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Technology-based Neurocognitive Assessment of the Elderly: a Mini Review

Оценка нейрокогнитивных функций на основе компьютерных технологий у пожилых людей: краткий обзор

doi: 10.17816/CP155
Review

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ABSTRACT

Neurocognitive disorders in the elderly are on the rise all over the world. Neuropsychological assessment is vital to monitoring the progress of cognitive deficits. Over the years, there has been significant development in neuropsychological assessment to predict the development and progression of MCI and dementia. One such area of recent advancement in the field of neuropsychology is technology-based assessment. There are several types of technology-based assessments available based on the type of usage, site of the assessment, type of administration, type of device used for assessment, etc. Virtual reality-based assessments and digital assessments of neurocognitions for early identification of subtle cognitive deficits in patients with mild cognitive impairment (MCI) and major neurocognitive disorders (MND) represent two newly developed technologies. A few studies have demonstrated their efficacy; however, there remain several limitations and drawbacks to their usage within the elderly population. In this review, we have briefly discussed technology-based neuropsychological assessment, along with their usage and limitations.

АННОТАЦИЯ

Распространенность нейрокогнитивных расстройств у пожилых людей растет во всем мире. Для мониторинга прогрессирования когнитивного дефицита решающее значение имеет нейропсихологическое тестирование. В течение последних лет наблюдается значительное усовершенствование системы нейропсихологической оценки, на основании которой возможно прогнозировать развитие и прогрессирование легкого когнитивного расстройства и деменции. Одним из важных достижений в области нейропсихологии является оценка на основе компьютерных технологий. Существует несколько видов тестирования на основе компьютерных технологий, которые различаются по месту и способу проведения оценки, по типу применения, виду используемого оборудования и т.д. Недавно были разработаны методы оценки нейрокогнитивных функций, основанные на виртуальной реальности и электронных шкалах: они предназначены для раннего выявления легкого когнитивного расстройства (mild cognitive impairment, MCI) и грубых нарушений когнитивных функций, соответствующих деменции. Результаты нескольких исследований продемонстрировали их эффективность, однако по-прежнему существует ряд ограничений и недостатков, связанных с их использованием у пожилых людей. В этом обзоре приводится краткое обсуждение нейропсихологического тестирования на основе компьютерных технологий, особенностей их использования и существующих ограничений.

Keywords: *neurocognitions; technology; dementia; digital; assessment*
Ключевые слова: *нейрокогнитивные функции; компьютерные технологии; деменция; цифровые методы; оценка*

INTRODUCTION

Aging is an inherent process that accompanies changes in the cognitive competencies and functionality of an individual. It is also now a well-known fact that, worldwide, the pace of population aging is much faster than in the past, and neuropsychiatric conditions have become a leading contributor of disability in the ageing population [1]. Neurocognitive disorders form the bulk of the neuropsychiatric conditions affecting the elderly, of which Alzheimer's dementia is the most common.

Dementia is an umbrella term used to describe the various symptoms associated with cognitive impairment. There is a gradual progression of neurocognitive impairment in the elderly, starting from the preclinical stage to mild cognitive impairment (MCIs) and, finally, major neurocognitive disorders (MND). Therefore, it is necessary that there should be appropriate assessment of cognitive functions for early identification of neurocognitive disorders in the elderly to develop strategies to slow down the progression of cognitive impairment and develop proper management strategies for early intervention [2]. The diagnosis of MCI and MND largely depends on clinical and neuropsychological assessment. Neuropsychological assessment is also vital to monitoring the progress of cognitive deficits. Over the years, there has been significant development in neuropsychological assessment to predict the development and progression of MCI and dementia. One such area of recent advancement in the field of neuropsychology is technology-based assessment. This review focuses on the technology-based neuropsychological assessment methods used for the elderly.

Methodology: A comprehensive literature search was conducted on digital technology neurocognitive assessment in the elderly using various search engines (PubMed, Scopus, PsyInfo, and Google Scholar) and through the cross-references included in relevant articles up to January 2021. Keywords included "technology", "digital", "neurocognition", "assessment", "elderly", "dementia", and "mild cognitive impairment" in various combinations. Only original articles (abstract and full text) and review articles published in English prior to January 2021 were reviewed and checked thoroughly. More than 300 articles related to the topic were found, out of which those relevant to technology-based neurocognitive assessment methods for the elderly have been included. Commentaries, viewpoints, and letters to editors related to the topic were excluded.

PROBLEMS WITH TRADITIONAL NEUROPSYCHOLOGICAL TESTING METHODS

There are several significant limitations to traditional neuropsychological tests and testing methods [3]. Some of these include: (1) findings cannot be correlated with real-time brain functioning in functional imaging studies; (2) traditional tests require the patient to travel to the hospital; (3) the scoring process can be complex; (4) many times, it depends on the administrator to decide alternative forms to avoid practice effect; (5) there can be an impact due to the 'white coat effect' while testing; and (6) there is occasionally a need to perform multiple tests in longitudinal studies, which can be quite cumbersome for the patient.

Another issue with the traditional neuropsychological tests is that they usually compare the findings of cognitively challenged individuals with normative data, i.e., those who are cognitively normal in the same age group, who themselves may not actually be entirely free of the markers of dementia. Therefore, there is a need to validate such tests with the biomarkers of dementia. There is also a need to explore the correlation of cognitive functioning with amyloid plaques over time [4]. For this, we need to have sensitive tests to pick up early cognitive changes associated with biomarker evidence of preclinical Alzheimer's dementia. To overcome these issues and for better assessment, technology-based assessments have come to the fore in recent times.

TECHNOLOGY-BASED ASSESSMENTS

Any instrument or method that utilizes a computer/ digital tablet/ handheld device, or other digital interface instead of a human examiner to administer, score, or interpret tests of brain function and related factors relevant to neurologic health and illness questions is understood to represent a form of technology-based assessment [5]. For neuropsychological assessment purposes, these can be broadly categorized as computer-based, tablet-based (mostly touchscreen devices), and mobile/smart phone-based assessments, and wearable devices. The number of tests based on digital cognitive assessments had increased exponentially in last few years.

Types of technology-based assessment

1. ***Based on type of usage, digital assessments can be of two types.***
    - Stand-alone apps and programs are digitized versions of traditional paper and pencil neuropsychological tests.

- Web-based apps that can be either completed on personal computers or on tablets are designed to be completed without active participation or the presence of an examiner [6].

2. ***Based on the site of assessment,*** technology-based assessments can be divided into office-based assessment and remote location assessment. However, there are certain problems with remote location assessments such as difficulty in maintaining participant engagement, issues related to data privacy, digital unsupervised evaluations, and frequent changes in the versions/updates to web-based apps, which often pose challenges to the administrator as well as the participant, etc. [6].
3. ***Based on type of administration,*** technology-based assessments can be categorized as either self-administered or clinically administered assessments
   - While self-administered tests have the advantage of being less time-consuming and less costly, there are also several disadvantages, such as difficulty in controlling environmental factors and distractions, problems with evaluating feigned performance, and problems with ensuring whether the examinee understands the task instructions perfectly or otherwise [5].
   - Clinician-administered assessments overcome the limitations of self-administered assessments, although they are more time-consuming and the patient needs to visit in person the clinician or needs to be actively engaged through video conferencing with the patient.
4. ***Based on the type of device***, the assessments can be categorized as Managed devices and Bring your own device (BYOD).
   - Managed devices — These are dedicated devices for cognitive assessment rather than the examinee's own device. They have the advantage of reducing the error variance associated with different hardware and software. However, high cost, reduced flexibility, and low familiarity with the device amongst the elderly are just some of the associated limitations.
   - BYOD-based cognitive assessment — These are primarily smartphone- and browser-based tests. These have the added an advantage of having a wider audience without the added expense of a managed device, and smartphones offer novel data collection methods too. However, there can be issues related to device size/type, touchscreen responsiveness, software-related problems (iOS or Android, updates, etc.), and unstable internet connectivity might also affect browser-based tests [5]. Therefore, when choosing a BYOD approach, it is essential to ensure or check the compatibility of the device's software and hardware with the minimum requirements as specified in the software manual.

Virtual reality-based assessments

Another development in the area of technology-based assessments is virtual reality (VR)-based assessments. VR-based assessments include variety of technologies and devices to assess the manipulation of objects in virtual space and time. They have virtual environments that can act as basic rooms for navigation tasks or bigger spaces like office room/classrooms. Initially, VR-based cognitive assessment was developed to integrate computerized versions of traditional paper and pencil-based tests into virtual environments [7]. This has the advantage of being able to assess multitasking in a simulated virtual environment (like running errands and completing kitchen tasks, etc.). Task completion in a simulated environment has the advantage of better representing everyday life as there will be distractions that represent real-world interruptions. In other words, these improve the ecological validity of the tasks. When compared to the manual administration of the Wisconsin Card Sorting Test, participants appeared to do more poorly on the VR-based version but reported enjoying the VR test far more than the manual one [7].

Different types of immersions have been used in VR-based assessments. These are non-immersive three-dimensional computer screens with mouse/joystick or sensor-based gloves, or semi-immersive large screen displays using shutter glasses or full immersive environments with a "green screen" and head-mounted display [7].

There can be two types of exploration within VR environments: active exploration, or passive exploration. In active exploration, participants are immersed within and navigate a virtual environment guided by a research assistant, or otherwise navigate and move around by themselves using a joystick. There is 360-degree 'first person view' of the environment in active exploration. In passive exploration, participants immersed in the virtual world do not move around or explore it. They stay in a fixed location and are exposed to stimuli but can look around and can have a 360-degree 'first person' view of the environment [8].

Cognitive assessment via wearable devices

In recent years, mobile and wearable technologies (such as smartphones, tablets, smartwatches and rings, smart suits) present a unique opportunity to massively detect neurodegenerative diseases in a timely and economical fashion. The onboard sensors at the hearts of these systems are able to provide metrics by means of active (prompted) or passive (unnoticed) measurements, with a considerably flexible approach [9]. There are several advantages to wearable devices. These are: (1) widespread usage of these newer technologies, (2) immediate access of information due to the internet connectivity, (3) increasing sensitivity and plurality of onboard sensors, (4) near accurate monitoring of physical and cognitive symptoms/abilities, and (5) extremely low burden on the healthcare system, as large segments of the population are increasingly using these devices [9]. There are also two types of data collection by the wearable devices, i.e., either active data collection (for example, prompted voice test by the device to note tremors in the vocal cords suggesting the possibility of Parkinson's disease) or passive data collection (for example — smartwatch-based step counter). Table 1 depicts some of the common sensors used in wearable devices and their respective domains they measure/interpret.

Table 1. Commonly used sensors and the respective domains they interpret [9]

Sensor	Metrics and sense domain measured
Microphone	• Voice power spectrum and tremor — voice features of speech and language • Vocabulary, pauses — cognition • Ambient noise level — environment
Touchscreen	• Swipe pattern efficiency — fine motor movement • Keyboard typing/Tapping speed — fine motor • Vocabulary — written text
Geoposition	• Location patterns — behavior and movement — mobility • Driving patterns and navigational efficiency — executive function and spatial memory
Device usage	• Reminder use, PIN and password attempts — memory • Number of apps used — executive function • Behavior disruptions, frequency of interactions — social interactions

Digital assessments

Some of the instruments developed for digital applications and that have also been validated [6] include (1) Cogstate Brief Battery, (2) the Computerized National Institutes of Health Toolbox Cognition Battery (NIH-TB), and (3) the Cambridge Neuropsychological Test Automated Battery (CANTAB).

- **Cogstate Bried Battery (CBB):** This was developed to mitigate the effects of language and culture on cognitive assessment. This test battery was initially developed in the early 2000s for PCs (where participants could respond via keystrokes) but is now available for tablets too. It measures response time, working memory, and continuous visual memory using the universal stimulus set of common playing cards. However, there are a few additional non–card-playing tasks (e.g., a paired associative learning task and a maze learning task). The Cogstate system was designed to be administered by an examiner, but there have been recent efforts to effect remote administration; additionally, once logged into the platform, the tasks are easy to progress through independently. More recently, the CBB has been made available for unsupervised testing using a web browser.

  It is being used in the Healthy Brain Project in Australia with a high acceptability and usability and low rates of missing data. The psychometric characteristics of the CBB were similar to those collected from supervised testing [6].

  A recent iteration of the Cogstate tasks is the C3 (Computerized Cognitive Composite) which includes the CBB in addition to two measures that are potentially sensitive to changes in early Alzheimer's, i.e., the Behavioral Pattern Separation–Object Version (BPS-O) and the Face-Name Associative Memory Test (FNAME). Behavioral versions of the FNAME and a modified version of the BPS-O were selected as they have been shown to be sensitive to activity in the medial temporal lobes in individuals at risk of AD based on biomarkers [6]. Additionally, Cogstate C3 battery's memory tasks were found to be best at identifying individuals' subtle cognitive impairments, as defined by paper and pencil measures (PACC) performance. It has been found to correlate well with paper and pencil measures of performance.
- **Computerized National Institutes of Health Toolbox Cognition Battery (NIH-TB):** This was designed as an easily accessible and low-cost

means to provide researchers with standard and brief cognitive measures for various settings. It was released in 2012 for PC, and a tablet version is also now available. Some tests have recently been implemented for remote administration via screen sharing in a web browser. It has been validated against standard neuropsychological measures, as well as against established cognitive composites for use in preclinical Alzheimer's dementia [6].
It consists of seven established neuropsychological tests, selected and adapted to a digital platform by an expert panel. The cognitive domains covered include attention and executive functions, language, processing speed, working memory, and episodic memory.

- **The Cambridge Neuropsychological Test Automated Battery (CANTAB) [10]:** This was intended as a language-independent and culturally neutral cognitive assessment tool initially developed by the University of Cambridge in the 1980s. It mostly uses non-verbal stimuli, and includes measures of working memory, planning, attention, and visual episodic memory. Administration of CANTAB was initially on PC but is now available through CANTAB mobile (tablet-based). It offers an online platform for recruitment by pre-screening patients using their cognitive assessment instruments.
- **Mobile/Tablet Versions of existing tests: These are some of the mobile/tablet versions of the commonly used tests.**
  - ◊ eSAGE — paper-based Self-Administered Gerocognitive Examination (SAGE) [11]
  - ◊ e-CT — K-T paper-based cancellation test, consisting of two blocks of stimuli composed of 30 symbols displayed on a tablet touch screen
  - ◊ Cambridge University Pen to Digital Equivalence assessment (CUPDE) — Saint Louis University Mental State Examination (SLUMS) CogState PC
  - ◊ eMOCA — standard paper-based Montreal Cognitive Assessment
  - ◊ Digital version of the Trail Making Test (dTMT)
- **Mobile/Tablet Versions of new tests:**
  - ◊ **Cognitive assessment for dementia, iPad version (CADi):** This is being used for mass screening for dementia. It has ten items including immediate recognition, semantic memory, categorization, subtraction, repeating backwards, cube rotation, pyramid rotation, trail making A and B, and delayed recognition tests [12].
  - ◊ **Smartphone-Based Color-Shape Test (CST):** This measures cognitive processing speed and attention. Participants match color and shape according to a legend showing paired colors and shapes at the top of screen by touching the color pad at the bottom of the screen. It records the number of attempts and the number of correct answers. CST scores correlate with scores on the MMSE and other speed and attention tests, showing the possibility of using smartphones for cognitive assessment in older adults [12].
  - ◊ **Computerized cognitive screening (CCS):** This consists of a symbol-matching task, a memory task, and an object matching task used to assess concentration, memory, and visuospatial functioning. A few studies have found a significant correlation between CCS scores and Montreal Cognitive Assessment (MoCA) scores [13, 14].
  - ◊ **Mobile Cognitive Screening (MCS):** This is a mobile-based neuropsychological test. It consists of 33 questions from 14 types of test that assess eight cognitive domains including arithmetic, orientation, abstraction, attention, memory, language, visual, and executive function. All test questions have been modified for a mobile platform [15].
  - ◊ **Brain Health Assessment (BHA):** This is a 10-minute tablet-based cognitive assessment to detect MCI and dementia. When compared with the MoCA, BHA demonstrated higher accuracy in detecting mild cognitive decline and similar accuracy in detecting dementia [15].
  - ◊ **Computerized Cognitive Composite for Preclinical Alzheimer's Disease (C3-PAD)**: This assesses episodic memory and working memory. It has demonstrated significant association between the in-clinic tests and the at-home tests, suggesting home-based cognitive assessment with mobile devices is feasible if sufficient training is provided [12].
  - ◊ **National Center for Geriatrics and Gerontology function assessment tool (NCGG-FAT):** This includes eight tasks used to assess memory, attention, processing speed, visuospatial, and executive function. It has high test–retest reliability and high validity in comparison with conventional neurocognitive tests, suggesting that the NCGG-FACT may be useful in assessing cognition in population-based samples [16].

- ◊ **Toronto Cognitive Assessment (TorCA) [17]:** This is a more comprehensive test than screening tests but shorter than a neuropsychological battery. It has 27 subtests to evaluate multiple cognitive domains. It can be administered on paper or on an iPad, with each mode using the same questions. TorCA demonstrated statistically significant ability to differentiate between MCI and normal cognition.
- ◊ **Computer-Administered Neuropsychological Screen for Mild Cognitive Impairment (CANS-MCI) [18]:** This is a 30-minute eight-task battery that can be self-administered. It measures episodic memory, executive functions, and language with good test-retest reliability and moderate correlations with standard neuropsychologic measures. It has the advantages of automated scoring, result interpretation, and provides care recommendations.

STRENGTHS OF DIGITAL ASSESSMENTS

Digital assessments are more accessible and cost-effective due to self-administration. These tests automatically generate alternative forms which may help minimize practice and version effects. They have automatic scoring recording and give immediate access to results. These tests utilize artificial intelligence (AI) methods and hence are faster, novel, and provide more sensitive cognitive data analysis [7]. These tests are highly scalable, and therefore can be used for remote assessment in a much larger population. These can be used for more frequent assessment with potentially more sensitive cognitive paradigms. Moreover, as these are performed in a familiar environment, they may accordingly increase the ecological validity. Another major advantage of digital assessments is that they provide cognitive assessment outside clinics with rapid data transfer to healthcare providers. Certain time-sensitive parameters, such as reaction time or inspection time, can be measured more accurately with digital tests [19].

In some tests, there are algorithmically defined approaches to a particular test (e.g., organization, planning), evaluation of pauses, perseverations, domain-specific errors, and/or response times in very specific measurements that add value to neuropsychological assessment data [7, 20].

Added advantages of smartphone-based assessments include reduced risk of the “**white-coat effect**”. They provide additional opportunities for an individual to track their own cognitive health over time, potentially leading to increased commitment to their well-being. They further reduce the need for in-clinic visits among participants of various trials and encourage those in more remote areas to participate. They also help with short- or long-term monitoring through repeated assessment outside the clinic to detect early, subtle signs of cognitive decline.

Collating these new data streams results in a composite description of a person’s behavior which is known as the **“Digital phenotype”**, i.e., alternative measurement of health-related behaviors. Digital phenotyping incorporates data from mobile sensors, keyboard interactions, voice, speech, and other streams obtained during everyday use of social media, wearable technologies, and mobile devices [7]. GPS technology in these devices can record daily movement data that can aid in the recognition of behavioral symptoms of incipient dementia.

LIMITATIONS OF DIGITAL ASSESSMENTS

Several variables can influence the outcome of a technology-based cognitive assessment, including test characteristics, test duration, test frequency, and training and prior technology experience of the person being assessed. Privacy issues are paramount when obtaining health data from any internet-connected device, especially someone’s personal device. Some of the authors caution against using these technologies as a sole means of diagnosis, but advocate their use in conjunction with comprehensive evaluations by trained clinicians [7].

Little attention has been paid to person-centered care and person-centered assessment concepts. Modern neuropsychological tests might only be available in some of the world’s regions. In many countries, there are large proportions of the population with little education, and for whom these modern neuropsychological tests might not be appropriate. Tests developed with culturally specific stimuli will not be applicable in some cultures [21].

Moreover, there can be technological issues, such as variations in computer hardware. Currently, only limited information on psychometric and normative properties for different clinical population is available for digital tests. These tests can be influenced by knowledge of computers or other technology. Limitations unique to virtual reality are dominated by physiological concerns (e.g., motion sickness) [7].

CRITIQUE OF TECHNOLOGY-BASED ASSESSMENTS

There is lack of consistent, consensual definitions of key neuropsychological concepts, which poses an ongoing challenge to the profession and researchers, resulting in problems in communication within and outside the field. Neuropsychologists tend to be molecular in their approach, dividing behaviors into abilities such as language, memory, and the like. In fact, behavior in the environment rarely involves using these abilities in isolation [22].

There is also a lack of consensus as to what constitutes a neuropsychological domain. For example, to assess executive functioning, there is no consensus about what constitutes this domain, and some theorists have even questioned its validity. Working memory is typically considered a part of executive functioning. When one is assessing working memory, whether one is actually setting attention, working memory, executive functioning, or a combination of these, is still not clear. Only a few studies have addressed the long-term reliability of neuropsychological assessments in stable patients. Moreover, the reliability of memory tests is consistently lower.

In addition to the above-mentioned, there are also issues related to patients' preferences and it is frequently seen that patients use devices less often due to cumbersome procedures related to wearing them or difficulty in logging in and out from their systems. Additionally, many of the elderly do not want to be dependent on caregivers or assessors to help them to use these devices daily.

Among all such devices, cognitive tests based on tablets are most acceptable. Studies have suggested that adults of more than 55 years of age have a greater preference for the use of touchscreen devices, as these devices have more direct and intuitive interaction, lower motor demands, and are relatively easy to use. Moreover, tablets offer greater mobility than personal computers and are more user-friendly than smartphones for older adults owing to the larger screen sizes and better response field views. In recent years, there had been a growing interest in developing and validating tablet-based cognitive assessment tools. Many neuro-cognitive tests have been validated for use with tablets [5].

Further, there are emerging legal and ethical issues related to technology-based monitoring. Some authors have raised privacy concerns with trackable wearable devices and the feeling of constantly being monitored during every activity. As wearable devices can also collect user data regardless of time and place, uploading data to the cloud can easily make the wearable device's system vulnerable to attack and data leakage. Defects in technology can sometimes cause problems such as lack of control over data flow links in wearable devices, and data and privacy leaks are more likely to occur. All these issues have raised serious privacy concerns and the elderly, being a vulnerable population, could be extremely vulnerable to attack by cybercriminals. Hence, proper data security should be taken care of by the wearable device manufacturers or technology software developers to tackle these emerging concerns [23].

Further, a vast majority of the aging population reside in low- and middle-income countries (LMICs), where these technology-based assessments and subsequent interventions are in a nascent stage. These technology-based devices are expensive and the patient population in LMICs is less educated as to their usage. More awareness and education programs are needed to propagate the message to the lay public regarding early identification of cognitive decline in the elderly and the subsequent need for monitoring and assessment.

CONCLUSIONS AND THE WAY FORWARD

It is essential to establish a neuropsychology data archive as an Open-Access Global Resource and develop a global collaborative network. It is also necessary to specify the latent traits assessed by each test and identify each trait's most efficient measurement models [24]. There should be constant efforts to improve the reliability and validity of mobile assessments and attempts to incorporate person-centered assessment and digital phenotyping in conjunction with mobile technologies. Patterns of mobile phone data can be used to identify changes in cognitive function, sleep patterns, mood, mobility, exploration of novel environments, social engagement, and other features that may provide critical indications of clinically meaningful change.

There is need for further validation when existing normed tests are translated to mobile platforms because the change in the delivery method may bias the test results, especially for self-administration. Future usability studies must include older adults with cognitive impairment to implement monitoring technologies to identify trends and acute changes outside the clinic in people with cognitive impairment.

Article history:
Submitted: 11.02.2022
Accepted: 28.02.2022
Published: 31.03.2022

Funding: None.

Conflicts of Interest: None.

For citation:
Sahoo S, Grover S. Technology-based neurocognitive assessment of the elderly: a mini review. Consortium Psychiatricum 2022;3(1):37–44. doi: 10.17816/CP155

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