Journal of Alzheimer's Disease xx (2022) x–xx
DOI 10.3233/JAD-220547
IOS Press

Systematic Review

Touchscreen Cognitive Tools for Mild Cognitive Impairment and Dementia Used in Primary Care Across Diverse Cultural and Literacy Populations: A Systematic Review

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Accepted 14 September 2022
Pre-press 14 October 2022

Abstract.
Background: Touchscreen cognitive tools opened new promising opportunities for the early detection of cognitive impairment; however, most research studies are conducted in English-speaking populations and high-income countries, with a gap in knowledge about their use in populations with cultural, linguistic, and educational diversity.
Objective: To review the touchscreen tools used in primary care settings for the cognitive assessment of mild cognitive impairment (MCI) and dementia, with a focus on populations of different cultures, languages, and literacy.
Methods: This systematic review was conducted following the PRISMA guidelines. Studies were identified by searching across MEDLINE, EMBASE, EBSCO, OVID, SCOPUS, SCIELO, LILACS, and by cross-referencing. All studies that provide a first-level cognitive assessment for MCI and dementia with any touchscreen tools suitable to be used in the context of primary care were included.
Results: Forty-two studies reporting on 30 tools and batteries were identified. Substantial differences among the tools emerged, in terms of theoretical framework, clinical validity, and features related to the application in clinical practice. A small proportion of the tools are available in multiple languages. Only 7 out of the 30 tools have a multiple languages validation. Only two tools are validated in low-educated samples, e.g., IDEA and mSTS-MCI.
Conclusion: General practitioners can benefit from touchscreen cognitive tools. However, easy requirements of the device, low dependence on the examiner, fast administration, and adaptation to different cultures and languages are some of the main features that we need to take into consideration when implementing touchscreen cognitive tools in the culture and language of underrepresented populations.

Keywords: Alzheimer's disease, dementia, detection, digital neuropsychological assessment, general practitioners, mild cognitive impairment

INTRODUCTION

Fighting against dementia in high and low and middle-income countries has become a top priority with an urgent need for innovative actions in pre-

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ISSN 1387-2877/$35.00

vention and care [1]. Cognitive impairment in older populations represents a major problem for families, caregivers, and healthcare institutions. In low and middle-income countries, the incidence of dementia is increasing possibly because of the aging population and the lack of actions to contain this epidemic. An under-detection rate of 61.70% worldwide has been registered as one key aspect that prevents the detection of new cases [2–4]. Early detection of mild cognitive impairment (MCI) and dementia relates to health, social, and economic outcomes. First, this allows for better medical management, from the early treatment of reversible causes to the management of comorbidities, and the involvement of patients in clinical trials for disease-modifying therapies on the horizon [5]. Second, early involvement of the caregivers of the people with dementia enhances patients' well-being and quality of care [6]. Third, the socioeconomic management of full-blown disease, since the identification of the early stages, may reduce the years of disability and may decrease healthcare's economic efforts for assistance [7].

Primary care is the ideal setting for the first-level cognitive evaluation, thanks to the continuous patient-provider relationship, the medical preferential point of view for the patient's history, and the consequent confidence to talk about cognitive difficulties [8]. Primary care providers include general practitioners (GPs), family physicians, geriatricians, nurse practitioners, and physicians' assistants working in private practice or public assistance [9]. GPs highly appreciate the early recognition of MCI and dementia [10]. A survey conducted in the USA revealed that although 94% of primary care physicians recognize the importance of periodic cognitive assessment for frail seniors, only 16% of them regularly received it during routine check-ups despite much greater monitoring of other clinical conditions, e.g., blood pressure (91%), cholesterol level (83%), hearing or vision loss (73%), or diabetes (66%) [11].

Traditional paper-and-pencil tests for GPs have been employed for periodic cognitive screening and include Montreal Cognitive Assessment (MoCA) [12], Mini-Mental State Examination (MMSE) [13], and the Mini-Cog [14]. These tests have better psychometric properties to detect dementia than MCI from normal cognition, and their use in primary care is limited [15]. GPs usually have a short time for visits and unsuitable offices (due to telephone and patient traffic), and the detection of MCI is also complicated by the lack of specific training for neuropsychological assessment in administering and interpreting cognitive tests [16]. Moreover, recently, a serious limitation stemmed from the social distancing needed to prevent the transmission of COVID-19, which is particularly aggressive for frail older persons [17] and prevents face-to-face paper-and-pencil assessment.

Technology-based cognitive detection (including tablet applications) could reduce time and physician involvement for administration and scoring [18]. Moreover, it may overcome limitations concerning the low availability of alternative forms to test and re-test individuals in a short period, the manual and time-consuming scoring, the potential bias related to different examiners, and the impossibility of recording response-times in executive/attention tasks [19]. Touchscreen devices were found to be independent of the experience of use, more intuitive and direct, as well as more manageable, compared to laptops or desktop personal computers (PCs) in adults over 55 years old evaluated in a clinical setting [20, 21]. Although digital cognitive measures opened new promising opportunities for the early detection of cognitive impairment in the English-speaking population and high-income countries [22], nowadays, there is a gap in knowledge about their clinical availability and use in populations with cultural, linguistic, and educational diversity. To be implemented in diverse populations, digital tools need to be adapted to multiple languages and clinically validated. Linguistic and cultural differences, in fact, introduce possible biases in the neuropsychological assessment among non-English speakers with low literacy.

Thus, we aimed to systematically review the cognitive touchscreen tools used in primary care settings for the early detection of MCI and dementia, describing their features (their relative strengths and weaknesses) and reporting their clinical accuracy. We particularly provided advancements about how digital cognitive assessment is currently implemented in the primary care setting of diverse cultural and literacy-underrepresented populations. With respect to previous reviews, the present study enriches the recent literature on digital screening tools for MCI and dementia, providing information on 1) both English and non-English cognitive tools, evaluating their current clinical use in diverse populations; 2) applications and software for any touchscreen device (i.e., tablet, smartphone, touchscreen monitor, iPad, etc.); 3) both self-administered and examiner-dependent cognitive tools. We finally delineated requirements and lines of development of clinical research to extend and improve the use of MCI and dementia touchscreen cognitive tools in primary care

settings, particularly in populations that are low-educated and living in countries where there are limited infrastructures for diagnostic care.

METHODS

Information sources and search strategy

The protocol of this systematic review was not registered, but it was structured in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [23]. An extensive literature search was conducted in MEDLINE using Pubmed, EMBASE using Web of Science, EBSCO using Cinhal, OVID using PsychINFO, Scopus, Latin American and Caribbean Health Literature (Lilacs), and Scientific Electronic Library online (Scielo). The search was concluded on July 12, 2022 without time restrictions. Two of the authors (FG, PB) independently conducted the literature search using the following keywords: ("cognitive decline" OR dementia OR Alzheimer OR AD OR MCI OR "mild cognitive impairment" OR geriatric OR neurocognit* OR "Lewy bodies" OR "Lewy body" OR "vascular cognitive impairment" OR FTD OR "Parkinson's Disease Dementia" OR "frontotemporal dementia" OR "frontal lobe dementia" OR "fronto-temporal dementia" OR FTD) AND (screen* OR "screening test" OR "screening tool" OR "screening instrument" OR "case finding") AND (apps OR "mobile app*" OR touchscreen OR technology OR tele) AND ("primary care" OR "general practi*" OR gp OR practitioner OR physician OR "family doctor"). No filter was used in the databases. To increase the likelihood that all the potentially relevant studies were identified, the two authors included further papers by a manual search, starting from the lists of references of previously retrieved papers or consulting reference lists included in previous reviews [16, 18, 22, 24–26]. We also used Google Scholar to search for any articles that were not previously retrieved. The search strategy structure specified the population of interest and the presence of the touchscreen tool as described in the "eligibility criteria". The search strategy based on the PICOS approach applied the following five concepts: 1) Patient, defined as older persons with MCI or dementia, or healthy controls; 2) Intervention, intended as the cognitive measures used; 3) Comparison, defined as the clinical diagnosis of dementia; 4) Outcome, defined as the predicted outcome, which was, for example, "diagnosis of Alzheimer's type dementia", and 5) Type of the study, which should be "cross-sectional" or "nested case-control studies".

Eligibility criteria

We included empirical studies that: 1) provide a first-level cognitive assessment with any touchscreen tools suitable to be used in the context of primary care; 2) reported psychometric measures of the tool, focusing either on the standardization (i.e., normative studies on healthy controls) or clinical validity (i.e., convergent and divergent validity) and/or their diagnostic accuracy (i.e., Area Under the Curve or AUC, sensitivity and specificity) with a clinical sample of people with MCI or dementia, and a control sample of older persons (age >50 years); 3) for clinical samples, included subjects who received a clinical diagnosis of MCI according to Petersen's criteria [27] and subsequent modifications [28, 29], or subjects with a clinical diagnosis of Alzheimer's disease (AD) according to McKhann's criteria or subsequent versions [30], or Lewy body dementia (LBD) [31] or subsequent versions, or vascular dementia (VaD) [32] or subsequent versions, or frontotemporal dementia (FTD) [33] or subsequent versions; 4) developed tools in any language.

We excluded studies in which: the clinical sample was not composed exclusively of MCI, AD, LBD, VaD, or FTD patients but included also patients suffering from psychiatric (e.g., schizophrenia) or other neurological diseases (e.g., multiple sclerosis, ictus, Parkinson's disease); the average age of the healthy controls was <50 years old; the tool used was not administered using a touchscreen monitor, tablet, iPad, or smartphone; the tool was not developed for use in the primary care setting and was used for other steps of the diagnostic process; computerized instruments that required a dedicated hardware platform (e.g., virtual reality, hardware kiosks, etc.) were used due to potential barriers of implementing these modalities in the primary care setting. Case reports/case series, reviews/meta-analyses, abstracts, research protocols, qualitative studies, and opinion papers were excluded.

Selection process and data collection

Screening and eligibility stages of records derived from database searches were performed using the website Rayyan (https://rayyan.qcri.org/welcome). The software detected replicated papers that were controlled and eliminated by the first author (FG),

who also screened titles and abstracts of all retrieved articles. Two authors (FG, PB) consulted reference lists of previous reviews independently. A consensus on which papers to screen the full text was reached by discussion. Next, the two authors independently screened full-text articles for inclusion. In case of a disagreement, a consensus was reached by discussion and if necessary, the third researcher (PA) was consulted. Two authors (FG, PB) performed data collection independently, consulting a third researcher (PA) in case of a disagreement. No automation tool was used to collect data. The first item we sought was the assessment tool used in the study. Next, we searched for its structural features, such as administrator, duration, tasks, cognitive domains assessed, and language. We sought items about: the diagnostic criteria; the reference test; the sample considered in the study, such as sample size, age (average and standard deviation), years of education, the prevalence of MCI and dementia; and, finally, the psychometric features of the screening tool: cut-off point and Area Under Curve (AUC), sensitivity and specificity in the detection of MCI and dementia, and, if available, the comparison with the reference test used in the study. A brief e-mail survey was also sent out to test developers to collect additional information about cultures, languages, theoretical framework, features related to the application of the touchscreen cognitive tools in primary care, commercial availability, and any cost associated with the use of the tools. The primary outcomes and extracted data have been summarized as follows: 1) theoretical framework of the tools; 2) features of the tools related to the application in the clinical setting (such as language, administration, duration, device, feasibility); and 3) a qualitative synthesis of the clinical validation for the detection of MCI and dementia. Data were also provided with several tables.

Quality assessment and risk of bias

Two reviewers (FG, PB) assessed the papers for risk of bias (RoB) independently. Disagreements were solved by discussion, involving the third reviewer (PA) if necessary. The quality of the studies was assessed using the RoB tool developed by Tsoy et al. [22]. We examined the following data: cognitive domains assessed; validation sample (for clinical and normative studies); reliability assessment; clinical validity and diagnostic accuracy; level of examiner involvement during the administration; availability for clinical use; availability of different languages; availability of feasibility studies; data security; and delivery of test results. For the scope of this review, we adapted and added the workup bias and the expectation bias items (Supplementary Table 1). Specifically, we assessed the risk of workup bias by checking whether all subjects evaluated using the cognitive tool also underwent the entire diagnostic process, while the presence of expectation bias was assessed by verifying the use of blind evaluators. Table 1 shows the final list of items included in the RoB tool. A total score from 1.00 to 3.00 can be achieved. We assigned three levels of quality: low quality (range: 1.00–1.67), moderate (range: 1.68–2.34), and high (range: 2.35–3.00).

RESULTS

A total of 2,319 records were identified by search on databases and previous review citations, which resulted in 1,975 records after the removal of duplicates. The Google Scholar search did not yield additional articles that were not previously retrieved from the other databases. After screening the titles and abstracts, 87 papers were selected for full-text examination and 42 studies satisfied the inclusion criteria. The PRISMA flowchart is reported in Fig. 1. Thirty different neuropsychological tools have been identified. The tools and the respective studies included in this review are shown in Table 2. Nineteen out of 30 tool developers responded to the web-mail survey (a response rate of 63.3%) and therefore their responses were considered in the results.

Theoretical framework

Almost all tools (90%) explore multiple cognitive domains. Most tools (37%) assess more than 4 domains. The domain most evaluated is memory (23 tools), followed by executive functions (16 tools), visuospatial skills and attention (14 tools), language (9 tools), temporal orientation (8 tools), processing speed (5 tools), working memory (4 tools), and other domains (such as learning, problem-solving, abstraction, and calculation). Only one tool (IDEA) also assesses praxis. Exceptions are represented by e-CT, which evaluates only executive functions; eHAST, which provides a single Global Functioning Score based on a culturally oriented task for the Greek population; CognICA, which assesses only Information Processing Speed; and TBDT, which measures time completion of a drawing task, considered sufficient to discriminate MCI and dementia

Table 1
Cultures, languages, theoretical framework, and features related to the application of the touchscreen cognitive tools in primary care

Tool	Reference	Administrator	Duration	Language	Country	Tasks	Domains assessed	Hardware	Website link
Brain-Check	[59, 60]	Self-administered remotely	18.2'–35.4'	USA-English USA-Spanish	USA	Immediate and delayed recognition Digit Symbol substitution Flanker Stroop TMT-A TMT-B	Memory Executive function Visuospatial skills Attention	iPad, iPhone	braincheck.com
CADi2	[61]	Non-specialized workers	<5'	Japanese	Japan	Immediate recognition Remember the end of World War II Digit backwards Orientation (month) Orientation (day of week) Calculation Cube rotation Sequence making A Sequence making B Delayed recognition	Immediate recognition Memory Working memory Temporal orientation Executive functions Visuospatial skills Delayed recognition	iPad and iPhone	apps.apple.com/it/app/cadi2
CAMCI	[46, 62]	Self	20'	Canadian-English	Canada	Star task Forward Digit Span Word Recognition Word Recall Picture Recognition Go/NO-Go Test Digit Reverse Span Others virtual reality tasks (new)	Attention Verbal memory Visual memory Executive function Working memory	Android Tablet	pstnet.com/products/camci-research
CANS-MCI	[45, 63, 64]	Self	Short: 16'–18' Long: 25'–35'	USA English USA Spanish Argentina Spanish UK English Canada English Canada French Brazilian Portuguese	USA UK Brazil Argentina Canada	General reaction time, Design matching, Word-to-picture Matching, Clock Stroop Free & Guided recognition Picture naming	Executive functions Memory Language fluency	Any touchscreen tablet with 10 inc or 19 inc of diagonal surface.	screen-inc.com

(*Continued*)

Table 1
(*Continued*)

Tool	Reference	Administrator	Duration	Language	Country	Tasks	Domains assessed	Hardware	Website link
Cantab Mobile	[65]	Self	10'	Non-verbal test	UK	Paired associates learning (new)	Visual associative learning and memory	iPad	www.cambridgecognition.com/products/digital-healthcare-technology/cantab-mobile
CCS	[66]	Self	<5'	UK-English	Ireland	Matching pairs of symbols (new) Memory task (new) Matching objects (new)	Attention Memory Visuospatial skills	Android Tablet	
CogCheck	[67]	Self	21.7' ± 2.2'	German	Switzerland	Temporal orientation Visual recognition Picture learning and recognition Digit span Spatial span Reaction time Attention TMT A B	Visuospatial Executive functions Memory and learning Orientation	iPad Air tablet computer with 9.7-inch dis- play using iOS 10.2 or 10.3	http://links.lww.com/JNA/A58
CognICA	[68]	Self	5'	Independent of language	UK USA Iran UAE	Visual categorization task with backward masking (new)	Information processing speed	iPad (Android tablet version will be soon available)	cognetivity.com/cognica
CogState BB	[69]	Self	10'–15'	USA-English	USA	Detection (new) Identification (new) One Card Learning (new) One Back (new) Groton Maze Learning Test (new)	Psychomotor speed Visual attention Learning and attention Working memory Spatial working memory	iPad/computer	www.cogstate.com/clinical-trials/computerized-cognitive-assessment
e-CT	[70]	Psychologist or trained staff (physicians or nurse)	2'	French (culture free)	France	Cancellation test	Executive functions	Android Tablet	
EC-Screen	[71]	Self or non-specialized workers or family member	4.5'	Chinese	Hong Kong China	Clock-setting test Story test 5-word delayed recognition test	Executive functions Visuospatial abilities Mental flexibility Memory	Tablet (IOS or Android)	

eHAST	[72]	Self or non-specialized workers or family member	NA	Greek	Greece	Cultural oriented task	Global cognitive function	Android Tablet 10.1" screen	
eSAGE - BrainTest®	[44]	Self	17.5'	USA-English	USA	Date Picture naming Verbal fluency modified Trails B Problem Solving task Determining similarities Word problem calculation Copying 3D constructions	Temporal orientation Language Memory Executive function Problem solving Abstraction Calculations Visuospatial abilities	Any tablet or touchscreen computer	
FACEmemory®	[73, 74]	Self with supervision of non-specialized workers	30'	Spanish English Catalan	Spain	Short-term memory Face recognition	Short-term memory Long-term memory	Android Tablet	facememory.fundacioace.com
GrayMatters ®	[75]	Self	20'	USA-English	USA	VDR (new) DAT	Visual Memory Problem solving	Desktop computer using 15.1" touch-screen monitors	
HK-VMT	[76]	Self	15'	Chinese	Hong Kong China	16-word list learning (new) Attention test (new) Delayed matching test (new)	Episodic memory Attention Visuospatial skills	Touch screen laptop	www.polyu.edu.hk/proj/hkvmt
IDEA	[77]	Non-specialized workers	19.2'	English Kiswahili	UK Tanzania	Naming Abstract thinking Spatial and temporal orientation Language fluency and comprehension Short-term memory Long-term memory Praxis	Naming, language, abstract thinking Orientation Memory and praxis	Android Tablet	www.ideastudy.org/idea-dementia-screening-tools
InbrainCST	[78]	Non-specialized workers	30'	Korean	Republic of Korea	Visual Span Test Difficult Naming Test Semantic/phonemic fluency Block design test Word Place Association Test TMT	Attention Language Visuospatial Memory Executive functions	Tablet	

(*Continued*)

Table 1
(*Continued*)

Tool	Reference	Administrator	Duration	Language	Country	Tasks	Domains assessed	Hardware	Website link
MCS	[79]	General practitioners and psychologists	30'–50'	Turkish	Turkey	TMT Clock Drawing, Attention, Visual Test, Shape Similarity, Arithmetic Test, Proverb, Naming, Numbers, Colorful shapes, Market test, date test, story recall	Arithmetic Orientation Abstraction Attention Memory Language Visual Executive function	Android Tablet Samsung 12 Inch	
Mindmore	[80]	self	45'	Swedish	Sweden	TMT-A, Symbol Digit Modalities Test, Simple RT test Rey 15-words, CERAD Word Fluency Test Cube Drawing Test TMT-B, PASAT, Stroop test, Tower of Hanoi	Attention and processing speed Memory Language Visuospatial functions Executive functions	Touch screen tablet of 12.3 inches	www.mindmore.com
Minnemera	[81]	Self	45'	Swedish	Sweden	MMSE, PASAT, TMT-A, TMT-B, RAVLT, Corsi Block tapping task, Victoria Stroop Test, Boston Naming Test	Attention Processing speed Learning and memory Executive functions Language	Touch screen tablet (10.1″ Windows)	thehub.io/startups/minnemera
mSTS-MCI	[43, 51]	NA	15'	Korean English	Republic of Korea	8 items 1 item (reaction times) 4 items	Memory Attention Executive function	Tablet	
NCGG-FAT	[82–84]	Non-specialized workers	20'–30'	Japanese	Japan	Word list memory TMT-A TMT-B Digit Symbol Substitution Test	Memory Attention Executive function Processing speed	iPad	www.ncgg.go.jp/hospital/kenshu/kenshu/27-4.html
RGA-RCS	[34]	Non-specialized workers	<5'	USA-English Chinese	USA Singapore	5-items recall Clock drawing Story recall	Memory Executive function Visuospatial skills	iPad and iPhone	apps.apple.com/us/app/rga-clinic/id1557596095
SATURN	[24]	Self	17.9'	USA-English	USA	Selective attention Words recognition Time orientation SLUMS Pintner's picture completion task Color-word Stroop	Attention Memory Orientation Calculation Visuospatial skills Executive function	Tablets running Windows 10 (a web version with Zoom is also available)	

TabCAT-BHA	[44, 85–88]	Non-specialized workers	10’	USA-English, Central-American Spanish, Cuban Spanish, USA-Spanish, Greek	USA Cuba Greece	Favorites (new) Match (new) Line orientation (new) Animal fluency	Memory Executive function and processing speed Visuospatial skills Language	iPads 9.7in and above, running iPadOS 13 or higher.	memory.ucsf.edu/tabcat
TBDT	[89]	Non-specialized workers	<5’	German	Germany	Visuospatial construction task	Visuospatial	Windows Surface Pro 4 digitizer with a handheld stylus pen	
TorCA	[90]	Any health care professional or trained assistant	30’–40’	Canada-English	Canada	Orientation CERAD word list CERAD delayed recall Benson Figure Clock Drawing Serial 7s 3s Digit Span Trails A B Alternating sequences Similarities Verbal Fluency MINT naming Repetition Single word Semantic Knowledge	Orientation Immediate memory Delayed recall Delayed recognition Visuospatial Executive functions Language	iPad	https://tdra.utoronto.ca/browse-tdra-tools#torca
TPST	[91]	Self	<5’	Japanese	Japan	3 words memory Temporal orientation 3D visual-spatial perception Delayed recall	Immediate and delayed recall Temporal orientation Spatial recognition	14-inch touch panel display MSP-1000	
Unnamed	[(Hall et al., n.d.)]	Non-specialized workers	NA	Japanese	Japan	Cookie Theft Picture VFT phonemic VFT semantic Count backward Subtraction	Production of free speech Verbal fluency Calculation	iPad Pro2	

Brain-Check; CADi2, Cognitive Assessment for Dementia iPad version 2; CAMCI, Computer Assessment of Memory and Cognitive Impairment; CANS-MCI, Computer-Administered Neuropsychological Screen for Mild Cognitive Impairment; Cantab Mobile; CCS, Computerized Cognitive Screening; CogCheck; Cogn-ICA, Integrated Cognitive Assessment; CogState BB, CogState Brief Battery; e-CT, tablet-PC-based cancellation test; EC-Screen, Electronic Cognitive Screen; eHAST, digital version of Hagia Sophia Test; eSAGE Brain Test®, digitally translated Self-Administered Gerocognitive Examination; FACEmemory®, Face-Name Associative Memory Exam; GrayMatters®, HK-VMT, Hong Kong – vigilance and memory test; IDEA, Identification and intervention for Dementia in Elderly Africans; InbrainCST, Inbrain Cognitive Screening Test; MCS, Mobile Cognitive Screening; Mindmore, Mindmore self-administrative cognitive screening battery; Minnemera, new digitized cognitive test battery; mSTS-MCI, Mobile Screening Test System for screening Mild Cognitive Impairment; NCGG-FAT, National Center for Geriatrics and Gerontology functional assessment tool; RGA-RCS, Rapid Cognitive screening of the Rapid Geriatric Assessment in Primary Care; SATURN, Self-Administered Tasks Uncovering Risk of Neurodegeneration; TabCAT-BHA, TabCAT Brain Health Assessment; TBDT, Tablet-Based Drawing Task; TorCA, Toronto Cognitive Assessment; TPST, touch-panel computer assisted screening tool; Unnamed, tool without name introduced by Hall, (2019).

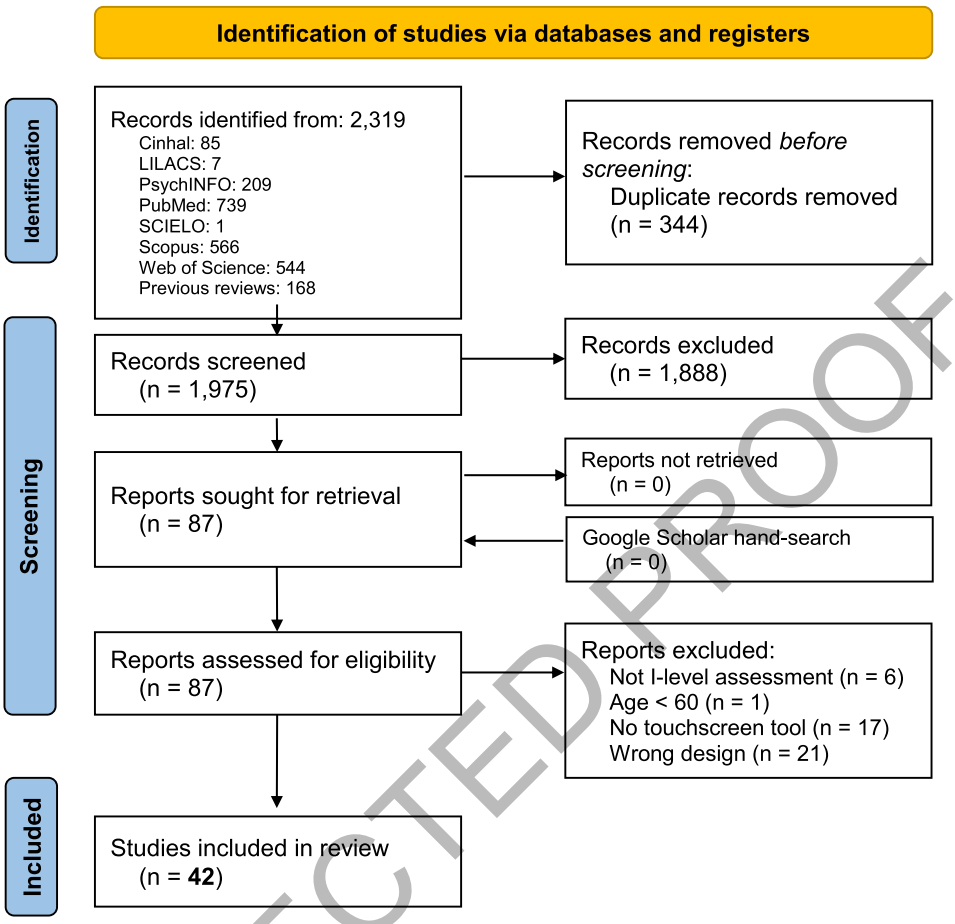

Fig. 1. Flow chart of review inclusion criteria.

cases from healthy subjects. Eight tools (26%) introduced original new tasks: CAMCI, Cantab Mobile, CCS, CognICA, CogState BB, GrayMatters®, HK-VMT, and TabCAT-BHA. The others are digitalized versions of existing paper-and-pencil neuropsychological tests.

Besides cognitive assessment, TabCAT-BHA, IDEA, and RGA-RCS include a measure of functional status and the patient's clinical history. TabCAT-BHA is accompanied by the Brain Health Survey, which is self-administered by an informant who knew the patient's neurocognitive and functional changes in the last five years. IDEA is related to the IDEA-IADL (Instrumental Activities of Daily Living) questionnaire and a self-rated subjective cognitive impairment scale. RCS (Rapid Cognitive Screening) is one of four tests completing the Rapid Geriatric Assessment (RGA) [34], which more widely explores the presence of geriatric pathologies, such as frailty, sarcopenia, and anorexia of aging.

Touchscreen cognitive tools employed in diverse cultural and literacy populations

Of the 30 measures identified, 13 standard languages are covered: English, Spanish, Greek, Japanese, French, Portuguese, Chinese, Catalan, Kiswahili, Korean, Turkish, German, and Swedish. For English, Spanish, and French, some instruments are validated in more than one language variant. The most common language is English (15 tools, see Table 2), followed by Spanish (6 tools), Japanese (4 tools), Chinese (3 tools), Greek, Korean, Swedish, German, French (2 tools), Portuguese, Catalan, Kiswahili, and Turkish (1 tool; Fig. 2a). Seventeen out of 30 tools have been originally developed in a non-English language. Cantab Mobile and CognICA are non-verbal tools with a record-voice guide for instructions translated into 20 and 2 different languages, respectively. Only 7 tools (23%) are validated in more than one language: CANS-MCI, CognICA,

Table 2
Psychometrics and clinical features of the touchscreen cognitive tools

Screening tool	First author, year	Clinical diagnosis	Diagnostic criteria	Validation sample	HC	MCI	DEM	Prevalence of MCI	Prevalence of DEM	Scoring	Reference Test	MCI Test vs. Ref.	Dementia Test vs. Ref.
Brain-Check	[59]	MCI All-causes Dementia	NA	N: 99 age: 70.63 ± 8.52 educ:39% post degree f: 49	N: 35 age: 67.80 ± 9.60* educ: 40% post degree f: 25*	N: 22 age: 73.50 ± 5.90* educ: 41% post degree f: 8*	N: 42 age: 71.50 ± 9.00* educ: 38% post degree f: 16*	22.22%	42.42%	Z-scores	/	AUC: 0.84 SN: 0.83 SP: 0.86	AUC: 0.95 SN: 0.94 SP: 0.88
Brain-Check	[60]	All-causes Dementia	NA	N: 84 age: 65.64 ± 14.91 f: 72	N: 65 age: 62.90 ± 16.50* f: 55#	/	N: 19 age: 75.00 ± 9.50* f: 17#	/	29.23%	Z-scores	/	/	SN: 0.89 SP: 0.78
CADi2	[61]	AD	[30, 38]	N: 54 age:77.42 ± 3.93 educ:10.55 ± 2.50 f: 27	N: 27 age:76.00 ± 3.00 educ:11.60 ± 2.90* f: 14	/	N: 27 age:78.10 ± 4.40 educ:9.50 ± 2.10* f: 13	/	50.00%	Z-scores+total response time	/	/	AUC: 0.98 SN: 0.96 SP: 0.89
CAMCI	[46]	MCI	[36]	N: 524 age:73.30 ± 6.52 educ:13.46 ± 2.67 f: 341	N: 296 age:71.84 ± 5.95* educ:13.74 ± 2.69* f: 199	N: 228 age:75.18 ± 6.76* educ:13.10 ± 2.61* f: 142	/	43.51%	/	Accuracy and reaction times	MMSE	SN: 0.86 vs. 0.45 SP: 0.94 vs. 0.92	/
CANS-MCI	[45]	MCI AD	[28–30]	N: 97 age: 73.41 ± 5.02 educ: 12.23 ± 4.40 f: 69	N: 41 age: 71.68 ± 4.62* educ: 13.41 ± 4.45 f: 33*	N: 35 age: 73.80 ± 5.50* educ: 11.25 ± 4.08 f: 27*	N: 21 age: 76.14 ± 4.98* educ: 11.57 ± 4.85 f: 9*	36.08%	21.65%	Z-score	/	AUC: 0.80 SN: 0.81 SP: 0.73	AUC: 0.98 SN: 1.00 SP: 0.97
CANS-MCI	[64]	MCI	[27]	N: 35 age: 78.90 ± 5.37 educ: 14.01 ± 2.94 f: 19	N: 20 age: 77.40 ± 4.00 educ: 14.70 ± 2.90 f: 9	N: 15 age: 80.90 ± 7.20 educ: 13.10 ± 3.00 f: 10	/		/	Z-score	MoCA	AUC: 0.87 vs. 0.89 SN: 0.89 vs. 0.90 SP: 0.73 vs. 0.67	/
Cantab Mobile	[65]	MCI All-causes Dementia	NA	NA	NA	NA	NA	NA	NA	NA	NA	SN: 0.83 SP: 0.82	SN: 1.00 SP: 0.92
CCS	[66]	All-causes dementia	[38]	N: 60 age: 75.16 ± 12.33 educ: 26% tertiary f: 31	N: 20 age:72.50 ± 12.00* educ: 35% secondary f: 8	/	N: 40 age:76.50 ± 12.50* educ: 30% primary f: 23		66.67%	Cut-off <4	MoCA	/	AUC: 0.94 vs. 0.99 SN: 0.94 vs. 0.95 SP: 0.60 vs. 1.00
CognICA	[68]	MCI mild AD	[30]	N: 230 age: 68.82 ± 7.81 educ: 13.52 ± 4.05 f: 118	N: 95 age:66.80 ± 7.60# educ:14.30 ± 4.40# f: 53#	N: 80 age:69.60 ± 8.00# educ:13.10 ± 4.00# f: 38#	N: 55 age:71.20 ± 7.90# educ:12.80 ± 3.50# f: 27#	34.78%	23.91%	AI model	MoCA	AUC: 0.81 vs. 0.77 SN: 0.76 vs. 0.73 SP: 0.75 vs. 0.81	AUC: 0.88 vs. 0.89 SN: 0.84 vs. 0.96 SP: 0.75 vs. 0.81

(*Continued*)

Table 2
(*Continued*)

Screening tool	First author, year	Clinical diagnosis	Diagnostic criteria	Validation sample	HC	MCI	DEM	Prevalence of MCI	Prevalence of DEM	Scoring	Reference Test	MCI Test vs. Ref.	Dementia Test vs. Ref.
e-CT	[70]	MCI	[27, 28]	N: 276 age: 67.48 ± 8.09 educ: 11.66 ± 4.11 f: 173	N: 154 age: 67.98 ± 7.92# educ: 12.62 ± 4.18# f: 93#	N: 122 age: 66.86 ± 8.32# educ:10.45 ± 4.03# f: 80#	/	44.20%	/	Cut-off 36.5	/	AUC: 0.77 SN: 0.73 SP: 0.72	/
EC-Screen	[71]	MCI All-causes Dementia	[28, 40]	N: 243 age: 73.96 ± 7.83 educ: 53% secondary f: 177	N: 126 age: 70.12 ± 8.59# educ:66% secondary# f: 100#	N: 54 age: 76.82 ± 6.71# educ: 55% primary# f: 31#	N: 63 age: 79.17 ± 7.29# educ: 62% primary# f: 46#	22.22%	25.93%	Cut-off 0,22	MoCA	/	AUC: 0,90 SN: 0.83 SP: 0.83
eHAST	[72]	MCI	/	N: 132 age: 72.46 ± 5.77 educ: 11.37 ± 4.50 f: 96	N: 30 age: 71.93 ± 4.30 educ: 12.27 ± 5.30 f: 22#	N: 102 age: 72.62 ± 6.20 educ: 11.10 ± 4.27 f: 74#	/	47.22%	/	Cut-off	/	AUC: 0.71 SN: 0.70 SP: 0.64	/
eHAST	[72]	All-causes Dementia	/	N: 55 age: 71.47 ± 4.30 educ: 11.51 ± 4.32 f: 39	N: 25 age: 71.00 ± 4.30 educ: 12.24 ± 4.60 f: 20#	/	N: 30 age: 71.86 ± 4.30 educ: 10.90 ± 4.08 f: 19#	/	25.00%	Cut-off	/	/	AUC: 0.96 SN: 0.92 SP: 0.97
eSAGE - BrainTest®	[44]	MCI All-causes Dementia	[28, 40]	N: 66 age: 75.20 ± 7.30 educ: 15.10 ± 2.70 f: 44	N: 21	N: 24	N: 21	36.36%	31.81%	Cut-off MCI: <16 Dementia: <13	SAGE	AUC: 0.78 SN: 0.90 SP: 0.75	AUC: 0.99 SN: 0.90 SP: 0.87
FACE-memory®	[73]	MCI	[27, 28]	N: 276 age: 67.46 ± 8.10 educ: 11.66 ± 4.11* f: 173	N: 154 age: 67.98 ± 7.92 educ: 12.62 ± 4.18* f: 93	N: 122 age: 66.86 ± 8.32 educ: 10.45 ± 4.03* f: 80	/	44.20%	/	Cut-off	/	AUC: 0.77 SN: 0.73 SP: 0.72	/
HK-VMT	[76]	MCI	[37]	N: 606 age: 69.50 ± 6.60 educ: 9.20 ± 5.00 f: 323	N: 509 age: 68.80 ± 6.30* educ: 9.80 ± 4.80* f: 279	N: 97 age: 73.40 ± 7.00* educ: 6.20 ± 5.10* f: 44	/	16.00%	/	Cut-off 21/22	/	AUC: 0.79 SN: 0.86 SP: 0.75	/
IDEA	[77]	All-causes dementia	[39]	N: 610 age:24% >85 educ: 45% no formal education f: 401	N: 505 age: 20% >85# educ: 58% some formal education# f: 326#	/	N: 105 age: 44% >85# educ: 65% no formal education# f: 75#	/	17.21%	Cut-off <7	/	/	AUC: 0.79 SN: 0.84 SP: 0.58
InbrainCST	[78]	MCI AD	[27, 30]	N: 97 age: 71.40 ± 7.46 educ: 12.46 ± 4.01 f: 62	N: 26 age: 68.46 ± 6.28* educ: 12.62 ± 3.68 f: 23*	N: 42 age: 71.69 ± 7.30* educ: 12.57 ± 3.89 f: 24*	N: 29 age: 73.62 ± 8.74* educ: 12.17 ± 4.48 f: 15*	43.30%	29.90%	Cut-Off MCI: 51.9 AD: 39.1	/	AUC: 0.81 SN: 0.81 SP: 0.76	AUC: 0.93 SN: 0.82 SP: 0.83
mSTS-MCI	[51]	MCI	[28]	N: 177 age: 74.73 ± 6.77 educ: 5.95 ± 4.52 f: 99	N: 103 age: 74.93 ± 6.96 educ: 5.83 ± 4.52 f: 58	N: 74 age: 74.45 ± 6.51 educ: 6.14 ± 4.53 f: 41	/	41.80%	/	Cut-off <18/19	MoCA-K	AUC: 0.99 vs. 0.82 SN: 0.99 vs. 0.94 SP: 0.93 vs. 0.60	/
SATURN	[24]	MCI All-causes Dementia	CDR>0 CDR > 0.5	/	/	/	/	/	/	Cut-off CDR >0:24 CDR >0.5:21	MoCA	CDR>0 AUC: 0.90 vs. 0.95 SN: 0.82 vs. 0.91 SP: 0.92 vs. 0.82	CDR >0.5 AUC: 0.95 vs. 0.94 SN: 0.92 vs. 0.92 SP: 0.88 vs. 0.88

TabCAT-BHA	[86]	MCI FTD LBD VaD AD	[31–33, 35]	N: 146 age:72.32 ± 6.40 educ:14.54 ± 4.54 f: 96	N: 53 age:70.40 ± 5.90* educ:16.20 ± 4.10* f: 39	N: 46 age:72.70 ± 7.50* educ:14.20 ± 4.10* f: 24	N: 47 age:74.10 ± 5.90* educ:13.00 ± 5.20* f: 33	31.50%	32.19%	Z-scores	MoCA	AUC: 0.94 vs. 0.73 SN: 0.87 vs. 0.36 SP: 0.85 vs. 0.85	AUC: 0.98 vs. 0.97 SN: 0.96 vs. 0.92 SP: 0.85 vs. 0.85
TabCAT-BHA	[85]	MCI All-causes dementia	[35, 39]	N: 239 age:73.16 ± 7.43 educ:17.29 ± 2.32 f: 114	N: 137 age:75.6 ± 6.3# educ:17.4 ± 2.1# f: 78#	N: 72 age:70.24 ± 8.94# educ:16.72 ± 2.88# f: 22#	N: 30 age:69.10 ± 9.90# educ:17.00 ± 2.00# f: 14#	30.12%	12.55%	Z-scores	MoCA	AUC: 0.94 vs. 0.74 SN: 0.93 vs. 0.56 SP: 0.75 vs. 0.75	AUC: 0.99 vs. 0.92 SN: 1.00 vs. 0.79 SP: 0.85 vs. 0.85
TabCAT-BHA	[87]	MCI All-causes dementia	[35, 39]	N: 850 age:72.20 ± 8.27 educ:16.63 ± 2.74 f: 441	N: 451 age:73.30 ± 8.20* educ:17.00 ± 2.50* f: 268*	N: 289 age:71.10 ± 8.80* educ:16.40 ± 3.10* f: 128*	N: 110 age:70.60 ± 10.30* educ:15.70 ± 2.80* f: 45*	34.00%	12.94%	Z-scores	MoCA	AUC: 0.92 vs. 0.85 SN: 0.84 vs. 0.73 SP: 0.85 vs. 0.85	/
TabCAT-BHA eHAST	[55]	MCI	/	N: 56 age: 71.28 ± 4.64 educ: 11.77 ± 4.62 f: 43	N: 19 age: 71.37 ± 4.03 educ: 12.16 ± 3.45 f: 15#	N: 37 age: 71.24 ± 4.95 educ: 11.57 ± 4.27 f: 28#	/	66.07%	/	Z-scores	BHA vs. eHAST	AUC: 0.81 vs. 0.65 SN: 0.89 vs. 0.58 SP: 0.68 vs. 0.73	AUC: 0.99 vs. 0.82 SN: 0.99 vs. 0.94 SP: 0.93 vs. 0.60
TBDT	[89]	MCI AD	[29, 30, 35]	N:70 age:66.90 ± 10.30 educ:12.24 ± 2.93 f: 34	N: 20 age:69.90 ± 9.40 educ:13.20 ± 3.20 f: 8	N: 30 age:65.30 ± 6.60 educ:11.90 ± 2.70 f: 15	N: 20 age:69.60 ± 6.10 educ:11.80 ± 3.00 f: 11	42.86%	28.57%	Cut-off (total time) MCI:36605ms AD:45396ms		AUC: 0.77 SN: 0.83 SP: 0.55	AUC: 0.93 SN: 0.80 SP: 0.95
TorCA	[90]	aMCI	[35]	N: 107 age: 76.42 ± 7.25 educ: 15.24 ± 3.29 f: 61	N: 57 age: 75.30 ± 7.90 educ: 15.02 ± 3.20 f: 38*	N: 50 age: 77.70 ± 6.50 educ: 15.50 ± 3.40 f: 23*	/	46.72%	/	Cut-off 275	/	AUC: 0.79 SN: 0.80 SP: 0.79	/
TPST	[91]	AD	[30]	N: 174 age: 78,30 ± 5,51 f: 133	N: 102 age: 77.10 ± 5.80# f: 65#	/	N: 72 age: 80.00 ± 5.10# f: 60#	/	41.37%	Cut-off Dementia: <13	/	/	AUC: 0.93 SN: 0.97 SP: 0.85
Unnamed	[53]	MCI FTD LBD AD	[27, 30, 31, 41]	N: 44 age: 73.56 ± 4.84 f: 24	N: 19# age: 71.63 ± 4.39# f: 12#	N: 15# age: 74.87 ± 4.73# f: 8#	N: 10# age: 75.30 ± 5.87# f: 4#	43.18%	22.72%	Cut-off	/	AUC: 0.82 SN: 0.84 SP: 0.80	AUC: 0.93 SN: 0.91 SP: 1.00

Brain-Check; CADi2, Cognitive Assessment for Dementia iPad version 2; CAMCI, Computer Assessment of Memory and Cognitive Impairment; CANS-MCI, Computer-Administered Neuropsychological Screen for Mild Cognitive Impairment; Cantab Mobile; CCS, Computerized Cognitive Screening; e-CT, tablet-PC- based cancellation test; EC-Screen, Electronic Cognitive Screen; eHAST, digital version of Hagia Sophia Test; eSAGE Brain Test®, digitally translated Self-Administered Gerocognitive Examination; FACEmemory ®, Face-Name Associative Memory Exam; HK-VMT, Hong Kong – vigilance and memory test; CognICA, Integrated Cognitive Assessment; IDEA, Identification and intervention for Dementia in Elderly Africans; InbrainCST, Inbrain Cognitive Screening Test; mSTS-MCI, Mobile Screening Test System for screening Mild Cognitive Impairment; SATURN, Self-Administered Tasks Uncovering Risk of Neurodegeneration; TabCAT-BHA, Brain Health Assessment; TBDT, Tablet-Based Drawing Task; TorCA, Toronto Cognitive Assessment; TPST, touch-panel computer assisted screening tool; Unnamed, tool without name introduced by Hall, (2019). *Sign. difference between groups. #Difference between groups not reported.

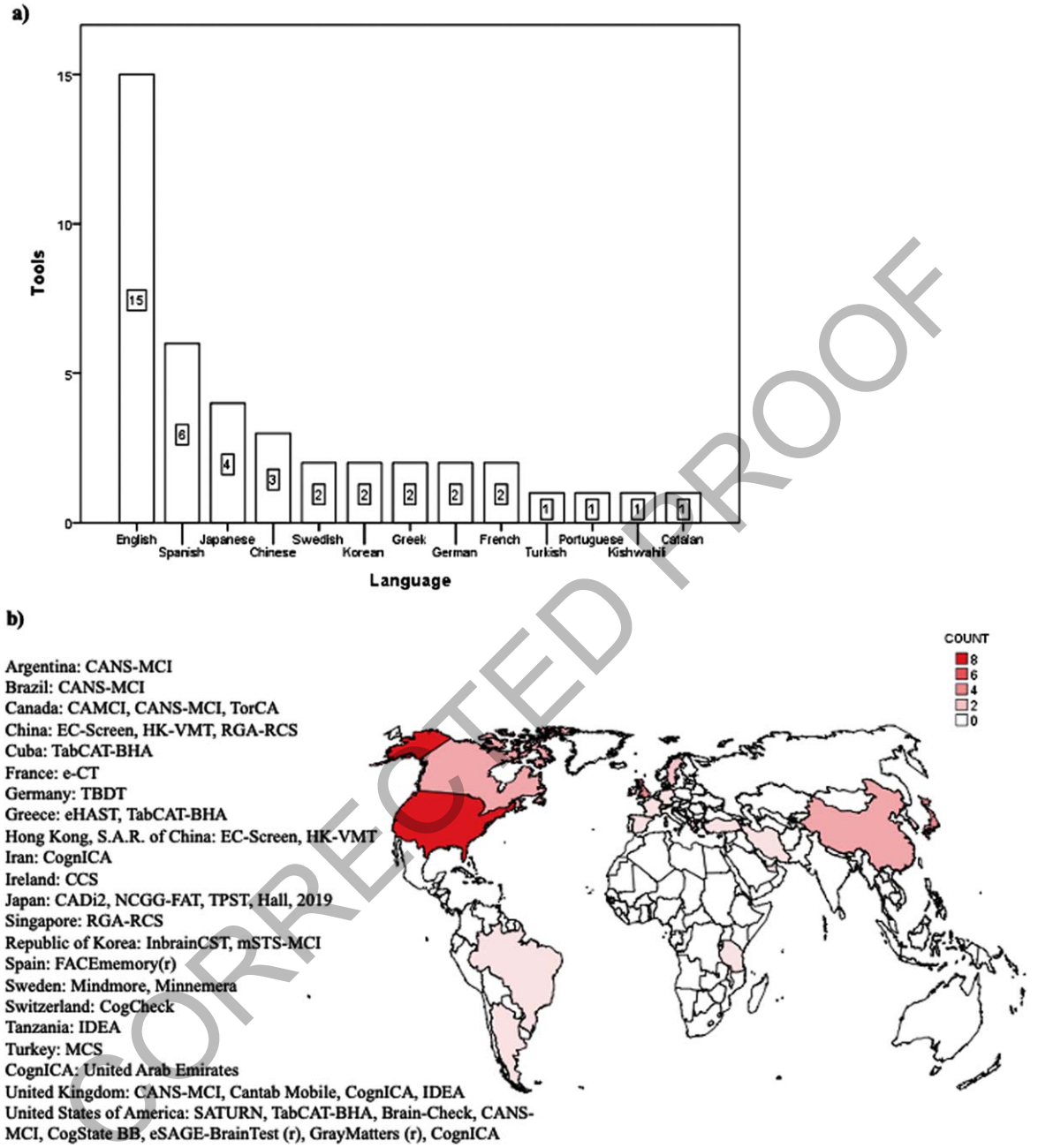

Fig. 2. a) Histogram of the availability of the tools in different languages. b) Map of touchscreen cognitive tools for dementia and MCI available worldwide.

FACEmemory®, IDEA, mSTS-MCI, RGA-RCS, and TabCAT-BHA. TabCAT-BHA was developed in the USA in the American-English language, and then it was translated into Spanish and Greek and culturally adapted for USA Spanish-speaking, Cuban, and Greek populations. CANS-MCI was originally developed in the USA in the American-English language, and then it was translated into Brazilian-Portuguese and culturally adapted for the Brazilian population. Furthermore, we retrieved information from the CANS-MCI website (screen-inc.com) about the availability of the test in Spanish and French languages but with a cultural adaption for USA and Canada, respectively. CognICA was developed in UK-English, then translated into Farsi, and adopted in Iran. RGA-RCS was developed in English and Chi-

nese. IDEA is the only tool developed and validated for use in Sub-Sahara Africa (Fig. 2b).

Concerning the demographic characteristics of the tools, 53% of the studies include a small sample size (N < 50 per group for clinical studies and N < 100 per group for normative studies). Regarding the clinical studies, the average age of the entire validation sample ranges from a minimum of 65.6 years to a maximum of 78.9 years between studies. Thirty percent of the studies reported a significant difference between groups in age, while 23% did not report this information. Sex was predominantly female for 59% of the studies. Thirteen percent of the studies reported a significant difference between groups on sex, while 36% did not report this information. Only two instruments (mSTS-MCI and IDEA) were validated in a sample with a low level of education (the average of the years of education is less than 9), while 50% of the samples ranged from 9 to 13 years of education and 40% of the samples were over 13 years of education. Twenty-seven percent of the studies reported a significant difference between groups in educational attainment, while 27% did not report this information.

Clinical validity and diagnostic accuracy of the touchscreen cognitive tools

Psychometric clinical features and diagnostic accuracy information are available for 22 measures included in this review, and extracted values are reported in Table 4. Regarding the studies conducted on clinical populations, 12 studies provide information about AUC, sensitivity, and specificity in both MCI and dementia, 9 studies in the MCI population only, and 7 studies in the dementia population only. Diagnostic criteria considered for MCI and subgroups of dementia were MCI [28, 29, 35–37], all causes of dementia [38–40], FTD [33, 41], LBD [31], VaD [32], and AD [30, 42].

Regarding the scoring, most of the tools use cut-off points and/or z-scores. Three tools (CADi2, CAMCI, and TBDT) also provide a reaction time score. CognICA uses an Artificial Intelligence (AI) algorithm based on binary logistic regression and machine learning. The study conducted by Park [43] introduced a logistic regression model to process scores to mSTS-MCI, with higher accuracy in screening MCI than MoCA.

Eleven studies compare the touchscreen tools with other paper-and-pencil reference tests: digital tools perform better than the traditional ones for the detection of MCI in 4 of 6 studies and better or similar to the traditional ones for dementia in 2 of 5 and 1 of 5 studies, respectively. The most used reference test is MoCA [12] (8 studies). In the studies considered, AUC scores for MoCA range from 0.73 to 0.95 for MCI and from 0.89 to 0.99 for dementia. Regarding the digital tools, AUC scores range from 0.71 to 0.99 for MCI and from 0.79 to 1.00 for dementia. The prevalence of MCI and dementia ranged from 16.0% to 66.1% and 12.6% to 66.7%, respectively.

Features related to the application in the primary care setting

Regarding the administration, 17 out of 30 tools can be self-administered, 9 can be administered by non-specialized workers, and 3 can be administered by psychologists or trained staff, GPs included. For 1 tool, this information is not available. Considering the level of the examiner involvement both in administration and scoring, 43%, 47%, and 10% of the tools require a low, moderate, and high level of involvement, respectively. Administration time varied from 2 min (e-CT) to 45 min (i.e., Minnemera and Mindmore). Twelve tools require less than 15 min to be administered, the same number of tools have a duration between 15 and 30 min, 3 measures require more than 30 min to be administered, and information about duration was not available for 3 tools. Regarding the features of the device, 11 tools are developed to be used with iPadOS or iPhoneOS only, 7 tools run on AndroidOS tablets, 2 tools are available for computers or laptops with a touchscreen monitor, 1 tool runs on a Windows Surface Pro 4 digitizer with a handheld stylus pen, 9 studies do not specify the features of the tablet, and only one tool (TPST) requires a specific touch-panel display called MSP-1000. Feasibility studies are provided only for 7 out of 30 tools.

A qualitative synthesis of clinical validation

The risk of bias associated with the studies has been assessed. Most of the studies (53%) reported moderate quality, 20% reported low quality, and 27% reported high quality (Fig. 3, Supplementary Table 2). Twenty-two tools (80%) measured diagnostic accuracy and clinical validity, while 20% collected normative data (on healthy controls). The validation sample is adequate in 47% of the studies, while 53% have a low sample size and/or lack of validated diagnostic criteria for selection or a non-stratified sample for normative studies. Few studies (23%) conducted

Fig. 3. Risk of Bias of included studies. Tools are divided into those with low-quality studies (red area), moderate-quality studies (orange area), and high-quality studies (green area).

more than one reliability measure (i.e., internal consistency, test-retest stability, inter-rater reliability), while 57% tested for ROC analysis and at least one kind of validity and accuracy measure. Fifteen tools (50%) are available for clinical practice in the countries where they have been validated, while the others are not available or did not report this information. We retrieved information on costs associated with use (subscriptions, software installation, report generation) for 60% of the tools included in the review.

Of these, 9 of the 30 (30%) tools are completely free (e.g., CADi2, CogCheck, EC-Screen, eHAST, FACEmemory®, IDEA, RGA-RCS, SATURN, TabCAT-BHA), 8 of the 30 (26.7%) tools (e.g., Brain-Check, CAMCI, CANS-MCI, Cantab Mobile, CogState BB, CognICA, eSAGE – Brain Test ®, Mindmore) have a cost that depends on the purpose of use (research or clinical practice) and testing volume, and 1 is not commercially available (e.g., MCS).

Among the user fee tools, 3 of the 8 specified the cost of their tool: eSAGE - BrainTest® [44] has a user fee that is determined by whether or not it is being used for research purposes or by consumers (for researchers, the cost is $15/test, which includes scoring and private portal for private/confidential results, while for clinical users, the cost is $25/test); CANS-MCI [45] is distributed free, but the software charges $35 for each report; CAMCI [46] is only available for research purpose and the research license comes with one year of unlimited testing for $1,500.

Only 43% of the studies clearly reported information about data security with reference to the laws in force in the countries where the tool can be used. Nine tools (30%) deliver results with the interpretation of numerical scores and guidance for medical decisions. Four and nine studies are at risk of workup bias or expectation bias, respectively.

DISCUSSION

This systematic review aimed at identifying touchscreen cognitive tools for the detection of MCI and dementia in the primary care setting, extending the

attention to different languages, cultures, and literacy levels around the world.

Overall, we found that digital tools perform relatively better than traditional paper-and-pencil tools in MCI detection, being able to overcome the limitations of traditional tools in primary care. A similar result has been shown by a recent systematic review that evaluated the diagnostic performance of digital cognitive tests for MCI and dementia and found 46 digital cognitive tests with comparable diagnostic performances with the paper-and-pencil tests, but all the digital tests had few validation studies to verify their performance [25]. Similarly, Thabtah et al. [47] reviewed only the touchscreen apps commercially available in the Apple and Google stores and found 20 apps suitable for MCI detection.

In a recent review, Tsoy and colleagues [22] restricted the field of interest to the primary care setting and identified 10 brief self-administered computerized measures (touchscreen, mouse, and keyboard input devices) to detect cognitive disorders in MCI and dementia but narrowed their attention to English-speaking older persons. In this study, examining 42 published studies, we found 30 neuropsychological tools, most of them (53%) with moderate risks of bias, a small proportion (23%) available in multiple languages, and 47% of them validated in non-English language; and either self-administered or examiner-dependent tools. We identified tools in 13 languages, i.e., Catalan, Chinese, English, French, Greek, Japanese, Kiswahili, Korean, Portuguese, German, Spanish, Swedish, and Turkish. Only 7 out of the 30 tools have a multiple languages validation: CANS-MCI, CognICA, FACEmemory®, IDEA, mSTS-MCI, RGA-RCS, and TabCAT-BHA. The availability of the same tool in different languages facilitates both the development of research in different countries and the clinical use of the tool with diverse populations. However, a mere translation is not enough to extend the validity for other ethnic groups. The ideal screening tool should be validated considering different cultures and educational backgrounds.

The incidence of dementia is growing in low- and middle-income countries and rural areas, and this is possibly due to the higher number of people with low-education [48]. First-level cognitive assessment tools need to be validated with adequate tasks and samples to be used in this setting [49]. In our review, we found that only two tools are validated in low-educated populations: IDEA and mSTS-MCI, conducted in Tanzania and South Korea, respectively. It should be noted that South Korea has a high-income economy, and this country is a global leader in innovation and technology [50]; therefore, we cannot conclude that the study by Park et al. [51] was conducted in a low-income country; instead, we assume that it has its own proportion of low-educated populations. Providing adequate instruments accessible to people with different technology literacy levels is, therefore, a crucial first step.

One of the great drawbacks of these studies is the low sample size, as consistent with a previous review [25]. Ninety percent of the studies included have a validation sample on high-educated population, and this is a crucial drawback that future studies need to overcome. The prevalence of MCI and dementia in all clinical studies is higher than in real-world data, and positive and negative predictive values may not be representative of the real frequency [52]. Furthermore, high sensitivity is more important than specificity in first-level screening because it will ensure that a high proportion of suitable subjects receives a second-level assessment [16]. In this review, 22 tools have at least a measure of diagnostic accuracy: Brain-Check, CADi2, CAMCI, CANS-MCI, Cantab Mobile, CCS, CogCheck, CognICA, e-CT, EC-Screen, eHAST, eSAGE – Brain Test®, FACEmemory®, HK-VMT, IDEA, InbrainCST, mSTS-MCI, SATURN, TabCAT-BHA, TBDT, TPST, and the tool proposed by Hall et al. [53]. However, only a few studies make a comparison between digital and traditional tools, and the significant variability across measures, consistent with previous review findings [22, 54], allows only qualitative comparisons. The clinical accuracy of these tools seems to be similar or, in some cases, better than the paper-and-pencil gold standard tests, in line with previous reviews [25].

Regarding the theoretical framework, most tools included in this review adopted a multi-domains approach for cognitive assessment. Memory, executive functions, visuospatial abilities, attention, and language are the most assessed domains, followed by temporal orientation, processing speed, and working memory. A potential limitation of touchscreen digital tools to be addressed is the difficulty in evaluating the cognitive domains that require motion analysis [55], for example, praxis, which is important to recognize non-amnesic forms of dementia [56]. Only IDEA proposes a task to assess this function through a task derived from Baiyewu et al. [57] that consists of correctly placing matchsticks in the shape of a rake. Although the potential use of some hard-

ware features (i.e., accelerometers, gyroscopes, and global position systems-GPS) is recognized for tablet and smartphone-based instruments [21], none of the measures exploited these functionalities adequately to evaluate the presence of apraxia or to produce new variables.

Digital technology, i.e., touchscreen, may offer innovative theoretical proposals for cognitive assessment. An attempt in this direction has been made by CognICA, a 5-min, self-administered tool based on a rapid language-independent categorization task that primarily tests Information Processing Speed, which underlies many areas of cognitive dysfunction and is one of the early changes of AD. The performance was assessed through an AI algorithm that uses accuracy, speed of responses, and age as inputs, and it produces an indication of the likelihood of impairment (output) by comparing the patient's performance and age to other healthy and cognitively impaired subjects' scores. The example provided by CognICA allows digital technologies to be considered as a new frontier for neuropsychological assessment exploiting machine learning strengths [58]. Digital tools offer the opportunity for real-time data storage in computer servers, making it easier to exploit AI to create a patient's personal profile. Furthermore, data security is a relevant issue, as data must be stored and processed in such a way as to guarantee the privacy of the data, in compliance with the laws in force in the country of use. However, only 9 studies address it specifically. It is our opinion that this issue, which is fundamental for the clinical use of the instrument, must be clearly addressed in the validation studies of the instrument.

All tools included in this review are developed to be administered by non-specialized personnel or the patient itself; however, some tools were administered by psychologists or trained staff. A potential limitation is that psychologists are not always present in a primary care setting; therefore, self-administered tools might be more suitable for such a clinical context.

Eight tools delivered an immediate interpretation of numerical results and provided a clinical guide for the physician: CADi2, CAMCI, CANS-MCI, Cantab Mobile, CognICA, EC-Screen, mSTS-MCI, and TabCAT-BHA. The availability of automated reports might enhance the probability that these tools will be used in primary care, overcoming the barrier of training physicians about scoring and interpretation of findings. The ideal tool will have to simplify the medical examination, not complicate it further. Most of the tools run on iOS, Windows, or Android, but not one has been adapted to more than one operating system. It is preferable to adopt software with different operating systems to facilitate their implementation in different countries.

Feasibility studies have been conducted for only 7 out of 30 tools, and there is a need for more evidence on the applicability of screening tools in the real-world context. When investigating the costs of the available touchscreen cognitive tools, we found that 40% of these tools do not report any information about the costs, 30% of these tools do not require any cost for installation, use, and reports generation, 26% are user fee tools, and only one (4%) is not commercially available. In the future, studies providing free or low-cost touchscreen cognitive tools will be important to address the health disparity issues related to MCI and dementia cognitive assessment. Moreover, although the use of tablets and smartphones is largely encouraged to save costs related to the time of administration and scoring [21], no cost-effectiveness evaluation compared to traditional measures has been conducted in the studies considered. For these reasons, future research needs to provide more feasibility and cost-effectiveness studies.

To conclude, the implementation of digital cognitive screening tools in the context of primary care requires multi-language availability, validation in cultures and languages of underrepresented populations, ease of use of the device (accessible to people with different levels of technology literacy), low examiner dependence, rapid administration, and availability of feasibility studies. The clinical validity of digital tools appears to be similar or superior to that of traditional tools, but larger and more adequate samples and comparable methodologies are needed to verify this difference. The development of easily accessible, well-validated, and low-cost digital cognitive tools would represent a powerful driver of health policies pointing to the promotion of cognitive well-being and early detection of cognitive impairment and would also address health inequalities linked to different access and treatment possibilities in the various populations/countries.

ACKNOWLEDGMENTS

We thank Dr. Kate Possin and Dr. Elena Tsoy for their helpful comments that improved the manuscript. Petronilla Battista is a Senior Atlantic Fellow at the Global Brain Health Institute (GBHI) and is

supported with funding from GBHI, Alzheimer's Association, and Alzheimer's Society (GBHI ALZ UK-22-866347). Paola Angelelli is supported with funding from Fondazione con il Sud (Demenza Network Project).

Author's disclosures available online (https://www.j-alz.com/manuscript-disclosures/22-0547r1).

SUPPLEMENTARY MATERIAL

The supplementary material is available in the electronic version of this article: https://dx.doi.org/10.3233/JAD-220547.

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