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RESEARCH PAPER

Cognitive impairment screening using m-health: an android implementation of the mini-mental state examination (MMSE) using speech recognition

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Key Summary Points

Aim This paper describes and evaluates an m-health application that allows cognitive functions to be tested.
Findings Using speech-processing techniques an Android application of a slightly modified Mini Mental state Examination (MMSE) test was developed. A small-scale pilot study was conducted in a nursing home showing comparable scores between the MMSE app and the (paper) MMSE test.
Message A mobile digital version of the slightly modified MMSE test has the potential to be used as an attractive alternative for the conventional paper version of the test.

Abstract

Purpose This paper describes an implementation of an Android application that allows cognitive functions to be tested.
Methods The application consists of a slightly modified Mini Mental state Examination (MMSE) test that provides examiner assistance in diagnosing cognitive impairments. The application deploys speech recognition techniques to allow easy and automated scoring of the test. The test results and test-related information are stored in a database providing easy access to data for follow-up and analysis, resulting in overall benefits to the examiner workflow. A small-scale pilot study of 5 months duration was conducted in a nursing home where 15 residents were tested with the MMSE app test and with the (paper) MMSE test with the aim of determining the agreement between the two test methods.
Results The final MMSE test scores, with a maximum score of 30, agree; the differences have a mean of 0.1, a standard deviation of 2.1 and fall in a [− 4, + 4] range as is illustrated in a Bland–Altman analysis. From examiner reflections, the motoric skills of the participant are indicated to contribute strongly to the time benefit of the assessment itself.
Conclusions The findings of this study suggest that the mobile digital version of the slightly modified MMSE test has the potential to be used as an attractive alternative for the conventional paper version of the test.

Keywords Android · m-Health · MMSE · Dementia · Smartphone application

Introduction

Nowadays, smartphones or tablets are used for many applications all over the world. The specific use of these mobile devices in the healthcare sector, known as mobile health (m-health) and m-health applications, generally reduce the workload for the healthcare staff and provide better services for the patients. In the last few years m-health is getting a boost because of the rapid changes in the technology sector and the efforts of local governments to introduce these technology changes in the standard healthcare [1–3]. Considering care for older people the need

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for technological support is strongly present in order to fulfil the increased care needs resulting from demographic changes. Cognitive impairment is common in old age, and its early detection as such is of great importance in the care of persons with dementia [4]. Moreover, assessing the cognitive impairment of a person on a periodically basis is needed to adapt the care to the level of impairment [5]. Among numerous tests with this purpose which have been considered, the mini-mental state examination (MMSE) is a very common and reliable test of cognitive assessment in geriatric clinical practice. While geriatricians are well trained using MMSE on a daily basis, the test has been often applied by neuropsychologists and other health care professionals when assessing older patients [6]. This questionnaire for geriatric assessment [7] consists of 11 questions reflecting the impairment of 6 different cognitive domains, indicated in the following cognitive functions: orientation, imprinting, attention and concentration, reproduction, language and constructive praxis. A score is linked to these results and an indication of the person's cognitive impairment (for instance, the state of dementia, if appropriate) is given. Due to differences in language and in cultural aspects many (regional) versions of the MMSE exist [4].

In current practice in care for older people, the MMSE test is taken on paper by the examiner (geriatrician, neuropsychologist or other health care professional) during the examination session with the participant. After this examination (collection of the answers) the workflow consists in the calculation of the score and in storing the answers and scores for future reference and follow-up. In clinical practice, the clinician is required to spend not only time, but also sufficient effort of interaction with the patient to catch the attention towards obtaining reliable answers to the different questions. Possible but common deficits such as hearing deficit, impaired concentration, require considerable effort of the examiner in this way.

It is clear that in an m-health paradigm the computerization of the various assessment aspects opens the way for different levels of automated cognitive assessment, which can range from remote assessment [8] to a complete cognitive screening of dementia using a mobile app [9]. The conception of such an app can range from an m-health tool for assisting the examiner (in order to address the mentioned problems in clinical practice) to an automated self-assessment tool, when an instructed participant having sufficient cognitive and physical abilities can accomplish the complete test protocol.

In this study, an m-health app that covers the complete workflow of a standard MMSE is presented. The application is designed to be used by a geriatrician or other health care professional taking and to assist in the examination of a patient. As the patients under consideration in this study are residents of a nursing home, with specific levels of cognitive and motoric deficits, a broad scale of self-participation in the assessment is accounted for, with the examiner supervising the assessment. In this way, the current version of the app is not intended for unsupervised self-assessment. This app decreases the workload of the examiner, since it automates the scoring of the test and stores all the data (participant information and test results) in a database, making it is easy to share the test results paperless with colleagues and to consult them at a later time. In a small scale pilot study the MMSE app was used as the screening tool in a nursing home and the results were compared with the conventional MMSE screening on paper.

The current paper is structured in the following way: in the next section the implementation of the MMSE app and its use in the pilot study is described. In the following section, the resulting app is explained and the results of the pilot study are given. These results are discussed and concluded in later sections.

Methodology

To evaluate the m-health version of the MMSE test, an MMSE app was realized using standard development tools. Using this app a small scale pilot study in a nursing home in Flanders, Belgium was conducted to obtain an indicative evaluation of the app.

Smartphone application

Application characteristics

The current MMSE app was developed for the open source Android operating system, as designed by Google. The Nougat (Android 7) version of this operating system was used, but the app can also be installed on devices with Android 4.1 or higher (all to Android 7). Since Android is widely deployed (almost 85% of all the smartphones worldwide) [10], it is clear that the MMSE app can reach many users of portable devices of different scale. The Java application was realized with a standard Graphical User Interface (GUI) containing (radio) buttons to collect the answers or choices in the test. As standard smartphones have functional audio interfaces, speech recognition was implemented to support automation of specific parts of the test. In the current version, the MMSE app is mainly intended to be used by the examiner during a face-to-face assessment for the evaluation and administration of the examination.

Table 1 Overview of the content and score of the questions of the MMSE test and the implementation in the MMSE app

	Content	App implementation	Score
1	Questions about time: a. What year is it? b. What season is it? c. Which month of the year is it? d. What is todays date? e. Which day of the week is it?	These questions are directly implemented in the application. The examiner asks the question to the patient, which has to indicate one of the answering options for each question ("Right"/"Wrong"/"The patient doesn't know")	5
2	Questions about location: a. In which state/province are we now? b. In which city/town are we now? c. In which hospital/institution are we now? d. What is the name of this department? e. On which floor are we now?	These questions are implemented the same way as the questions in 1.	5
3	The examiner names 3 common objects (like "apple", "key" and "door"). The patient has to repeat the words of these 3 objects	This question is implemented using speech recognition. The patient says the words one by one to the smartphone and the application detects the spoken words. It is possible to repeat the words again in case of a false detection	3
4	This question has 2 parts: a. The patient is asked to subtract 7 from 100, 5 times b. The patient is asked to spell the word "world" in reverse order Only the highest score from these 2 parts is used for the overall score	These 2 questions are both implemented with an input textbox. The patient or examiner (if the patient can't do it) has to type the numbers/letters one by one with the keyboard of the smartphone	5
5	The patient is asked to repeat the 3 objects from question 3	Like in question 3 this question is also implemented using speech recognition.	3
6	The examiner shows 2 objects to the patient. The patient is asked to answer the name of these objects	In the application, this question is implemented with 2 images. The examiner has to click "Right" or "Wrong" using radio buttons. The images can be enlarged to the screen size	2
7	The patient is asked to repeat the sentence: "No ifs, ands, or buts"	This is also implemented with speech recognition	1
8	The examiner shows a sentence "Close your eyes" on a piece of paper. The patient must then close his eyes	The examiner shows the sentence on the smartphone. It is possible to enlarge the sentence to the size of the screen. The examiner has to click "Correct" or "Incorrect" using radio buttons	1
9	The patient has to take a piece of paper from the examiner with his right hand, fold it and lay it on his lap	The patient has to take the smartphone from the examiner with his right hand, turn it and put it on the table/bed. The turning is detected automatically. The correctness of the other of the 2 actions needs to be entered in the app using radio buttons	3
10	The patient has to type a complete sentence. It must have a participant, proverb and a meaning	This question is implemented with an input textbox. The patient or examiner (if the patient can't do it) has to type the sentence with the keyboard of the smartphone	1
11	The patient has to draw a picture of 2 overlapping pentagons on a piece of paper. The overlapped area must be a tetragon	The patient has to draw a picture of 2 overlapping pentagons on the smartphone	1

MMSE questions

As the standard MMSE test consists of 11 questions (reflecting the impression of six cognitive domains), each of these questions was implemented in the MMSE app. Due to the nature of specific questions it was not possible to implement all questions in the MMSE app in a straight forward way. Some questions (e.g. question 9) needed slight adaptation to make an m-health implementation possible. An overview of the question content and the implementation in the MMSE app is given in Table 1. The maximum score of the slightly adapted test remains 30.

Pilot study

To determine the validity of the MMSE app a pilot study was conducted in a nursing home in Flanders, Belgium (WZC Leiehome, Drongen, Belgium). Taking into account the size of the nursing home population and the necessary level of physical and cognitive abilities needed for acceptable interaction with an examiner only 19 residents were considered to be suitable to participate in the pilot study. Following the scheduling of the clinical practice, and taking into consideration not to introduce excessive assessment sessions, 15 participants (nine females, six males; average age: 86.5, standard deviation age: 5.95) were examined both with the traditional paper MMSE and the MMSE app in a Dutch version during the pilot study duration which was limited to 5 months. All participants had a geriatric profile (with multimorbidity and impaired functionality) and could not function independently at home any more. However, the underlying medical condition were stable under the existing treatment. The education level of the participants was as follows: seven participants with lower education level, seven participants with middle education level and a single participant with a high education level. Most participants showed a mild cognition deficit, all participants showed a stable cognitive condition. In this way, the successive testing with the paper MMSE and MMSE app with an examination interval of maximum 5 months was conducted, as is the common interval in the practice of the nursing home. To guarantee anonymity of the data collected with the app no test date information was saved during the current pilot study. In this way, an upper limit of 5 months for the time difference between the completion of the MMSE test and MMSE app needs to be considered. Both the paper and the app version of the test were taken by the care staff of the nursing home, having large experience in taking these tests from the participants. In addition, identical examination circumstances and similar practices were used when conducting the tests. The participants were examined with the app test during a standard examination session, where the examiner assisted the participant in taking the app test on a smartphone device (Samsung Galaxy J5 with a screen size of 5 inch). Statistical analysis of the obtained results was performed using SPSS Statistics 25. After the test period in the nursing home, the experiences of the staff in using the app were collected and discussed in a focus interview with the representative of the examiners.

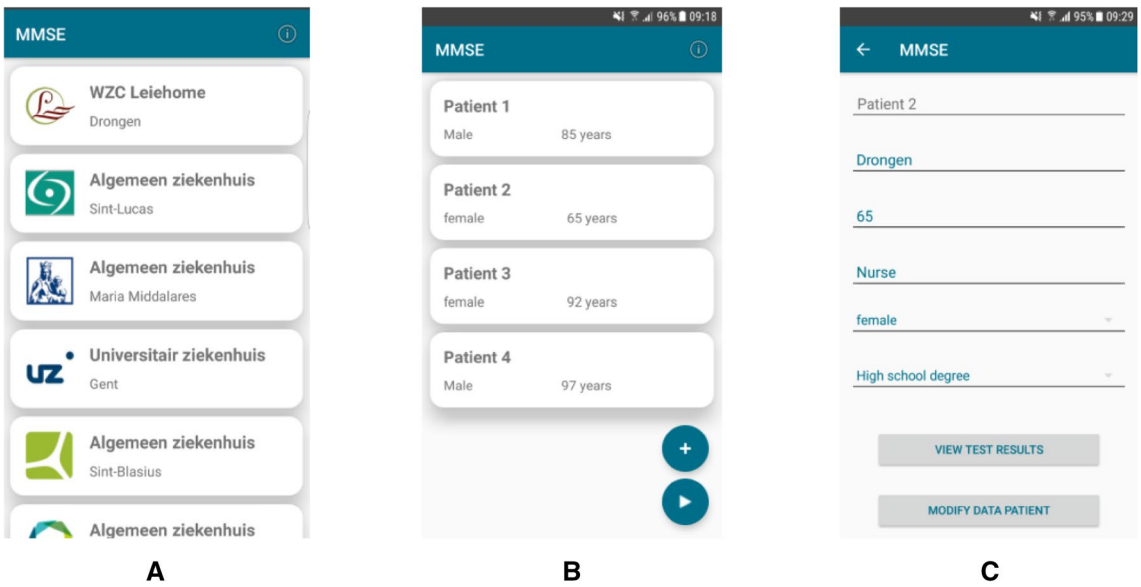

Fig. 1 Graphical user interface for the administrative part of the app: **a** list of the registered hospitals/nursing homes; **b** list of the registered patients; **c** personal data of patient 2, with the options to view the previous obtained test results and to modify the patient data

Results

Smartphone implementation

Structure of the application

In this subsection, a short summary of the structure of the application is given. The patient administration is implemented in the beginning of the application. The user has to select the care institution (from a list of hospitals and nursing homes) where the test will take place and the patient (from a list of patients) (Fig. 1). New patients can be added, and by clicking on a patient, all available data of a patient can be shown to the user (Fig. 1c). Moreover, it is possible to view (and modify) the previous obtained test results. Since the app is connected with a database the data from the hospitals and the patients are retrieved from this database.

When a patient is selected to make the test (long click on the patient and press play) a dialog window shows up with some general information about the MMSE test. When closing the dialog window question 1 is visible on the screen. The next question can be reached by swiping right on the smartphone screen. It is always possible to go back to a previous question by swiping left on the smartphone screen. After all the questions are answered the examiner can have an overview of all the answers given and the score is calculated with a click of a single button. The score and rating (based on the score) of the patient is given and is stored in the database.

The user interface of current app is implemented for two languages (i.e. English and Dutch) and is designed to facilitate the use of other languages by uploading a file with the translated sentences to be incorporated in the user interface application files.

The data of each patient and the results of the MMSE test of each patient in this application are transferred to a database, in accordance with the institutional data practice. As cloud services improve the connectivity and operational aspects of data storage, the option was provided to use a cloud database with anonymized data for this purpose, resulting in an attractive data storage solution. The cloud Bluemix platform (IBM) offers different services and was selected in this way as the data platform [11]. It offers services to access and link an application to an online database. In addition, it provides very efficient data synchronization services. A local copy of the database is stored on the smartphone device (local files). Each time a test is made, the results will be changed locally. After that, a synchronization process is started between the local files and the online database files. The process searches for differences between the two file sets and only changes are copied from one location to the other location, instead of transferring all the data. In this way, the application does not need permanent connection to the Internet, connection of the smartphone with the Internet once in a while will allow to synchronize all the local files to the database. This makes it possible to use the MMSE app in locations where no internet (wireless) connection is available, as can be the case in different parts of a nursing home.

Implementation of the MMSE questions

As can be seen from Table 1, the majority MMSE questions can be implemented in the m-health app in a straightforward manner, while some questions need specific attention or can be implemented using speech recognition.

Considering question 9, the detection of the turning of the smartphone is realized with the accelerometer and gravity sensor of the smartphone. An accelerometer detects the linear acceleration of the device in three directions (the x, y and z direction fixed to the device). The gravity sensor measures the direction of the gravity force, so when the device is faced horizontally this will be the direction of the z-axis. When the smartphone is flipped, the output of the gravity sensor will change in sign, which can easily be detected.

Considering question 11, the participant has to make a drawing of two intersecting pentagons, which can be made on the smartphone with the finger or with a drawing stylus, giving more accuracy. An example of such a drawing is given in Fig. 2.

The MMSE application provides for every question an information button and a comment button. When pressing on the information button a dialog window shows up with all

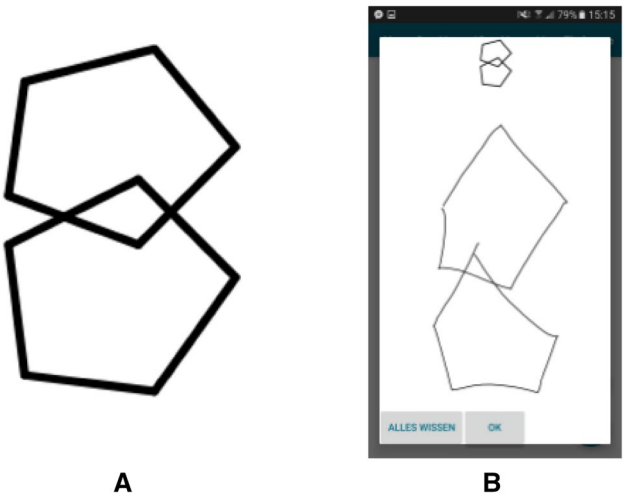

Fig. 2 User interface for the drawing question 11: **a** picture that needs to be drawn by the participant (two overlapping pentagons); **b** resulting figure in the MMSE application (where the upper drawing is presented as a guide drawing for the participant)

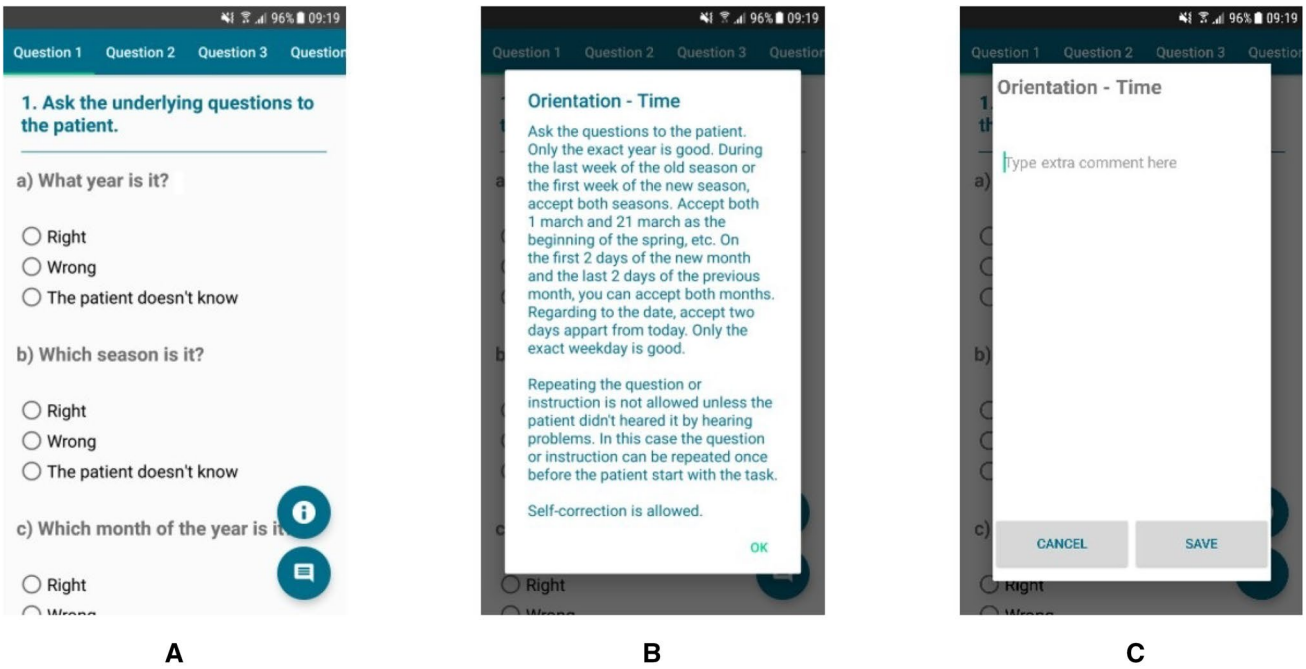

Fig. 3 Example of the information and comment button: **a** Question 1 with the information and comment button in the bottom right corner; **b** information dialog window of question 1; **c** commentary dialog window of question 1

the necessary information about the current question. Pressing the comment button shows a dialog window where extra commentary about the answer of the patient can be typed. An example of the two buttons and the dialog windows is shown in Fig. 3a–c.

Speech recognition

The speech recognition used in the MMSE application is the speech recognition provided in the Android framework (Android Speech API). This speech recognition can be used in different languages, the language that will be used depends on the language settings of the smartphone. The speech recognition can be used online and offline. If the smartphone is online the spoken word will be send to a server which will process the speech recognition. It is possible to use the speech recognition offline. In this case, a file needs to be downloaded for the language of interest. The offline speech recognition performs a bit slower and less accurate than the online speech recognition (due to the hardware limits) but with recent fast smartphones this is barely noticeable. In the MMSE app questions 3, 5 and 7 were implemented used speech recognition. In the current implementation speech recognition was only used when correct answers could be given with a single specific word (questions 3 and 5) and not with different alternative words (synonyms or dialect words), as is the case in other questions (e.g. question 6). In this way successful speech processing

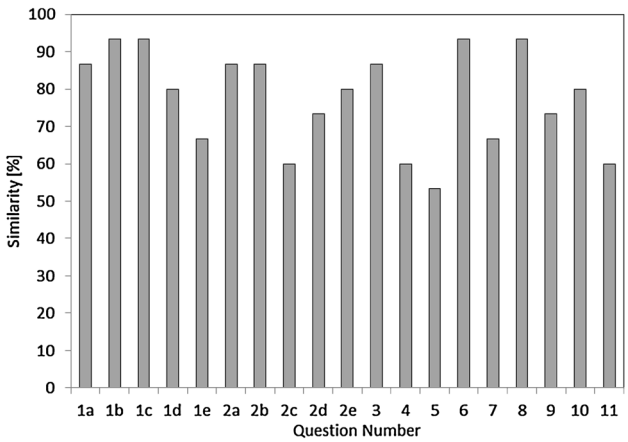

Fig. 4 Similarity (percentage of identical scoring) between the MMSE test and the MMSE app for the different questions

results were guaranteed. To account for the participant's responsiveness the recognition part in the question can be repeated. In order to evaluate question 7 the sentence spoken by the participant is recognized, and the resulting text leads to the score for this question.

Pilot study

The examination of the different participants with the app test took place during a standard examination session with a

mean duration of 20 min 31 s (range from 9 to 59 min) and a standard deviation of 12 min 19 s. The MMSE test scores ranged from 17 to 30 with a mean test score of 25.0 and a standard deviation of 4.0, indicating a participant group with a rather mild cognitive deficit.

Differences on the level of the individual questions

The comparison of the test results is showed in Fig. 4, where the similarity (percentage of identical scores) of the question scores is given for the different questions. The similarity between the MMSE test and the MMSE app scores, is overall higher than 50%. The overall score weighted average similarity is 74%. The questions for which speech processing was used to score the results (questions 3, 5 and 7) show a slightly lower accordance, but the score weighted averaged accordance for this type of processing remains at 70%.

Difference on the level of the final test result

Considering the final test score of a participant, with a maximum score of 30, the correspondence of the MMSE test result and the MMSE app result was analyzed. The difference between the paper and app test score lies between −4 and 4 with a mean value of 0.1 and a standard deviation of 2.1. The normality of the distribution of the differences between the test results (MMSE app versus MMSE test) was tested and confirmed using the Shapiro–Wilk test (significance level of 0.88). From a Pearson correlation analysis (r value = 0.90, p-value < 0.01, slope = 0.75, intercept = 6.3) the final test scores are shown to be clearly positively correlated over the present above mid-range data range, reflecting the cognitive level of the participant population.

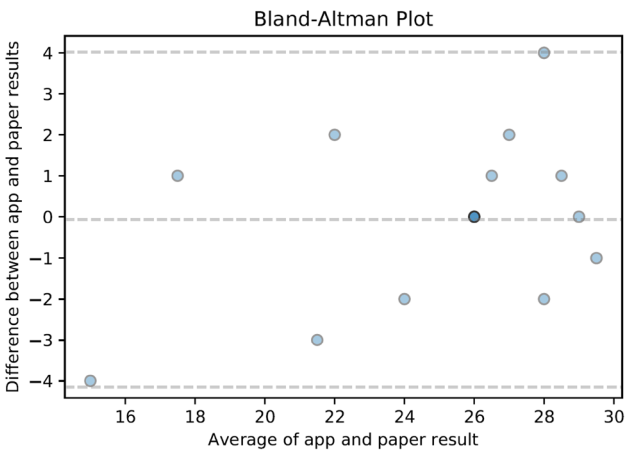

Fig. 5 Bland–Altman plot of the agreement between the MMSE app assessment method and the MMSE test assessment method, with the mean level (middle dotted line), upper 95% confidence level (upper dotted line) and lower 95% confidence levels (lower dotted line). The darker point indicates a triple data point.

To investigate the agreement between the MMSE app and MMSE test methods the results were analyzed using a Bland–Altman analysis, in which the statistics of the differences versus the means of the two assessment methods are reflected. The resulting Bland–Altman plot is given in Fig. 5 where the mean difference between the two assessment methods and the 95% upper and lower confidence limits for these assessment methods are indicated.

Examiner experience

After the testing period and during the focus interview with the responsible examiner some difficulties of the present app were indicated and reported. They consisted mainly in difficulties in the motoric use of the app's user interface, like in question 11 where the participant is asked to draw two pentagons. Since the tests were taken with a smartphone, the drawing could in some cases not be made on this small scale device, making it necessary for the examiner to switch to a paper drawing. The use of a device with a larger form factor (e.g. tablet) seems to be preferred. In addition, the typing of sentences by the participant (as necessary for question 10) is dependent upon the motoric capabilities of the participant. In practice many persons use their wrist as a support point during writing, a gesture which is giving false lines on the touchscreen of a smartphone. As a consequence, to achieve an acceptable time load for the assessment itself, the examiner can give support in typing the answers himself, in a way that the reliability of the reported answers is under his supervision.

Discussion

The development of the current MMSE app is an example of an m-health application which offers many different advantages [12]: data can be recorded precisely with extended levels of sensitivity; their use can represent cost savings not only with regards to materials and supplies, but also in the time required by the test administrator; they support standardization of test formats; they allow for broader administration by health care associates as long as critical aspects are performed by the appropriate professional. In the use of computerized assessment a major concern is the demonstration of the equivalence between the participants experience of computer versus traditional test administration [12].

The primary goal of the current MMSE app lies in the assistance of the professional examiner in the process of the evaluation. A main advantage is the increase of workflow efficiency as compared to the classical use of the paper MMSE: the examination preparation (planning, preparation of test material) is strongly reduced since it can be automated or ignored. The test scores and the test result are ready

for further use as they are digitally stored in a database and allow for automated resident follow-up and reporting. While test automation is a basic aspect in a computerized m-health app, from the patient perspective there is a need for balance between human and computer intervention, making the m-health app addressing participants with cognitive decline to be used successfully in practice [13]. Moreover, the use of the MMSE app allows for personalization in a way that a slightly modified personal version of the MMSE app which proceeds personal information could be used [14]. The app allows easy switching between different languages and regional settings, as can be expected to be important in cities or regions with international and multi diverse residents, making that the tailored care for older people can be given to everybody [15]. In an advanced practice, the app can facilitate standardization of test protocols and can give rise to enhanced exchange of collected data (test results) to support public or governmental studies on cognitive impairment [16].

Concerning the validity of the MMSE app as compared to the paper MMSE test the obtained results from the item-by-item analysis indicate that the MMSE app results are in line with the paper MMSE test. The overall MMSE test results are clearly positively correlated and the overall test results agree with a mean difference of 0.1 and standard deviation of 2.1 points for the difference between the two test methods. These findings confirm the results of a similar Japanese validation study [17] and validate the potential of using an m-health MMSE version in clinical practice.

The main use of the app can be seen as an examiner assisting use where the participant, depending on his skills can use the m-health device himself to answer the questionnaire or where the examiner can take over the input of the answers, taking care of an acceptable time load for the assessment. In any case, the examiner has the complete supervision of the assessment. As it was experienced with the current app, sufficient motoric skills to use an m-health device are necessary. Where the elderly population nowadays has only limited digital experience and skills, it is expected that this will increase in the future, improving the benefits of such an app. In addition it can be expected that due to the higher digital skills of younger clinicians, these examiners will have more motivation to use this MMSE app in their bedside practice and will contribute to paper-free healthcare records.

As the app can be used on devices with different form factors (smartphones, tablets) its size can be adapted to the need of a participant. Besides, it is possible to adapt the hardware to the different motoric and sensory abilities of the resident. The different modalities of the user interface of these standard devices offer different possibilities to adjust the in- and output interfaces to the participant (e.g. support for enhanced sound delivery with a headset in case of a hearing deficit). On the other hand as the proficiency or experience with mobile devices older people in the future is expected to increase, it can be expected that that future use of such devices in care for older people will become strongly accepted and appreciated by older people themselves.

Conclusion

While cognitive impairment tests are common practice in current care for older people, the use of m-health applications is still not widespread and is hindered by many factors. In the present study the use of the MMSE was investigated in this context. Using standard programming techniques the standard MMSE was converted into an MMSE app, where speech processing was implemented to support the scoring of different test questions. The benefits of such an m-health application lie in the increased work flow efficiency, the ease of adaptation (e.g. to different languages), the ease of data exchange and use, and the presence of hardware options to adapt the examination to the capabilities of older people (e.g. hardware form factor).

Taking into account the restrictions of the current pilot study we anticipate that the level of agreement between the MMSE app test and MMSE test is supporting the potential of an MMSE app to be used in a clinical setting. In the current study such an app is perceived and demonstrated to be used by an examiner to support his work and levering benefits in his workflow. Since the motoric skills of a participant strongly influence the participation level of the participant, addressing the implementation of technological assisted solutions for this problem, will result in an m-health app with higher benefits and can give rise to the possibility of self-assessment.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest concerning this article, and that no funding was received to conduct this study.

Ethical approval All procedures performed in studies involving human participation were in accordance with the ethical standards of the institutional research committee (Ghent University Hospital, reference numbers: B670201732520 and B670201732522) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Based on the practice of the participating nursing home, no individual informed consent was provided, as was covered by the ethical approval of the study.

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