Electronic devices for cognitive impairment screening: A systematic literature review

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Abstract

Objectives: The reduction in cognitive decline depends on timely diagnosis. The aim of this systematic review was to analyze the current available Information and Communication Technologies´ (ICT) based instruments for cognitive decline early screening and detection in terms of usability, validity and reliability.

Methods: Electronic searches identified 1785 articles of which 34 met the inclusion criteria and were grouped according to their main purpose into test batteries, measures of isolated tasks, behavioral measures and diagnostic tools.

Results: Thirty one instruments were analyzed. Fifty two percent were PC based, 26% Tablet, 13% laptop and one was mobile phone based. The most common input method was touchscreen (48%). The instruments were validated with a total of 4307 participants: 2146 were healthy older adults (M = 73.59, SD = 5.12); 1104 had dementia (M = 74.65, SD = 3.98) and 1057 mild cognitive impairment (M = 74.84, SD = 4.46). Only 6% were administered at home, 19% reported outcomes about usability and 22% about understandability. One study reported users' experience. Twenty-three percent of the instruments included information about convergent validity and 34% about discriminant validity; most of them obtained acceptable values of specificity and sensitivity. The methodological quality of the studies was good, the weakest methodological area being usability. Most of the instruments obtained acceptable values of specificity and sensitivity.

Conclusions: It is necessary to create home delivered instruments and to include usability and users´ experience studies in their design. Involvement of people with cognitive decline in all phases of the development process is of great importance to obtain valuable and user-friendly products. It would be advisable for researchers to make an effort to provide cut-off points for their instruments.

Key words: Cognitive dysfunction, Computers, Dementia, Screening, Human engineering.

Acknowledgments

Introduction

People aged over fifty years currently represent 37% of the population in Europe, and population projections foresee that the number of people aged over 60 will increase by about two million people per annum in the coming decades and it is expected that by 2060 this group will represent around 30% of the total population (1). Dementia and cognitive impairment are age related conditions that constitute a major public health challenge due to their prevalence and consequences in the older population. Forms of mild cognitive impairment (MCI) have been reported to be a risk factor for dementia affecting more than 20% of those over 70 years (2). Recent studies suggest that slowing the progression of dementia by one year would lead to a better quality of life for people living with dementia and a significant cut in the related socioeconomic costs (3). In this context, the early detection of dementia is the first step to initiate timely treatments, to manage the disease and to reduce morbidity (4). There is no evidence to support screening of asymptomatic individuals, but the monitoring and evaluation of persons suspected of cognitive impairment is justified as they have an increased risk for developing dementia (5). A computational model-based prediction found that the reduction in cognitive decline and dementia depends on initial screening age, screening frequency, and specificity (6).

Information and communication technologies (ICT) is an umbrella term that refers to any communication device or application comprising computer and network hardware and software, radio, television, mobile phones, wireless signals and the various services and applications associated with them (videoconferencing, tele-healthcare, distance learning, etc.). In the neuropsychological assessment field, new screening instruments should capitalize on new technological advances (7); ICT devices have been increasingly used for neuropsychological assessment, with good correlations with well-

established paper-and-pencil neurocognitive testing batteries. ICT instruments for cognitive impairment early detection and assessment can be grouped into four categories: electronic devices (personal computers, laptops, mobile phones, tablets, etc.); internet based devices; monitoring devices (which measure users´ behavior in different areas) and virtual reality (which immerse the user in a more complex and integral sensorial experience). Computerized test batteries have been reported to have advantages compared to paper-and-pencil neurocognitive testing batteries in areas such as the standardization of administration and stimulus presentation; the automatic collection of data; the reduction of human error in administration; accurate measures of response latencies; automated comparison with an individual's prior performance and with age-related norms; efficiencies of staffing and costs (8); tailoring tests to the examinee´s level of performance; minimizing floor and ceiling effects (9); and their potential to capture time-related information such as spatial planning strategies (10). On the other hand, older adults' limited familiarity with computers (8) and a general lack of psychometric standards (11) have been raised as an obstacle for these instruments.

In a review about computerized cognitive testing for older adults (8) 17 test batteries were identified which had adequate discriminant validity and test-retest reliability; the authors concluded that a large number of available batteries could be beneficial to the clinician or researcher. However, they warn clinicians about the necessity to choose the correct battery for each application considering variables such as cost, the need for a specialist either for administration or for scoring, and the length of administration. In a previous review (9) the authors identified 18 computerized test batteries, of which 11 were appropriate for older adults; they recommended that test batteries should be evaluated on a one to one basis due to the variability they displayed. In a comparative study of tools for the assessment of cognition the authors reviewed 16 assessment

instruments, of which 14 were computer based (7). Their goal was to identify measures capable of assessing cognitive changes before noticeable decline suggestive of MCI or early Alzheimer's disease. They concluded that there was no single recommended "gold standard" battery but, rather, a subset of instruments to choose from, based on individual study needs. They recommended researchers compare performance on a given cognitive test/battery with changes in known disease-related biomarkers (structural MRI, cerebrospinal fluid, etc.). A review of computerized tests for older adults in primary care settings (12) identified 11 test batteries from which three were judged potentially appropriate for assessment in primary care based on good test-retest reliability, large normative samples, a comprehensive description of patient cognitive performance, and the provision of an overall score or probability of MCI.

Usability is a key aspect of ICT programs development. The International Organization for Standardization (ISO) defines usability as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' (13). It comprises concepts as understandability, learnability, acceptability, user experience, operability and attractiveness (14). User experience is a subjective feeling related to having a satisfactory experience when using technology (15). There is a need to better understand the usability of ICT for persons with dementia, their preferences for specific interfaces, and their acceptance of different technologies (16). Consultation with people with dementia (PWD) and their carers is crucial to address usability in the design of ICT based instruments (17).

Despite the previous reviews of this subject, two fundamental aspects remain conspicuous by their absence: usability and the possibility of home based self-administration. Thus, it is necessary to analyze the state of the art of this area in the

available instruments to address this issue if necessary. The objective of this systematic review is to analyze the current available ICT based instruments for cognitive decline early screening and detection in terms of validity, reliability and usability.

Method

A protocol was developed for this systematic review (Supplementary File 1) following the PRISMA reporting guidelines; the supporting PRISMA checklist is available as Supplementary File 2.

Types of interventions

This systematic review centered on ICT based instruments assessing or monitoring older adults with potential cognitive decline. This included electronic devices (ED) (personal computers, laptops, tablets, phones or mobile phones, etc.), internet (I), monitoring devices (MD) and virtual reality (VR). Due to the profuse amount of instruments in this area, we decided to focus in this paper on the study of electronic devices.

Inclusion and exclusion criteria

All studies describing ICT based instruments for the screening, evaluation and assessment of cognitive and functional decline in older adults published between 2010 and 2015 were included. Screening and assessment instruments not validated for older adults, not discriminating results for older adults, or which did not provide minimum normative data (e.g. mean age of participants, diagnosis, etc.) were excluded.

Selection of studies

A search was performed in July 2015 of the databases Medline and PsycINFO with the search terms (Dementia OR Alzheimer) AND (computer OR ICT) AND (screening OR diagnosis OR assessment OR evaluation) and yielded 13893 papers (3891 after the exclusion of duplicates). Of them, 1785 where published between 2010 and 2015. On the basis of the inclusion criteria, the titles, keywords and abstracts were assessed by the first author obtaining a total of 89 relevant papers in this first stage of the selection process. Those 89 papers were then assessed by two authors on the basis of abstracts and full copies of the article when needed. Any disagreement about the inclusion of papers was discussed in a consensus meeting. Seventeen further studies were found through hand search, tracking cited references in other studies and relevant previous literature reviews in this area.

Data synthesis

The selected studies were analyzed by two reviewers with a standardized data extraction form, as suggested by the Cochrane Handbook for Systematic Reviews of Interventions. Tests, early detection tools and screening instruments were grouped according to their main purpose into cognitive test batteries, measures of isolated tasks, behavioral measures (measures of motor and sensory processes) and diagnostic tools (used by clinicians to help them in the diagnostic process).

Self-administration was defined as "*test-taking that is unsupervised after the test platform has been set up, and can occur in the clinic or home setting*" (18). Cognitive domains were depicted as described by the authors in the article. Concurrent validity was reported as correlations with other previously validated instruments. Discriminant Validity was reported as sensitivity and specificity rates and/or capacity to distinguish people with and without cognitive impairment. When discriminant validity was reported as lack of correlation with unrelated measures the information was also included.

Quality assessment

Schlegel and Gilliland (19) have proposed 20 critical elements that constitute a competent quality assessment for computer based test batteries grouped in 4 clusters (module information, test functionality, data recording and interface usability/anomalous behavior). These elements can be summarized in a systematic list of problems sorted by instrument and identified by severity of problem from 1 (severely affects test integrity) to 8 (affects look and feel). A checklist with these items was used for the quality assessment of the instruments.

Results

The reviewers agreed that 34 articles covering 31 instruments met the inclusion criteria. Figure 1 presents a flowchart illustrating the selection process. The instruments and their characteristics are summarized in Tables 1 (Descriptive data) and 2 (Psychometric properties). All the selected articles were cross sectional descriptive studies, which is coherent with the fact that all of them validated a test or test battery. See Supplementary File 3 for the references of the reviewed articles. A list of instruments reviewed in the previous literature is provided in Supplementary File 4; twenty three of the 31 instruments included in this review had not been included in the previous literature reviews.

Study quality assessment

The total score of the studies in Schlegel and Gilliland checklist (2007) ranged from 2/20 (10%) to 20/20 (100%). The average score was 15.40, equivalent to 77% of the possible marks. Table 3 shows the checklist with the scores of each instrument. Module information and version control was the better quality area, with 92% of the possible marks accomplished. Data recording got 88% of the possible marks, and test

functionality 71%. The weakest areas of the instruments were usability (18%) and anomalous behavior reporting (29%).

Descriptive Data

Of the 31 instruments, 52% (16) used a PC, 26% (8) a Tablet, 13% (4) a laptop, one was set in a mobile phone, one used the telephone and another one used a specifically designed technology. Three of the tablet based instruments could also be displayed in a personal computer. The most common input device was the touchscreen in 48% (15) of the instruments, followed by buttons or keys in 29% (9); of which 5 had two buttons simplified input pads. Other input modalities were mouse (3), microphone or voice recognition (2), eye tracker (1) and multiple devices (1). Fifty five percent (17) of the instruments were test batteries, 36% (11) individual tasks, 2 diagnostic tools and 1 a behavioral measure. The instruments were validated with a total of 4307 participants, 1104 of whom were PWD (M = 74.65, SD = 3.98), 1057 people with MCI (M = 74.84, SD = 4.46) and 2146 healthy older adults (M = 73.59, SD = 5.12). Eighty four percent (26) were administered to healthy older adults, 58% (18) to people with MCI and 65% (20) to PWD. Seventy nine percent of the articles (27) provided information about the years of education of the participants and 94% reported exact results and quantitative normative data. The instruments' administration time ranged from five to 44.2 minutes (M = 21.99, SD = 12.05). Sixty eight percent (20) were self-administered; of them, 13% (4) were completely self-administered while 19% (6) had to be initiated by a technician, 29% (9) needed assistance or supervision and one had to be corrected by a professional. Twenty six percent (8) were administered by a technician and three did not report the way of administration.

Six percent (2) were delivered at home, 39% (12) were delivered at a clinic or laboratory but had the potential of being delivered at home and 55% (17) could only be delivered at a clinic. Ninety four percent (29) had cognitive outcomes while the remaining two were diagnostic tools assessing the risk to convert to AD.

Usability

Results about usability and understandability are summarized in Table 1. Nineteen percent (6) of the instruments reported outcomes about usability defined as acceptability, efficiency and stability. In a single paper the development of the instruments was carried out in several stages, including in each step the suggestions from the usability assessment performed in the previous step through an iterative process (18). In another case, the researchers used a computerized system including a Perception Response Evaluation (PRE) module that established whether a participant met minimum perceptual and response requirements for taking various tests (20).

Additionally, 22% (7) of the instruments provided information about understandability. In three cases, understandability was used as a synonym for the participants' ability to complete the assessment, but it was not assessed with tests or questionnaires, with one exception (COGVAL) that used a non-standardized questionnaire (21). In one study (22), the test instructions were automatically reiterated by the computer program when the pattern of errors suggested that instructions were misunderstood. User experience was assessed in only one instrument (18) and other two articles addressed it generically (23, 24)

Psychometric Properties

Twenty three (74%) instruments provided information about concurrent validity. Of them, five were validated against well stablished neuropsychological test batteries (e.g.

ADAS-Cog), seven were validated against brief tests (e.g. MMSE, MOCA, HDS-R) and 11 against individual tasks or parts of batteries.

Twenty four (77%) instruments reported information about discriminant validity, obtaining in general good levels of sensitivity and specificity in detecting population with cognitive impairment.

Regarding internal consistency, six instruments provided information about intra-class correlation, and 11 about test-retest reliability. Two instruments had had a factor analysis performed and seven provided cut-off points for cognitive impairment.

Discussion

Even though computer-based testing has been used for more than 65 years in research until recently assessment was always carried out by a trained professional in a clinical context (clinic, laboratory, hospital, etc.). General access to personal computers, tablets and smartphones has opened a wide new horizon of opportunities for community-based assessments that can be self-administered or administered by a carer improving accessibility and the potential for early detection without compromising validity and reliability. However, the results of this review indicate that despite the range of different and accessible technologies developed in the last years, most of the instruments are still delivered through a personal computer, only 8 using a tablet and one a mobile phone. It is necessary to design screening instruments that can be delivered through the most accessible technologies like tablets and smartphones.

One of the strengths and potentials of ICT based devices is the possibility of being delivered at home, eliminating the need to travel to a health care facility. This would

allow early screening and detection to be more feasible in comparison with traditional paper and pencil instruments, yet most of the instruments could only be delivered at a clinic (55%). As a matter of fact, even though 39% of the instruments had the potential to be home delivered (based on the technology needed and automated completion), most of them still needed the assistance of a technician to be administered. In some cases the role of the technician included aspects that the current technology can overcome with remote control or automatic systems like collecting demographic data (25); side by side supervision (20); or repeating the instructions (22). This might be caused by a gap between the health system capacity to work with automatically generated data and current ICT development. An effort should be made to develop completely self-administered instruments and to design software that can be initiated by end users or their carers at home. In addition, clinicians and health care systems should develop their capacity to gather and use remote automatically generated clinical data for diagnostic and screening purposes. Ethical concerns about home-based assessments should be addressed, obtaining informed consent from persons with dementia due to possible difficulties understanding complex technology and loss of awareness over time of the data being collected.

Usability

Of the areas analyzed in this review, usability is the most under reported, with only six studies including it into their design process. The fact that 81% of the instruments did not address the subject of usability, and 78% did not assess understandability poses a concern over their design processes. There seems to be a lack of consensus of the scope of the term; in one of the five studies, for example, usability was taken as a synonym for acceptability (24).

Integration of electronic devices in the assessment and treatment of older adults with cognitive impairment has raised critics and skepticism, being regarded as solutions not acknowledging their interests, needs and values. In this context, it is essential to incorporate person centered design (26) to the development of ICT based instruments for early screening and detection of cognitive decline. The usability of the system and the application of user-centered design are more important than the level of education or the familiarity with ICT (27). ICT instruments can be embedded in a person-centered model; a good example of this is the provision of feedback sessions after the completion of the assessment to ensure patient and family understanding of diagnosis and prognosis, to answer questions and to collaboratively discuss recommendations and their implementation (28). The interface of the devices should be designed according to individual's age, gender and preferences, personalizing their appearance (29). While the previous findings of the literature recommend touchscreens as the best interface for older people (30), still almost half of the instruments do not include this technology. The match of person and technology has to be considered as it is a key factor in the decision to use technology or not. The inclusion of older adults with cognitive decline in the design and evaluation of these instruments is fundamental, as well as assessing users' experience (31). Unfortunately, this was not the case in most of the instruments reviewed. User experience information is necessary for the design and adaptation of the technology to the participant´s desires, thoughts, learning style and aesthetics.

Lack of computer experience has been repeatedly reported as a characteristic that decreased the odds of independent completion of tests and correct understanding (25). The evidence found in this systematic review suggests that this situation could be overcome by the introduction of pre-assessment practices. Pre-test training sessions are often used to let participants become familiar with the novel technology (32-36).

Practice and training before using electronic devices is advisable, as older adults can learn to use them and improve their performance. Another field to be explored in future studies is the comparison of individuals´ test scores in different contexts: does the performance of the assessed person change because of the presence or absence of the clinician? Does it get worst or better in independent and automatic evaluation compared to face to face assessments? Another direction to move forward is to increase the accessibility of the instruments by carrying out trials that assess their suitability for independent administration. Usability assessment is vitally important if tests are to be administered independently.

The assessment of usability can be performed through different methods. The ISO/IEC 9126-4 metrics recommends that usability assessments should comprise: effectiveness (the accuracy and completeness with which users achieve specified goals); efficiency (the resources expended in relation to the effectiveness); and user satisfaction (comfort and acceptability of use). There are specific usability assessment tools like the "Usefulness, satisfaction and ease of use questionnaire" (37); the Everyday Technology Use Questionnaire (38); the After Scenario Questionnaire (39); and the System Usability Scale (40). There is also a questionnaire that captures perceived usability and acceptance according to the technology acceptance model (41). In addition, there are also empirical ways in which usability can be measured through observation (e.g. difficulty to release the touchscreen after pressing it, number of times the users pressed the screen, number of times they requested help from the technician and why help was requested, etc.). Automated evaluation mechanisms should also be adopted to improve the empirical methods employed to assess usability (42).

Validity and reliability

A quality assessment evaluation should represent a required initial step before psychometric properties and validity evaluation, and it should be performed by someone independent of the developer of the instrument (11). The methodological quality of the instruments was good according to Schlegel and Gilliland checklist, but only four scored 100% of the items (10, 18, 21, 24), showing a potential for quality improvement, especially in the fields of usability and test functionality.

The validation of the instruments reviewed was carried out with healthy older adults as well as PWD and MCI as distinct groups. This is an asset to be highlighted as it has been reported that persons with cognitive impairment are likely to have decreased ability to manage everyday technology (43). People with dementia have greater impairment than people with MCI (44). The fact that researchers have validated their instruments for the three groups provides clinicians with the tools needed to make clinical decisions regarding the assessment of the different populations. Most of the instruments obtained acceptable values of specificity and sensitivity. Still, only seven studies provided cut-off points for cognitive impairment. It would be advisable for researchers to make an effort to provide cut-off points for their instruments, as they are essential for screening purposes.

In terms of concurrent validity, most of the instruments were validated against brief tests (MMSE) or individual tasks. This is an aspect to be improved in the validation of screening instruments, as brief batteries like MMSE have significant limitations for early detection of cognitive decline (45). Ecological validity of the assessments was not assessed in any of the instruments. Bardram (2006) raised awareness about the necessity to utilize technological assessments in a real world setting, outside the laboratory, and to carry out longitudinal studies which assess the evolution of the relationship between the end user and technology (46). The mean duration of administration varied across

instruments, but in general it remains as an added value of ICT based instruments as they achieve good levels of specificity and sensitivity with reasonably brief assessments. There is a need to develop longitudinal studies to analyze the reliability of early detection of cognitive impairment and inherent risk to develop dementia.

Test batteries vs. individual tasks

The existence of tests of specific domains like visuospatial function, which present good specificity and sensitivity for the detection of cognitive impairment opens the debate about the cost/benefits of performing full assessment batteries for screening purposes. On the other hand, many screening tools are weighted towards assessment of memory impairment; however deficits in other areas are crucial for differential diagnosis (47). In this regard, the next step should be the design of brief screening instruments that assess key markers for early detection. Indeed, some computer based batteries have been analyzed to see if specific subtests would have enough sensitivity to discriminate healthy older people from people with cognitive impairment. Automated speech recognition technology is a promising field (12); and research on brain-computer interfaces could offer in the near future an opportunity for the assessment, diagnosis and treatment of people with communication impairments (48).

Limitations

As pointed out elsewhere (7), some of these instruments are subject to proprietary issues like license fees which leave them out of reach for the general public, or copyright aspects which prevent researchers and clinicians from modifying them. Researchers, grant funders and the industry should strive to deliver open access instruments. Even though wide scale cognitive screening can reliably identify individuals with cognitive impairment, additional neuropsychological, clinical and biomarker data are necessary to

identify prodromal dementia (49). The instruments reviewed in this paper are not meant to replace neuropsychological assessment, and cannot carry out a dementia diagnosis on their own; they are instruments that allow the identification of those subjects that could be referred to specialized units.

Conclusions

As ICT develop, clinicians and health services fall behind in using technological advances for improving health care for older people. Electronic devices for dementia and cognitive impairment early detection and assessment are still in their infancy in terms of accessibility and usability. Innovative and comprehensive instruments with the capacity to be delivered in the community are still to be developed and the current existing gap between research and applied technological solutions integrated in the health care services and policies should be narrowed. All in all, we have all what is necessary to tackle the problem of early detection of cognitive impairment in older adults, now the challenge is to find the way to integrate the existing solutions in user friendly and accessible instruments.

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Table 1. ICT Instruments Descriptive Data: Electronic Devices (PC, Laptop, tablet, iPad, mobile phone)

Name	Author / Year	Technology	Input	Ty	n / diagnosis (mean age ± S.D.)	Ed	SR	T	Adm.	Domains	Usability	Understandability	Home	Lang.
cADAS	O´Halloran et al., 2011	CMINDS (Examiner & Patient station)	Voice, light pen, finger tapping	TB	88 AD	NR	Yes	44.2	SA with assistance	Verbal memory; language; orientation; ideational & constructional praxis	Perception Response Evaluation (PRE) module established whether a subject met perceptual & response requirements for taking various tests	_	No	Eng.
CADi	Onoda et al., 2013	Tablet (iPad)	Touchscreen	TB	35 H (70.7 ± 5.0), 50 PWD (75.9 ± 5.6)	Yes	Yes	10	SA (initiated by technician)	Immediate, delayed, semantic & working memory; executive function; spatial rotation; TMT A & B	_	Participants found it nonthreatening and enjoyable	No, P	Jap.
CAD-PAD	Alom et al., 2012	PC	Keyboard	DT	63 H (70.2 ± 6.9), 89 MCI (72.3 ± 7.3)	Yes	Yes	NR	Technician	Risk to convert to AD	_	_	No	Span.
CAMCI	Tierney et al., 2014	Tablet	Touchscreen	TB	263 Adults (≥65), 130 with cognitive concerns	Yes	Yes	30	SA (initiated by technician)	Attention; executive function; processing speed; verbal, nonverbal functional & incidental memory	Good. Assessed through coding of answers. Lack of computer experience decreased odds of completion	241/263 did not need assistance	No, P	Eng.
CANS-MCI	Memória et al., 2014	PC / Tablet	Touchscreen	TB	41 H (71.68 ± 4.62), 35 MCI (73.80 ± 5.50), 21 AD (76.14 ± 4.98)	Yes	Yes	30-50	SA (initiated by technician)	Memory; language/spatial fluency; executive function	_	Test instructions were automatically reinforced by program when pattern of errors suggested instructions were misunderstood		Eng. Span.
	Ahmed et al., 2012				20 H (77.4 ± 4.0), 15 MCI (80.9 ± 7.2)	Yes	Yes	30			_		No, P	Port. Dutch.
CANTAB-PAL	Junkkila et al., 2012	PC	Touchscreen	IT	22 H (70 ± 4.48), 17 MCI (73 ± 6,3), 17 probable AD (73 ± 6.76)	Yes	Yes	NR	SA with assistance	Visual paired associate learning	_	_	No	Eng.
CDR (COGDRAS-D)	Wesnes et al., 2010	laptop computer	2 button response box	TB	51 AD (76.5 ± 6.85)	NR	Yes	30	Technician	Attention / concentration; verbal & visuo-spatial recall & working memory; psychomotor & processing speed	_	_	No	Eng.
ClockMe System	Kim et al., 2012	Tablet PC	Touchscreen & stylus	IT	20 H	Yes	NR	NR	SA	Executive function; visual-spatial & constructional abilities	Good. Assessed through observation and comparison with P&P	_	No, P	Eng.
CogState	Hamers et al., 2011	PC / Laptop	2 keyboard keys or mouse	TB	23 H (68.4 ± 9.5), 20 MCI (73.5 ± 5.9), 52 AD (70.8 ± 8.7), 9 DLB (70.4 ± 8.5), 10 FTD (64.2 ± 8.1)	Yes	Yes	NR	Technician	Psychomotor processing speed; attention; working memory; new learning; divided attention; associative learning	Good acceptability, efficiency and stability	_	No	Eng.
	Fredrickson et al., 2010				263 H (64.6 ± 7)	NR	Yes	15				Good		
CogState Brief	Hamers et al., 2012	PC / Laptop	2 keyboard keys	TB	22 H (67.7 ± 9.1), 16 MCI (73.7 ± 6.3), 37 AD (72.0 ± 8.8), 5 DLB (73.0 ± 6.9), 7 FTD (61.6 ± 6.7)	Yes	Yes	NR	Technician	Processing speed; attention; working memory; learning	_	_	No	Eng.
CogVal-Senior	Solís et al., 2015	PC & Tablet	Touchscreen (mouse alternative)	TB	110 H (77.1 ± 8.7), 110 AD (82.4 ± 7.9)	Yes	Yes	10-15	SA (initiated by technician)	Orientation; learning capacity; verbal memory; calculation; executive function; perception	Good. Assessed by patient & clinician by questionnaire	Good, assessed with questionnaire	No, P	Span.
CRRST	Ramratan et al., 2012	PC	Microphone	IT	303 H (79.8 ± 5.2), 87 MCI (81.7 ± 5.5)	Yes	Yes	NR	SA with assistance	Verbal learning & memory	_	All participants completed the task	No	Eng.
C-TOC	Jacova et al., 2014	PC	Mouse	TB	16 H (68.1 ± 7.5), 16 MCI (64.3 ± 6.5), 6 PWD (66.3 ± 7.1), 11 Aphasics (61.4 ± 9.9)	Yes	Yes	NR	SA with assistance	Memory; processing speed; language; visuospatial & constructional abilities; executive functions	Good. Thoroughly assessed with PWD. Results were included in a 3-cycle user consultation design	Long written instructions not adequate	No, P	Eng.
DETECT	Wright et al., 2011	Ultra-mobile PC + noise-cancelling headphones	Head mounted display & Handheld input unit with 2 buttons	TB	172 H , 201 possible or probable MCI , 32 AD	Yes	Yes	07 - 10	SA (initiated by technician)	Complex attention; Selective Reminding Memory; Executive function; Working Memory; information processing speed	_	423/425 completed the test	No, P	Eng.
	Wright et al., 2010				20 H (85.1 ± 12.6), 20 MCI (82.3 ± 10.3)	Yes	Yes	NR			_	_		

Table 1. (Continued)

Name	Author / Year	Technology	Input	Ty	n / diagnosis (mean age ± S.D.)	Ed	SR	T	Adm.	Domains	Usability	Understandability	Home	Lang.
GrayMatters®	Brinkman et al., 2015	PC	Touchscreen	TB	157 H (72.2 ± 7.6), 78 Impaired (79.94 ± 8.3)	Yes	Yes	20	SA	Visual memory & executive function	_	_	No, P	Eng.
HGT	Laczó et al., 2011-2012	PC	mouse	IT	21 AD (75.9 ± 5.6), 10 HaMCI (77.3 ± 10.8), 32 Non HaMCI (72.7 ± 9.2)	Yes	NR	NR	NR	Spatial Navigation	_	_	No	Eng.
IVR	D´arcy et al., 2013	Telephone / computer	Voice recognition	TB	61 H (69.99 ± 5.98)	Yes	Yes	NR	SA, corrected manually	Declarative, working, short-term, long-term & semantic memory; mood	_	All completed assessment. Volume input regulation	Yes	Eng.
MCI Screen	Rafii et al., 2011	PC	Keyboard	IT	25 H (80.3 ± 8.6), 12 MCI (74.8 ± 9.0), 31 AD (76.4 ± 9.8)	Yes	Yes	10	SA with assistance	Memory; executive function; language	_	_	No	Eng.
MCS	Zorluoglu et al., 2015	Android Mobile Devices	Touchscreen	TB	9 H (81.78 ± 4.77), 14 PWD (72,55 ± 9,95)	Yes	Yes	NR	SA	Visual configuration; language; memory; attention; orientation; calculation; executive functions	_	_	No, P	Turk.
NCGG-FAT	Makizako et al., 2013	Tablet PC	Touchscreen & digital pen	TB	20 H (71.6 ± 4.6)	Yes	Yes	20-30	SA with assistance	Memory; attention; executive function; processing speed; visuospatial perception	_	_	No, P	Jap.
NIHTB-CB	Heaton et al., 2014	PC / Tablet	Keyboard & touchscreen	TB	268 H (108 65-85 years)	Yes	Yes	31	SA with assistance	Language; executive Function; episodic & working memory; processing speed. Composite scores: cognitive function; fluid cognition; crystallized cognition	_	_	No	Eng. Span.
NIHTB-PSMT	Dikmen et al., 2014	PC / Tablet	touchscreen	IT	268 H (108 65-85 years)	Yes	Yes	8.1	Technician	Episodic memory	_	_	No	Eng. Span.
PredictAD	Liu et al., 2013	PC	Keyboard	DT	233 MCI (75 ± 8), 158 AD (74 ± 7)	Yes	Yes	NR	Technician	Risk to convert to AD	_	_	No	Eng.
SCIT	Friedman et al., 2012	PC	two-button touchpad	IT	96 H (75.2)	Yes	Yes	NR	Technician	Visuospatial discrimination tasks	_	_	Yes	Eng.
SDRST	Satler et al., 2015	Tablet	Touchscreen	IT	64 H (70.45 ± 2.6), 22 AD (78.27 ± 6.7)	Yes	Yes	NR	SA (initiated by technician)	Visuospatial working memory	_	_	No, P	Eng.
TDAS	Inoue et al., 2011	14-inch touch screen & computer	Touchscreen	TB	34 AD (79.2)	NR	Yes	30	SA with assistance	Memory; visuospatial perception; language; praxis; orientation; executive function	_	Subjects could operate by themselves, program can´t respond flexibly according to condition	No	Jap.
TPST	Ishiwata et al., 2014	PC	touchscreen	TB	105 H, 56 MCI, 152 AD, 34 VD	NR	Yes	5	SA	Immediate & delayed verbal memory; orientation; spatial recognition	_	_	No, P	Jap.
TPT (2 pilot versions)	Vacante et al. 2013	PC (2 versions)	Mouse	IT	40 H, 20 MCI & 18 AD (76.5 ± 7.09)	Yes	Yes	20	NR	Visual associative memory	_	_	No	Eng.
VECP	Bayer et al., 2014	laptop PC	Single response pad button	IT	31 H (72.8 ± 5.0), 45 MCI (73.0 ± 6.3)	Yes	Yes	NR	SA with assistance	Visuospatial attention	_	Participants´ understanding was checked during testing.	No	Eng.
VPC	Lagun et al., 2011	PC & ASL Model 5000	Infrared eye tracker	B	30 H (70.9 ± 7.1), 10 MCI (72.2 ± 6.9; 20 AD (72.4 ± 10.0)	NR	Yes	25-30	Technician	Recognition memory	_	_	No	Eng.
VSM	Maki et al., 2010	PC	Touchscreen	IT	29 H (78.3 ± 5.3), 10 MCI (73.7 ± 10.3), 27 PWD (77.6 ± 9.3) & (81.9 ± 4.5)	NR	Yes	NR	NR	Visuo-spatial memory	_	_	No	Jap.

Notes: AD = Alzheimer Disease; **Adm.** = Administered by; **B** = Behavioural Measure; **cADAS** = Computerized ADAS-Cog; **CADi** = Cognitive Assessment for Dementia, iPad Version; **CAD-PAD** = Clinical Approach to Diagnosis of Pre-Dementia Alzheimer's disease; **CAMCI** = Computerized Assessment of MCI; **CANS-MCI** = Computer-Administered Neuropsychological Screen for Mild Cognitive Impairment; **CANTAB-PAL** = CANTAB Paired Associate Learning; **CDR** = Cognitive Drug Research Computerized Assessment; **CRRST** = Cued-Recall Retrieval Speed Test; **C-TOC** = Cognitive Testing on Computer; **Domains** = The cognitive domains were depicted as described by the authors; **DT** = Diagnostic Tool; **Ed** = Level of Education Reported (Yes/No); **FTD** = Frontotemporal Dementia; **H** = Healthy; **Ha** = Hippocampal; **HGT** = Hidden Goal Task; **IT** = Isolated Task; **Lang.** = Language; **LW** = Dementia with Lewy Bodies; **MCI** = Mild Cognitive Impairment; **MCS** = Mobile Cognitive Screening; **n** = sample size; **NCGG-FAT** = National Center for Geriatrics and Gerontology functional assessment tool; **NIHTB-CB** = NIH Toolbox Cognition Battery; **NR** = Not Reported; **P** = potentially able to be delivered at home; **PC** = Personal Computer; **PSMT** = Picture Sequence Memory Test; **PWD** = People With Dementia; **RAVLT** = Rey Auditory Verbal Learning Test; **SA** = Self-administered; **SCIT** = Subtle Cognitive Impairment Test; **S.D.** = Standard Deviation; **SDRST** = Spatial Delayed Recognition Span Task; **SR** = Scores Reported; **T** = Administration Time in minutes; **TB** = Test Battery; **TDAS** = Touch Panel-type Dementia Assessment Scale; **TPST** = Touch-Panel Computer Assisted Screening Tool; **TPT** = The Placing Test; **Ty** = Type of Intervention; **VD** = Vascular Dementia; **VECP** = Visual Exogenous Cuing Paradigm; **VPC** = Visual Paired Comparison; **VSM** = Visuo-spatial memory test.

Table 2. ICT Instruments Psychometric Data: Electronic Devices (PC, Laptop, tablet, iPad, mobile phone)

Name	Author / Year	Concurrent Validity	Discriminant Validity	Reliability	Test - Retest Reliability	Factor Analysis	Cutoff
cADAS	O´Halloran et al., 2011	Excellent intraclass correlation coefficient with p&p ADAS-cog for total score (0.96) & subscores (ranged 0.78 - 0.93)	–	–	Short term mean ICC = 0.96, long term mean ICC = 0.91). Higher than p&p ADAS-cog.	–	–
CADi	Onoda et al., 2013	Good correlation with MMSE (r = 0.74)	96% sensitivity & 77% specificity in discriminating HC from AD	Acceptable Cronbach's alpha (over 0.7)	Significant correlation (1 year), (r = 0.47, P < 0.001, weighted CADi: r = 0.55, P < 0.001)	–	7/8
CAD-PAD	Alom et al., 2012	-	100% sensitivity & 93.2% specificity identifying pre AD patients	–	–	–	–
CAMCI	Tierney et al., 2014	-	Sensitivity 80% specificity 74%	–	–	–	≤40
CANS-MCI	Memória et al., 2014	Moderate correlation with MoCA (r = 0.76, p < 0.001)	81% sensitivity & 73% specificity for MCI	High internal consistency (Cronbach's α = 0.77)	3 months: significant & robust (0.875; p < 0.001)	Memory, language, and executive function	–
	Ahmed et al., 2012	-	Compared HC & MCI, able to discriminate	–	alpha = 0.74 (previous study)		–
CANTAB-PAL	Junkkila et al., 2012	-	p < 0.0001, 81.0% of the cases correctly classified. Higher discriminatory power in differentiating between H, aMCI and	–	–	–	Yes
CDR (COGDRAS-D)	Wesnes et al., 2010	Correlations with MMSE (0.47 to 0.7), ADAS-Cog (0.25 to 0.7), Ab42 (-0.4 to	Sensitivity to change after 6 months	–	High (previous study)	Well established (previous study)	–
ClockMe System	Kim et al., 2012	–	–	–	–	–	–
CogState	Hamers et al., 2011	–	Sensitive to cognitive impairment in dementia. Able to distinguish between H	–	Good in short periods	–	–
	Fredrickson et al., 2010	–	–	–	Strong reliability correlations	–	–
CogState Brief	Hamers et al., 2012	Range of modest correlations with p&p	Effective in distinguishing MCI from controls but not identifying specific	–	–	–	–
CogVal-Senior	Solís et al., 2015	Good correlation with MMSE (r=0.722; p<.00)	94% sensitivity & 85% specificity in discriminating HC from PWD	Acceptable Cronbach's alpha (over 0.84)	Good intraclass coefficient	–	≤54
CRRST	Ramratan et al., 2012	Correlations with P&P ranging from 0.36 to 0.41 with p-values < 0.0001	Able to distinguish between MCI & H	–	–	–	–
C-TOC	Jacova et al., 2014	Correlated with NPT (r=0.4 to 0.7)	Compared HC & impaired, able to discriminate	–	–	–	–
DETECT	Wright et al., 2011	Good correlation with NPT	Able to differentiate HC, PWD & MCI	–	–	–	–
	Wright et al., 2010		Able to differentiate HC & MCI	–	–	–	–

(Continues)

Table 2. (Continued)

Name	Author / Year	Concurrent Validity	Discriminant Validity	Reliability	Test - Retest Reliability	Factor Analysis	Cutoff
GrayMatters®	Brinkman et al., 2015	Good correlation with P&P	Compared HC & impaired, able to discriminate	–	Good for Visual Delayed Recognition / low for Delayed Alternation Task	–	–
HGT	Laczó et al., 2011-2012	Strong correlation with real space version	Specificity 88% - sensitivity 85% to detect dementia. Able to discriminate AD, HaMCI & Non HaMCI	–	–	–	–
IVR	D´arcy et al., 2013	Correlation with face to face assessment: 0.51 to 0.87	–	Significant interclass correlations	–	–	–
MCI Screen	Rafii et al., 2011	Statistically significant correlations with several neuropsychological measures (r = -0.413 to 0.737)	92% sensitivity & 72% specificity. Significantly discriminated among aMCI, AD, & HC	–	–	–	–
MCS	Zorluoglu et al., 2015	Correlation coefficient r^2= 0.57 (p < 0.01) (MOCA)	Able to differentiate between HC & PWD (p < 0.05)	–	–	–	–
NCGG-FAT	Makizako et al., 2013	moderate to high correlation with conventional cognitive tests (r = 0.496 to 0.842)	–	–	Acceptable (intraclass correlation	–	–
NIHTB-CB	Heaton et al., 2014	Strong vs. gold standard Crystallized (r = .90), Fluid (r = .78), and Total Cognition (r = .89) Composite scores	Low correlations vs. unrelated gold standards (r: 0.19–0.39). Vs. expected age effects (r = 0.18 crystallized, r = –0.68 fluid, r = – 0.26 total)	Internal consistency: (Cronbach's alphas = 0.84 Crystallized, 0.83 Fluid, 0.77 Total)	excellent (r: 0.86–0.92)	2 first order Factors (crystallised and Fluid). 5-6 second order factors.	–
NIHTB-PSMT	Dikmen et al., 2014	Good correlation with RAVLT & BVMT-R (r = 0.64 to 0.72)	No significant correlation with PPVT	–	Excellent (ICC = 0.77)	–	–
PredictAD	Liu et al., 2013	Strong correlation of predictAD alone & the clinician with assistance of PredictAD	Sensitivity 73%, specificity 71% in predicting AD	kappa= 0.800, p<0.001 & 0.850, p<0.001	–	–	–
SCIT	Friedman et al., 2012	Significant correlation with MMSE (r(94) = −0.24, p < 0.05)	Able to differentiate according to performance in MMSE.	–	–	–	–
SDRST	Satler et al., 2015	–	Able to distinguish between AD & HA	–	–	–	–
TDAS	Inoue et al., 2011	Significant correlation with ADAS-cog (r = 0.69, P < 0.01)	–	–	–	–	–
TPST	Ishiwata et al., 2014	Good correlation with MMSE	Sensitivity 96% & specificity 97% in dementia detection	–	–	–	12
TPT (2 pilot versions)	Vacante et al. 2013	Good correlation with P&P (r = .770, p < .001)	Able to differentiate H, MCI & AD. Sensitivity & specificity provided	–	–	–	Yes
VECP	Bayer et al., 2014	–	Able to distinguish between MCI who did & did not develop dementia along a 2.5 longitudinal study	–	–	–	–
VPC	Lagun et al., 2011	–	97% sensitivity & 77% specificity discriminating HC from MCI	–	–	–	–
VSM	Maki et al., 2010	Moderate correlation with HDS-R	Able to discriminate HC from MCI & AD. sensitivity 93%, specificity 85%	–	good correlation (1 week, r = 0.76)	–	5.5

Notes: Abbreviations of instrument names can be seen in Table 1. **ADAS-cog =** Alzheimer´s Disease Assessment Scale Cognitive Subscale; **BVMT-R =** Brief Visuospatial Memory Test-Revised; **CVLT =** California Verbal Learning Test; **DRS =** Dementia Rating Scale; **HC =** Healthy Controls; **HDS-R =** Hasegawa Dementia Scale-revised; **ICC =** Intraclass Correlation Coefficient; **MCI =** Mild Cognitive Impairment; **MMSE =** Mini Mental State Examination; **NPT =** Neuropsychological Tests; **P&P =** Paper and Pencil; **PC =** Personal Computer; **PPVT =** Peabody Picture Vocabulary Test; **PWD =** People With Dementia; **RAVLT =** Rey Auditory Verbal Learning Test; **WCST =** Wisconsin Card Sorting Test; **WMS-R =** Wechsler Memory Scale Revised

Table 3. Methodological quality of included studies (Schlegel and Gilliland, 2007)

Instrument	Author / Year	1. Module information - version control	2. Initial title screen	3. User instructions	4. Experimenter instructions	5. Help screens/menus	6. Supporting modules	7. PC software	8. Display configuration	9. Stimulus generation	10. Test-specific parameters	11. Warm-up trials	12. Trials/feedback	13. Event timing	14. Abort handling	15. Response configuration	16. Event recording	17. Data accuracy	18. Data file specification	19. Interface usability/documentation	20. Occasional anomalous behavior	Total (20)	%
		MODULE INFORMATION - VERSION CONTROL							TEST FUNCTIONALITY							DATA RECORDING				OTHER			
cADAS	O´Halloran et al., 2011	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	NR	19	95
CADi	Onoda et al., 2013	1	1	1	1	1	1	1	1	1	0.5	1	1	1	0	1	1	1	1	NR	NR	16.5	83
CAD-PAD	Alom et al., 2012	1	0	0	0	1	0	0	0	NA	0	NA	NA	NA	0	0	0	0	0	0	NA	2	10
CAMCI	Tierney et al., 2014	1	1	1	1	1	1	1	0	1	1	0	1	1	0	0.5	1	1	1	0.5	1,0	16	80
CANS-MCI	Memória et al., 2014 Ahmed et al., 2012	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	NR	16	80
CANTAB-PAL	Junkkila et al., 2012	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	18	90
CDR (COGDRAS-D)	Wesnes et al., 2010	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	18	90
ClockMe System	Kim et al., 2012	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100
CogState	Hamers et al., 2011 Fredrickson et al., 2010	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100
CogState Brief	Hamers et al., 2012	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	19	95
CogVal-Senior	Solís et al., 2015	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100
CRRST	Ramratan et al., 2012	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	NR	17	85
C-TOC	Jacova et al., 2014	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	100
DETECT	Wright et al., 2011 Wright et al., 2010	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	NR	16	80
GrayMatters®	Brinkman et al., 2015	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	NR	16	80
HGT	Laczó et al., 2011-2012	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	NR	16	80
IVR	D´arcy et al., 2013	1	NA	1	1	NA	NA	1	NA	1	1	0	0	NR	0	0	0	0	1	0	1	8	40
MCI Screen	Rafii et al., 2011	1	NA	NA	1	NA	NR	1	NR	NR	NR	0	1	NA	0	0	0	0	0	0	0	4	20
MCS	Zorluoglu et al., 2015	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	16	80
NCGG-FAT	Makizako et al., 2013	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	16	80
NIHTB-CB	Heaton et al., 2014	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	16	80
NIHTB-PSMT	Dikmen et al., 2014	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	17	85
PredictAD	Liu et al., 2013	1	0	0	0	1	0	0	0	NA	0	NA	NA	NA	0	0	0	0	0	0	NA	2	10
SCIT	Friedman et al., 2012	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	17	85
SDRST	Satler et al., 2015	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	16	80
TDAS	Inoue et al., 2011	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	16	80
TPST	Ishiwata et al., 2014	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	16	80
TPT	Vacante et al. 2013	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	16	80
VECP	Bayer et al., 2014	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	0	0	15	75
VPC	Lagun et al., 2011	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	0	0	16	80
VSM	Maki et al., 2010	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	17	85
Total		31	27	28	29	29	27	29	26	28	27.5	12	25	27	9	26.5	27	27	28	5.5	9	478	77
%		92							71							88				24			

Notes: **NA** = Not applicable; **NR** = Not reported.

Figure 1. Flowchart of study selection

```
┌─────────────────────────────────────────────────────┐
│ 13893 records identified through database searching   │
└─────────────────────────────────────────────────────┘
        │
┌─────────────────────────────────────────────┐
│ 3891 records after duplicates removed         │
└─────────────────────────────────────────────┘
        │
┌─────────────────────────────────────────────┐
│ 1785 records published 2010-2015 screened     │
└─────────────────────────────────────────────┘
        │
        │      ┌──────────────────────────────────────────┐
        │─────▶│ 1696 records excluded on Title/Abstract    │
        │      └──────────────────────────────────────────┘
        │
        │      ┌──────────────────────────────────────────┐
        │◀─────│ 17 records included based on hand search    │
        │      └──────────────────────────────────────────┘
        │
┌─────────────────────────────────────────────┐
│ 106 full text articles assessed for eligibility │
└─────────────────────────────────────────────┘
```

36 articles excluded with reason:
- Reviews (13)
- Descriptive, editorials (10)
- Critiques (2)
- Younger adults (6)
- No normative data (age) (3)
- Other language (1)
- Feasibility study (1)

70 articles selected

- Electronic devices (34)
- Internet / online (13)
- Monitoring devices (18)
- Virtual Reality (5)

34 articles included in this systematic literature review

- Electronic devices
  - Articles (n=34)
  - Instruments (n=31)