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stering Cognitive Tests Through Screen Tablet Devices: Potential

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chnologies, such as tablet devices, open up new possibilities for health-related diagnosis, monitoring, lder adults and healthcare practitioners. Current evaluations of cognitive integrity typically occur within n as memory clinics, using pen and paper or computer-based tests. In the present study, we investigate iated with transferring such tests to touch-based, mobile technology platforms from an older adult s may include individual variability in technical familiarity and acceptance; various factors influencing ty; response characteristics and thus validity *per se* of a given test. For the results of mobile technology- on time to be valid and related to disease status rather than extraneous variables, it is imperative the investigated in order to determine potential effects before the test is fully developed. Researchers have rtance of including the 'user' in the evaluation of such devices; thus we performed a focus group-based nt of the processes involved in the administration and performance of a tablet-based version of a typical nformation processing speed (a multi-item localization task), to younger and older adults. We report that regarded positively, indicating that using a tablet for the delivery of such tests is feasible, it is important sider factors surrounding user expectations, performance feedback, and physical response requirements mation to inform further research into such applications.

tention, cognition, focus groups, qualitative research, tablet computers

scale up for a large number of users
demand.

re technology (mHealth) has been
different healthcare challenges to
ving with chronic conditions such
Due to the 'connected' nature of
the growing availability of broad-
dea of 'information to support the
anded beyond traditional medical
rovides a platform for community-
here users share experiences and
g a condition [4]. More advanced
include the idea of using on-body
to monitor people's health and to
e readings to their mobile device
y area networks [5, 6]. Data gath-
ated through these means can be
agnosis and monitoring processes
their use in physical conditions
also be applied to the management
[9]. However, although research
of various health-related apps by
ing to indicate what factors affect
ps by this population [2, 8–10],
f research investigating the use of
s in assessing information or cog-
n older adults. This is especially
individuals living with cognitive
ementia. Although it sounds sim-
ove away from testing on PCs by
tests for use with touch screen
this platform can introduce new
related to the technology per se
human interface. Biases may, for
tally affect the accuracy, validity,
cificity of the test and the robust-

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

Arguably, RT and IIV_{RT} testing appear particularly suited to delivery or presentation via a touch screen tablet as they tend to be cheaper and simpler to use than laptops or desktop computers and can have multiple advantages over computers for testing information processing in older adults [9, 18, 19]. However, it is also increasingly clear that factors unrelated to brain structure and function and a disease process can influence RT and IIV_{RT} and that it is vital to determine, investigate, and ameliorate such effects with respect to the touch screen tablet platform, in order to ensure test validity.

Evidence already reveals that 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, frustration, the need for specific training, age, gender, dry finger skin, and age-related cognitive motor skills [2, 18–22], all factors likely to affect the performance of RT and IIV_{RT} tests using a touch screen platform and thus their clinical validity, usefulness, and robustness. Furthermore, RT research has revealed many participant and methodology-related factors capable of significantly affecting RT study outcome including: the test item, the environment, response requirements,

f the iPad MILO task used in the current

erform sequences of actions [29, to other well-established paper- The Trail Making Task [31]) and ncellation tests [32] in requiring a to be identified in a specific order. typical trial from the tablet imple- O that was used in the current study the participant would be to touch all in sequence, from one to eight. antages of computer-based presen- to paper-and-pencil tasks include 's for each item, rather than simply time (e.g., [32]) and the ability to ial patterns of search organization tion to these, the MILO task makes ly manipulate the sequence type , or both) and sequence behavior ing or remaining, sequence posi- d or shuffling between responses)

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° visual angle, with gaps between items varying between 0.8° and 8° 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 intertrail 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

al-time feedback upon task accept-
nance. Furthermore, the researcher
stering the test typically sits close
king the test; anecdotally this has
off-putting to the person taking the
uations, but it may also be reassur-
herefore also examined this factor
k acceptability and performance.
al. [28], recruited eleven younger
rs) and twelve older adults (65+
nd a half hour focus group. The
re recruited via University block-
notices, and word of mouth. The
ecruited via the Older People and
nd Development Network (OPAN)
- Networks. Poor general health
xterity limitations and participa-
search studies formed exclusion
nbers of the research team were
g and the other observing and tak-
structured schedule was followed.
od is discussed in full in Jenkins
iterate; there are of course limita-
th this qualitative technique, which
and addressed in order to ensure,
hat they did not introduce bias. For
ledge, skills, and experience of the
the focus group can have an unfa-
e generation of information from
n order to avoid such an impact,
ensured there were two members
am present, one leading and the
d taking notes. A semi-structured
owed but also encouraged expan-
reas. Qualitative analysis is rarely
ld of computer science therefore

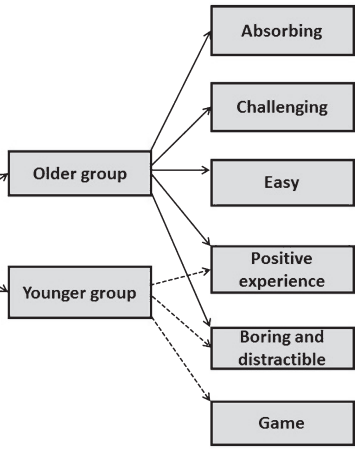
Table 1
Focus group schedule (iPad test experience)

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

RESULTS

A number of themes and sub-themes have been identified highlighting categories rather than preva-



Views of test experience.

-theme 'absorbing' which repre-some of the older participants said l into the iPad test experience. For

it quite absorbing myself because entrate on what was in front of you o pin point what the next number say it occupied all my thoughts I to do it as quickly as I could, and as I could. I was totally absorbed umbers. Which is strange for me nd does tend to wander and it didn't occasion".

-theme reflects the older partici-ews that the test was a 'challenge', -theme that it was 'easy'. For

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*".

e I was thinking well what the pur-
ne is, what it is going to be used as.
it is something to do with cognitive
wondered what well if it would be
ave like a kind of positive feedback
in because I made a mistake and
le sad face and that was feedback
ow to get people to play it maybe
maybe it would have like increas-
nd a score. That would make them
don't know if I would play it reg-
the sake of doing it as it is now
ust like tapping the numbers and
that I am doing good. [A]: yeah
ou want to improve and beat your
n like progression or how well I am
different levels, like the next level
10 numbers".

nd materials

eme has three sub-themes devel-
ngs of both the older and younger
e first sub-theme reflects the views
arding the experience they had of
instance:

ence (older): "*[R]: yes but she*
g scores, what's more important
edback from the tests. Did you find
o use? [A]: yeah. [G]: well I did
e very well but it was fine. [J]: I
akes the same as you; as soon as I
bit I was more accurate. And these
n all the time [glasses], but it was
ed them back up. [R]: yeah ok so

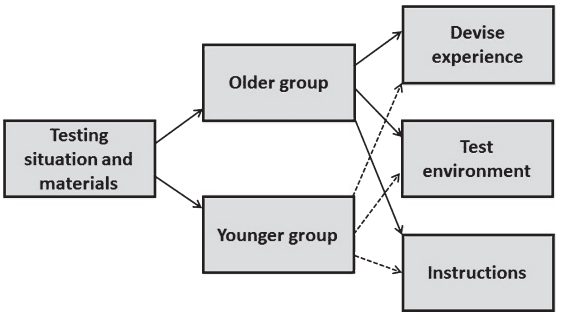


Fig. 3. Testing situation and materials.

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

Device experience (younger): "*[R]: ok, thank you. How about the positioning of the iPad? [L]: fine. [P]: I moved it. [R]: where did you move it to? [P]: I just moved it closer. The angle was a bit well I didn't move the angle. For me it would have been better flat but maybe because it was quite far into the table. [RB]: it would have been helpful to have one of those holders, what are they called? [P]: like a copy holder? [RB]: yeah, just*

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

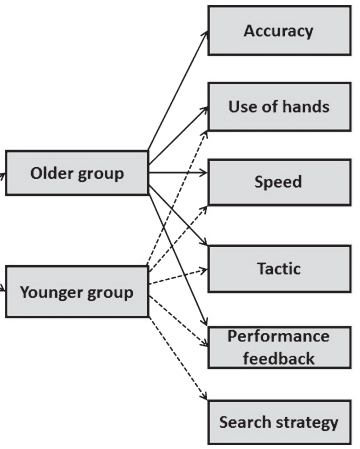
Test performance

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

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

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

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



4. Test performance.

eme 'speed' is also shared by the groups. It reflects the speed par- ey were supposed to go, or did go d. For instance:

'[G]: we know ultimately what the and that's cognitive impairment. eed. [G]: I don't think speed mat- nce between speed and accuracy. curacy. [R]: there are lots of fac- eed and accuracy. [R]: so how do]: I would say about 85%, I think

r): "*[R]: so did you find the test : in the beginning. [C]: yeah with edge to it. [L]: yeah I was a bit wish we was being timed and we*

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): "*[JC]: 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:

hter]. [P]: see you have got no I have to hit the keys with my podgy er]. [C]: yeah it was like 6 and 8 ked similar, that was the two that I rong. I went for an 8 instead of a 6 ook so similar, but I knew straight it wrong".

eme 'search strategy' is unique to It reflects the strategies employed unger participants to perform the nce:

e it depends on how you attend to whether you're a linear searcher u look at the holistic picture and lly sit back and look at the whole at point you're more susceptible to s because I could just sit there with then if they were split between left nd it easier to go from one side of he other using two hands rather re grouped around one area".

main aim of this study was to pro- p-based qualitative evaluation of gnitive test on a mobile device and cceptability with both younger and ularly related to the participant's let technology. The potential influ- feedback and researcher presence ance was also examined.

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]". The younger participants also expressed the test experience as positive, for instance,"*[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.* However, others also deemed it to be 'boring and distractible', thus "*[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*".

Feedback

In the MILO test, performance feedback was given in the form of an unhappy face icon when a mistake was made. However, we can 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., their poor performance. These factors may detrimentally affect test results and render the individual less likely to want to do the task again. Related to this was the finding that people could feel very self-conscious when being watched; again the presence or not of an observer may affect an individual's test performance. A number of participants were embarrassed at the thought that the researcher present could see if they had an unhappy face pop up. Although this might not be of importance if the tests are self-administered, it is a pertinent consideration when administered by another individual.

eedback *per se* and how it is pre-
ce performance. It is certainly the
ls in our focus groups definitely
about this issue.

hat one would best engage with the
vidualistic. Some said they would
ttentive early in the morning, oth-
Using this test in a clinical setting
to take into account the test users'
ay and the actual time of day. Real-
ceptional circumstances where the
ly tired could allowances be made.
test being used regularly as a cog-
ool, they would be advised to use it
me of day and the times tests were
orded if the impact was severe.

sociated instructions

in this study have highlighted sev-
nt to the development of tablet or
of attention and reaction time tests
ed in the assessment of cognitive

may introduce bias, variability and
t outcome is the reported hetero-
strategy, e.g., the use of one or two
oth hands. It is important therefore
ss highly specific instructions are
tcome (e.g., speed and accuracy)
individual's choice and execution
ch strategy. This is also a factor to
same test is repeated, i.e., does

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

These issues seem to suggest that participants might have treated the test more like it was a video game as opposed to a cognitive test with an approach that involves strategizing to maximize the score they receive and possibly an increased sense of motivation or competitiveness with other players to get a "high score". Researchers have not examined the attitudes and motivations of people who engage with cognitive testing, however, the motivations for video game play are quite well understood. 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 the digital tests are first, whether the test motivates practice in the same way a game does, and second, whether this practice invalidates the test. For example, if one becomes too practiced, then test-performance ceiling effects can be induced.

g in the room could also interfere see the stimuli. Again, the tilting tand could assist in reducing the t also the researcher should take nt when selecting an appropriate

aving long finger nails physically rs and affected their responses as ngers, and having arthritis in their ngers (see above). Some of the par- the use of a pen/pointer instead of conductance of their fingers. This te the need for too much empha- hands or fingers should be used, se the pen/pointer. This indicates considering when developing such dexterity and concurrent illnesses physical ability to respond appro- llowances need to be put in place chers and clinicians to control for affecting their results.

allenges reported above are consis- n Weilenmann [42] in the context le phones. The senior informants d text on the mobile phone, which al pressing of keys within certain ipants reported issues regarding ythm of key-pressing: (1) Doing ressing was not a straightforward ed to press too slowly or pressing of time than the other, (3) slow nd movements.

been argued that touch-displays e intuitive to use for older adults obust evidence in the HCI litera- is commonly believed argument

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

CONCLUSION

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

- Without highly specific instructions, response strategy to test components and stimuli can vary between individuals, despite clear instructions given

tely. As such, allowances need
ce in order for researchers and
ol for changes in physical ability

pants treated the test more like a
posed to a cognitive test and thus
n approach that involves strategies
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s of the focus group) to get a "high
related to videogame play is rel-
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t that come with it [40]. In conven-
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ore and become extremely skilled
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d cognitive tests are whether the
tice in the same way a game does
nilarity with a given game or the
commonly used for gaming) and
vation can affect RT speed perfor-
nether this practice invalidates the
if one becomes too practiced then
eiling effects can be induced, or
s may help to improve or stabilize
se with cognitive decline.
he MILO test, performance feed-
the form of an unhappy face icon
as made. However, we see from
de in this study that in real life,
g a potential learning opportunity

• 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

tion, whether individuals always
onse strategy throughout the test
ent people use different strategies.
nsiderations regarding the optimal
rmance such as fixed viewing dis-
viduals may move the iPad closer
compensate for changes in their
he angle of the iPad during stim-
(at an angle or flat on a table),
nd lighting, technical aspects such
operating systems [11], the fea-
e internet to access the test or to
[9], how used to using the internet
gy a person is [9], how to ensure
cation of the person taking the test
he intrinsic design of the iPad can
e [11]. Finally, it is important to
a test to be included in routine
d in research practice, the needs
(e.g., patient, clinicians, scientists,
lopers) need to be investigated and
evelopment stage of such tests with
opment of quality criteria for the
ps.
the results of this small study lead
gation of such factors relevant to
t-based tests of cognitive function.
ork will need to focus on better
impact of physical challenges to
technical familiarity as the num-
who regularly engage with such

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[3] Georgsson M, Staggers N (2006) Quantifying usability: An evaluation of a diabetes mHealth system of effectiveness, efficiency, and satisfaction metrics with associated user characteristics. *J Am Med Inform Assoc* **1**, 5-11.

[4] Peyton T, Poole E, Reddy M, Kraschnewski J, Chuang C (2014) Information, sharing and support in pregnancy: Addressing needs for mHealth design. In *Proceedings of the Companion Publication of the 17th ACM Conference on Computer Supported Cooperative Work and Social Computing*. ACM, pp. 213-16.

[5] Jones V, Gay V, Leijdekkers P (2010) Body sensor networks for mobile health monitoring: Experience in Europe and Australia. In *Digital Society, ICDS'10 Fourth International Conference on IEEE*, pp. 204-209.

[6] Cinaz B, Amrich B, La Marca R, Tröster G (2012) A case study on monitoring reaction times with a wearable user interface during daily life. *Int J Comput Healthc* **1**, 283-303.

[7] Alepis E, Lambrinidis C (2013) M-health: Supporting automated diagnosis and electronic health records. *Springer Plus* **2**, 1-9.

[8] Zapata BC, Fernández-Alemán JL, Idri A, Toval A (2015) Empirical studies on usability of mHealth Apps: A systematic literature review. *J Med Syst* **39**, 1.

[9] Rentz DM, Dekhtyar M, Sherman J, Burnham S, Blacker D, Aghjayan SL, Papp KV, Amariglio RE, Schembri A, Chenhall T, Maruff P, Aisen P, Hyman BT, Sperling RA (2016) The feasibility of At-Home iPad cognitive testing for use in clinical trails. *J Prev Alzheimers Dis* **3**, 8-12.

[10] Waters AJ, Li Y (2008) Evaluating the utility of administering a reaction time task in an ecological momentary assessment study. *Psychopharmacology* **197**, 25-35.

[11] Schatz P, Ybarra V, Leitner D (2015) Validating the accuracy of reaction time assessment on computer-based tablet devices. *Assessment* **22**, 405-410.

[12] Crabtree DA, Antrim LR (1988) Guidelines for measuring reaction time. *Percept Mot Skills* **66**, 363-370.

[13] Eckner JT, Chandran S, Richardson JK (2011) Investigating the role of feedback and motivation in clinical reaction time assessment. *PM R* **3**, 1092-1097.

[14] Firbank M, Kobeleva X, Cherry G, Killen A, Gallagher P, Burn DJ, Thomas AJ, O'Brian JT, Taylor JP (2015) Neural correlates of attention-executive dysfunction in lewy body dementia and Alzheimer's disease. *Hum Brain Mapp* **37**, 1254-1270.

rer H, Deussen O (Hrsg.), Workshopband: niert – allgegenwärtig und allumfassend!? ag, München, pp. 53-59.
, Takagi H, Asakawa C (2013) Characteris- er behavior on mobile multi-touch devices. *uter Interaction – INTERACT 2013*, Kotze indgaard G, Wesson J, Winckler, M, eds. Heidelberg, pp. 323-341.
Mobile touch interfaces for the elderly. In: *CT, Society and Human Beings*.
OJ (2014) Effects of upper respiratory tract fen and caffeine on reaction time and alert- *rmacology* **231**, 1963-1974.
JA, Prado-Olivarez J, Amador-Licona N, LM, Galicia-Resendiz D, Diaz-Carmona J simple reaction and choice times in patients tes. *Comput Biol Med* **43**, 368-376.
onessi A (2011) Functional assessment of d konio-cellular pathways; current state and pplications. *J Ophthalmic Vis Res* **6**, 119-

ael A, Bullmore ET, Sahakian BJ, Robbins adoxical enhancement of choice reaction e in patients with major depression. *J Psy-* **4**, 471-479.
GE, Shickle DA, Roberts BA, Deary IJ sm combined with slower and more vari- me: Synergistic risk factors for 7-year e in females. *J Gerontol B Psychol Sci Soc*

mbolchilar P, Lindsay S, Tales A, Thorn- tudes towards attention and ageing: What een younger and older adults tell us about gy design, *IJMHCI* **8**, 46-67.
orowitz TS (2004) The Multi-Item Local- ask. *Percept Psychophys* **66**, 38-50.
hornton IM (2008) Objects or locations in ? Evidence from the MILO task. *Vis Cog*

8) Validity of the Trail Making Test as an anic brain damage. *Percept Mot Skills* **8**,

an der Stigchel S, Nijboer TC, Cornelissen 2015) Cancellation tools: All-in-one soft- tration and analysis of cancellation tasks.

[35] Kobayashi M, Hiyama A, Miura T, Asakawa T, Hirose M, Ifukube T (2011) Elderly user evaluation of mobile touchscreen interactions. In *Proceedings of the 13th IFIP TC 13 International Conference on Human-Computer Interaction (INTERACT'11)*, Campos P, Nunes N, Graham N, Jorge J, Palanque P, eds. Springer-Verlag, Berlin, Heidelberg, pp. 83-99.

[36] Leitao R, Silva PA (2012) Target and spacing sizes for smartphone user interfaces for older adults: Design patterns based on an evaluation with users. In *Conference on Pattern Languages of Programs*, Arizona, United States, pp. 19-21.

[37] Motti LG, Vigouroux N, Gorce P (2013) Interaction techniques for older adults using touchscreen devices: A literature review. *25eme conference francophone sur l'Interaction Homme-Machine, IHM'13, Nov 2013*, Bordeaux, France.

[38] Braun V, Clarke V (2006) Using thematic analysis in psychology. *Qual Res Psychol* **3**, 77-101.

[39] Cox A, Cairns P, Shah P, Carroll M (2012) Not doing but thinking: The role of challenge in the gaming experience. In *Proceedings of the 30th Annual ACM Conference on Human factors in Computing Systems (CHI '12)*. ACM, New York, pp. 79-88.

[40] Yee N (2006) Motivations for play in online games, *Cyberpsychol Behav* **9**, 772-775.

[41] Green CS, Bavelier D (2006) Effect of action video games on the spatial distribution of visuospatial attention. *J Exp Psychol Hum Percept Perform* **32**, 1465-1478.

[42] Weilenmann A (2010) Learning to text: An interaction analytic study of how seniors learn to enter text on mobile phones. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, pp. 1135-1144.

[43] Werner F, Werner K, Oberzaucher J (2012) Tablets for seniors- An evaluation of a current model (iPad). In *Ambient assisted Living*, Wichert R, Eberhardt B, eds. Springer Berlin Heidelberg, pp. 177-184.

[44] Culén AL, Bratteteig T (2013) Touch-screens and elderly users: A perfect match? *Changes* **7**, 15.

[45] Burkhard M, Koch M (2012) Evaluating touchscreen interfaces of tablet computers for elderly people. *Workshopband Mensch and Computer, S*, 53-59.

[46] Harada S, Sato D, Takagi H, Asakawa C (2013) Characteristics of elderly user behavior on mobile-touch devices. In *IFIP Conference on Human-Computer Interaction*