances (in that individuals may move the iPad closer or further away to compensate for changes in their visual function), the angle of the iPad during stimulus presentation (at an angle or flat on a table), viewing distance and lighting, technical aspects such as the display and operating systems [11], the feasibility of using the internet to access the test or to upload test results [9], how used to using the internet or tablet technology a person is [9], how to ensure the correct identification of the person taking the test [9], and whether the intrinsic design of the iPad can affect performance [11]. Finally, it is important to recognize that for a test to be included in routine clinical and indeed in research practice, the needs of all stakeholders (e.g., patient, clinicians, scientists, programmers/developers) need to be investigated and considered in the development stage of such tests with the resultant development of quality criteria for the use of mHealth apps.

Our hope is that the results of this small study lead to a greater investigation of such factors relevant to the validity of tablet-based tests of cognitive function. However, future work will need to focus on better understanding the impact of physical challenges to use, practice, and technical familiarity as the number of older adults who regularly engage with such technology rises.

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