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Systematic Review

Diagnostic Accuracy of Touchscreen-Based Tests for Mild Cognitive Disorders: A Systematic Review and Meta-Analysis

Nathavy Um Din [1], Florian Maronnat [2], Bruno Oquendo [3], Sylvie Pariel [3], Carmelo Lafuente-Lafuente [3,4,5], Fadi Badra [1] and Joël Belmin [1,3,4,*]

1 Laboratoire d'Informatique Médicale et d'Ingénierie des Connaissances en e-Santé (LIMICS), Université Sorbonne Paris-Nord, 75005 Paris, France; nathavy.umdin@gmail.com (N.U.D.); badra@sorbonne-paris-nord.fr (F.B.)
2 Centre Hospitalo-Universitaire de Brest, Université de Bretagne Occidentale, 29200 Brest, France; florian.maronnat@chu-brest.fr
3 Hôpital Charles Foix, 7 avenue de la République, 94200 Ivry sur Seine, France; bruno.oquendo@aphp.fr (B.O.); sylvie.pariel@aphp.fr (S.P.); carmelo.lafuente@aphp.fr (C.L.-L.)
4 Faculté de Santé, Sorbonne Université, 91-105 Boulevard de l'Hôpital, 75013 Paris, France
5 Clinical Epidemiology and Ageing (CEpiA) Team, Université Paris Est-Créteil, INSERM, IRMB, 94010 Créteil, France
* Correspondence: j.belmin@aphp.fr

Abstract

Background/Objectives: Mild neurocognitive disorder (mNCD) is a state of vulnerability, in which individuals exhibit cognitive deficits identified by cognitive testing, which do not interfere with their ability to independently perform in daily activities. New touchscreen tools had to be designed for cognitive assessment and had to be at an advanced stage of development but their clinical relevance is still unclear. We aimed to identify digital tools used in the diagnosis of mNCD and assess the diagnostic performance of these tools. **Methods**: In a systematic review, we searched 4 databases for articles (PubMed, Embase, Web of science, IEEE Xplore). From 6516 studies retrieved, we included 50 articles in the review in which a touchscreen tool was used to assess cognitive function in older adults. Study quality was assessed using the QUADAS-II scale. Data from 34 articles were appropriate for meta-analysis and were analyzed using the bivariate random-effects method (STATA software version 19). **Results**: The 50 articles in the review totaled 5974 participants and the 34 in the meta-analysis, 4500 participants. Pooled sensitivity and specificity were 0.81 (95%CI: 0.78 to 0.84) and 0.83 (95%CI: 0.79 to 0.86), respectively. High heterogeneity among the studies led us to examine test performance across key characteristics in a subgroup analysis. Tests that are short and self-administered on a touchscreen tablet perform as well as longer tests administered by an assessor or on a fixed device. **Conclusions**: Cognitive testing with a touchscreen tablet is appropriate for screening for mNCD. Further studies are needed to determine their clinical utility in screening for mNCD in primary care settings and referral to specialized care. This research received no external funding and is registered with PROSPERO under the number CRD42022358725.

Keywords: older adults; mild neurocognitive disorder; mild cognitive disorder; touchscreen; diagnosis; digital tools

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1. Introduction

Mild neurocognitive disorder (mNCD) is a condition in which people experience cognitive difficulties and dysfunction which do not interfere with their ability to indepen-

dently perform in daily activities. mNCD may be secondary to neurocognitive diseases like Alzheimer's disease, Parkinson's disease, vascular dementia, or others. This condition offers a window of opportunity for cognitive stimulation, treatment of symptoms, implementation of compensatory strategies and introduction of healthier lifestyle habits (diet, exercise, etc.) that may delay the onset of a major neurocognitive disorder [1]. Early diagnosis of these conditions is recommended [2], first and foremost for the personal management of the person and their family, but also to enable rapid management by specialized professionals. However, diagnosing mNCD is challenging because coping mechanisms, types of cognitive deficits, and levels of cognitive reserve vary greatly from one individual to another, resulting in considerable variation in patients' experiences and symptoms and making it difficult to accurately diagnose this condition [2]. The mNCD and its diagnostic criteria were defined by the DSM-5, and these criteria are very close to those for mild cognitive impairment (MCI), a clinical condition very similar to mNCD, which was widely used before the emergence of mNCD [3]. Early diagnosis can also support clinical research and provide a better understanding of the mechanisms of disease progression or enable participation in clinical trials. The purpose of early diagnosis of mNCD is to slow the progression towards major NCD. Although there is no curative treatment at present, there are numerous strategies that can be implemented to prevent the onset of a major NCD, which is not without consequences for the family and caregivers, with the attendant loss of autonomy for the patient [4,5].

The diagnosis of mNCD relies on medical and neuropsychological evaluation performed in memory centers by a specialized team. Diagnostic criteria have evolved, from mild cognitive impairment (MCI), initially including only memory complaints, to mNCD defined by DSM-5 criteria that now encompasses broader cognitive complaints [3,6]. In both definitions, the person exhibits cognitive deficit identified by cognitive tests and retains autonomy in their daily life. The diagnostic process is long and tedious, often with long waiting times before the first appointment, resulting in a loss of opportunity for the patient. mNCD is insidious, and those affected do not always seek medical attention. The general practitioner (GP) is in the front line when it comes to detecting mNCD and referring to specialized centers [7]. It is therefore important to provide accessible and easy-to-use tools for primary care. Detection is not easy for primary care physicians, since no clearly defined strategy exists to identify people at risk and refer them appropriately to a memory center. The most widely used conventional tests are the Mini Mental State Examination (MMSE) [8] and the Montreal Cognitive Assessment (MoCA) [9]. Both are effective in screening for major neurocognitive disorders [10], but they require training and time and are rarely used by general practitioners. In a systematic review, Chun [11] analyzed the screening tools available for MCI and found that the three most frequently used were the MoCA, the MMSE and the Clock Draw Test (CDT). According to their evaluation criteria, the Six Item Cognitive Impairment Test (6 CIT), the MoCA (with thresholds of $\leq$24/22/19/15.5) and the MMSE (with a threshold of $\leq$26) as well as the Hong Kong Brief Cognitive Test (HKBC) were the most effective. However, the authors highlighted the lack of evaluation of these new cognitive tools, with threshold values determined according to the populations and environments in which they are used. The performance of the MMSE and MoCA was compared in the meta-analysis by Pinto [10] and their accuracy in identifying mNCDs was found to be 0.780 (95% CI 0.740–0.820) and 0.883 (95% CI 0.855–0.912), respectively. Both tests have been regularly criticized for their threshold values. Thus, there is still progress to be made in identifying patients with mNCD in primary care [2,10].

Tests are progressively digitized to improve objectivity and speed, with the possibility of automated scoring, which would reduce test-taking time and make them more accessible

in primary care for GPs [5,12]. In addition, digital tools make it possible to record more detailed results, such as reaction times or pressure on the screen, which are not accessible to a human assessor. Furthermore, touchscreens are more accessible and intuitive thanks to their direct input, compared to keyboard and mouse use [6,13]. In previous work, we showed good detection of major neurocognitive disorders with touchscreens, which is encouraging for primary care [14].

In the present review and meta-analysis, we aimed to investigate the use of touchscreens for screening for mild cognitive disorders comprising mNCD and MCI, in older adults. We also sought to analyze the performance of these tests in relation to the reference diagnosis.

2. Materials and Methods

The protocol was registered with the International Prospective Register of Systematic Review (PROSPERO CRD42022358725), and the report follow the PRISMA-DTA guidelines [15] (see checklist in Supplementary Materials).

2.1. Search Strategy

We searched four databases (Medline, Embase, Web of Science and IEEE Xplore) and included all articles published up to 31 December 2024. The last extraction was in April 2025. We used terms relating to screening or diagnosis, older adults, neurocognitive diseases, touchscreen device (see Table A1 in Appendix A). The search terms were broadened to dementia, but we selected only articles dealing with early stages, taking into account the continuum of neurocognitive diseases from MCI/mNCD to dementia. The search strategies were prepared with the help of an experienced librarian. The reference lists of all articles were manually searched to retrieve relevant studies.

2.2. Article Selection

We included articles whose participants: (i) were over 60 years of age, (ii) were classified according to the presence of mNCD/MCI determined using a conventional assessment of cognition, based on reference diagnostic criteria (Petersen, National Institute on Aging-Alzheimer's Association; National Institute of Neurological and Communicative Disorders and Stroke/Alzheimer's disease and related Disorders Association; Alzheimer's Disease in neuroimaging initiative, etc.), and (iii) were examined using a novel tool using a digital touchscreen device (tactile tablet, touchscreen computer or smartphone). We did not include studies in which the results for mNCD and M-NCD were mixed and could not be analyzed separately.

2.3. Data Extraction

The first two authors independently selected relevant articles from the results of the queries in PubMed, Embase, Web of Science and IEEE Xplore. Any discrepancies were discussed among evaluators until consensus was reached. A third author was consulted in case of disagreement. Reference lists were managed using Zotero® (version 6.0.30) and Excel 2013®. Duplicates were individually checked by the two authors. Each investigator evaluated the study selection criteria independently. Reasons for exclusion were noted in Zotero and differences were resolved by discussion.

Descriptive data for each article were collected by two authors and included the descriptive characteristics of the studies, namely: country, year of publication, period of inclusion of participants, mean age of population, reference diagnostic criteria, neuropsychological tests for reference diagnosis. We also recorded the characteristics of the touchscreen test, namely: name of the new test, mode of administration (self-administered or interviewer-administered), cognitive functions assessed, duration of the new test. Sensi-

tivity, specificity and contingency tables were also included for performance analysis in the meta-analysis. If data were missing or unclear to both investigators, they were recorded as "not specified" (NS) in the table. When the contingency table was not included in the original article, we contacted the authors to obtain it, and in the absence of a reply, we calculated the number of true positives, false positives, true negatives and false negatives with sensitivity and specificity from available data.

2.4. Quality Assessment

The quality of the included articles was assessed by two authors (NUD, FM) using the Quality Assessment of Diagnostic Accuracy Studies 2 instrument (QUADAS-2) [16] which measures the risk of bias and applicability of diagnostic accuracy studies. It comprises four key domains: patient selection, index test, reference standard, flow and timing. Each domain is considered for its risk of bias and applicability, and judged as high, low or unclear.

There are no official or validated decision rules for determining whether a study is of good or poor quality. We chose to exclude articles that were not of sufficiently high quality, and for this purpose, we defined our own decision rule, namely exclusion of studies with: 2 high risks of bias; or 2 high applicability concerns; or 3 risks of unclear bias; or 2 unclear applicability concerns; or 1 unclear applicability concern and 1 high applicability concern.

2.5. Meta-Analysis

We sought to complement the information about the performance of the tools tested. To this end, we collected information on true positives, false positives, true negatives and false negatives. If the information did not appear in an article, we contacted the corresponding author to obtain it.

Meta-analysis was performed with the METADTA program [17] in STATA software (version 19), which uses the bivariate random-effects method. Inter-study heterogeneity was assessed by the I2 coefficient. We performed subgroup analyses according to the type of touchscreen used (touchscreen computer or touchscreen tablet), ease of transport (fixed or mobile device), type of questionnaire administration (rater-administered or self-administered), and test duration (brief test lasting less than 10 min, and longer test lasting more than 10 min).

3. Results

3.1. Studies Included

The database query yielded 6516 articles. After removal of duplicates and exclusions, 181 articles remained to be evaluated for eligibility. After the QUADAS-2 assessment, we finally included 50 studies in the review and 34 articles in the meta-analysis (Figure 1).

3.2. Study Characteristics

We included 50 articles in the systematic review. The characteristics of the included studies are presented in Appendix A. The results are presented in 2 tables according to the digital device used, namely studies using a tactile tablet (Table A2), and studies using a computer touchscreen (Table A3). Articles were published between 2005 [18] and 2024 [19] and were performed in 17 countries located in Europe, Asia, North America and South America.

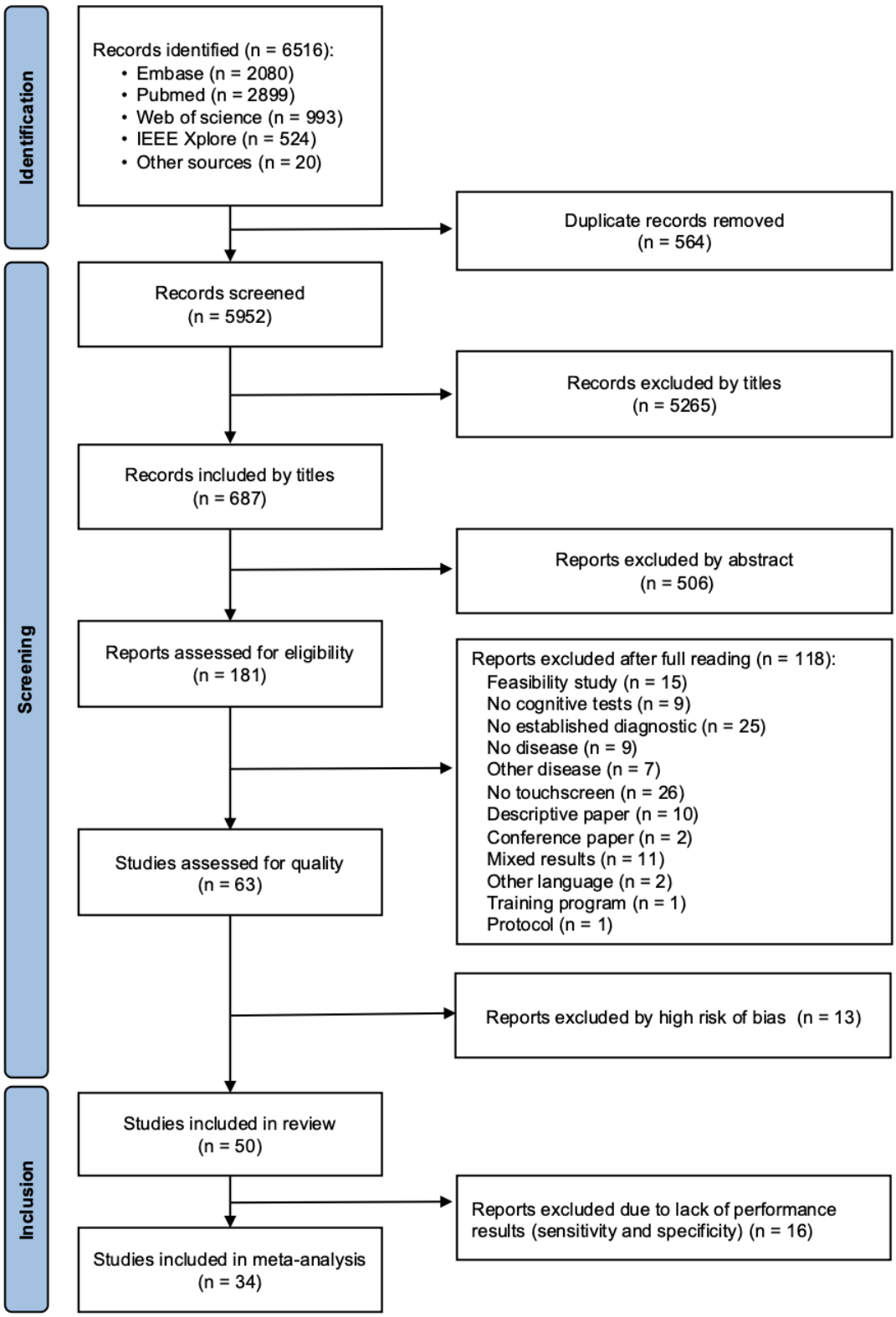

Figure 1. Flow chart of the studies included.

3.2.1. Participants and Settings

The studies involved 5974 participants (3368 women and 2255 men) (4 studies did not mention the participants' sex). The number of participants by study varied from 12 [20] to 524 [21] with an average of 119. Mean age of participants was 72 years, and ranged from 53 to 81 years [22,23]. The recruitment was performed in memory centers (n = 27), in the

community (n = 8), in both memory centers and the community (n = 3), hospitals (n = 14), daycare centers (n = 3), health institutions (n = 5), memory clinic and research registry (n = 2), memory clinic, research registry and community (n = 3), hospital, agencies or community advertisements (n = 2), hospital, retirement home and community (n = 1), nursing home and association (n = 1), GP offices and community (n = 1), and from a demographic surveillance record (n = 1). Three studies did not specify their recruitment methods.

3.2.2. Reference Diagnosis

The reference diagnosis of mNCD/MCI was determined by specialized professionals using reference criteria and tests or parts of tests validated and accepted by the scientific community and are detailed in Appendix A (Tables A2 and A3). The reference diagnosis was considered as that established by a team of specialists in their own clinic, using official criteria. The studies used diagnostic criteria specific to their usual practice: Petersen's criteria (n = 24), the National Institute on Aging and Alzheimer's Association (NIA-AA) criteria (n = 5), the National Institute of Neurological and Communicative Disorders and Stroke and Alzheimer's Disease and Related Disorders Association (NINCDS/ADRDA) criteria (n = 4), Jak's criteria (n = 1), the National Alzheimer's Coordinating Center (NACC) criteria (n = 1), the American Academy of Neurology (AAN) criteria (n = 1), the DSM 5 criteria (n = 1), ADI criteria (n = 1), NIA-AA and DSM-5 criteria (n = 1), Alzheimer's Disease Neuroimaging Initiative (ADNI) criteria (n = 1), Alzheimer's Disease Research Centers (ADRC) criteria (n = 1), and international working group criteria (n = 1). Eight studies did not specify diagnostic criteria but reported that a diagnosis was made following a comprehensive medical and neuropsychological evaluation. A sensitivity analysis was carried out to compare the 24 studies using Petersen's criteria for MCI with the others, and we found no difference between them (see Figure A1 in Appendix A).

3.2.3. Touchscreen Test Procedures

A phase of learning and familiarization with the digital tool was mentioned in 16 studies and was not specified in the others.

Digital test times ranged from 2 min [24] to 2.5 h [25], 13 studies did not specify the duration and one study did not record the test duration [26]. The time needed to complete the tests was less than 5 min in 8 studies, between 10 and 15 min for 7 studies, between 15 and 30 min for 12 studies, between 30 and 60 min for 6 studies and more than an hour in 3 studies.

Thirty-one studies used a self-administered assessment (62%), 13 were assessor-administered (26%) and 6 studies (12%) did not report this information. The professionals involved were health practitioners or researchers trained in the assessments required.

The studies used tactile tablets (n = 34) and touchscreen computers (n = 16).

Forty of these devices were mobile (80%) versus 6 fixed (12%), while 4 studies did not specify the characteristics of their tool (8%).

3.2.4. Performance Results

Thirty-four studies measured the performance of their digital tests by calculating the sensitivity and specificity of their conclusion compared to the reference diagnosis. Sensitivity ranged from 0.41 (95%CI: 0.21 to 0.64) to 1.00 (95%CI: 0.74 to 1.00) [27,28]. Specificity ranged from 0.56 (95%CI: 0.28 to 0.85) to 1.00 (95%CI: 0.80 to 1.00) [26,28].

3.3. Quality Assessment

Overall, the quality of the studies assessed by QUADAS-2 was quite good [18–79] (Table A4 in Appendix A). We excluded 13 studies based on our decision rule.

3.4. Meta-Analysis

3.4.1. Main Results

We included 34 articles in the meta-analysis, totaling 4500 participants. Pooled sensitivity and specificity were 0.81 (95%CI: 0.78 to 0.84) and 0.83 (95%CI: 0.79 to 0.86), respectively (Figure 2). The positive likelihood ratio (LR+) was 4.71 (95%CI: 3.88 to 5.73), the negative likelihood ratio (LR-) was 0.23 (95%CI: 0.19 to 0.27), and the diagnostic odds ratio (DOR) was 20.55 (95%CI: 14.66 to 28.80). The summary ROC curve indicated a high overall discriminative performance of the tests, with a summary point near the upper-left corner of the ROC space and reasonably narrow confidence region (Figure 3). I2 coefficient was 56.2, indicating that the studies were quite heterogenous.

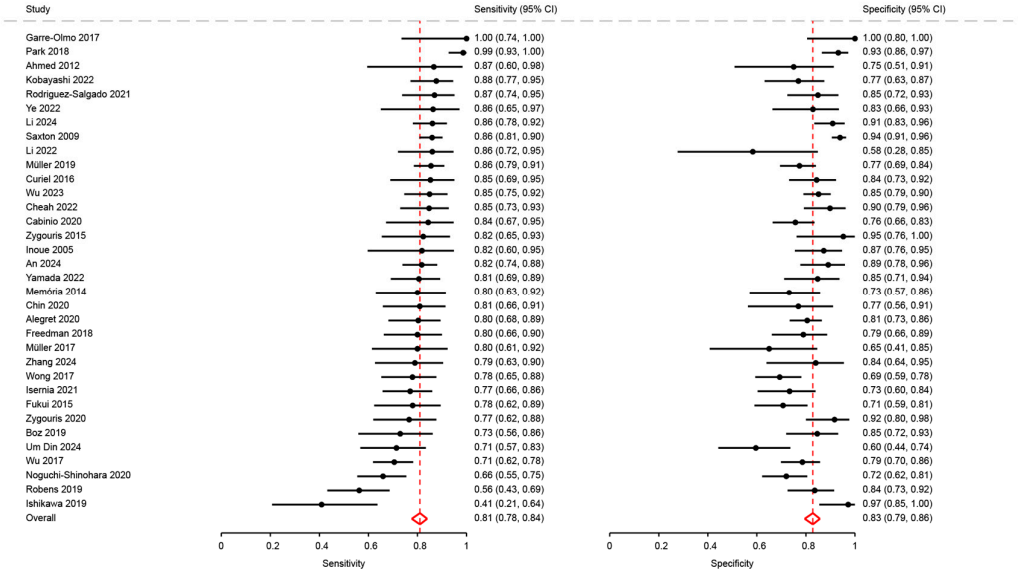

Figure 2. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders [18,21,23,26–29,31,32,34–38,41,43,46–48,50,51,53,54,62–66,68,69,72,74–76].

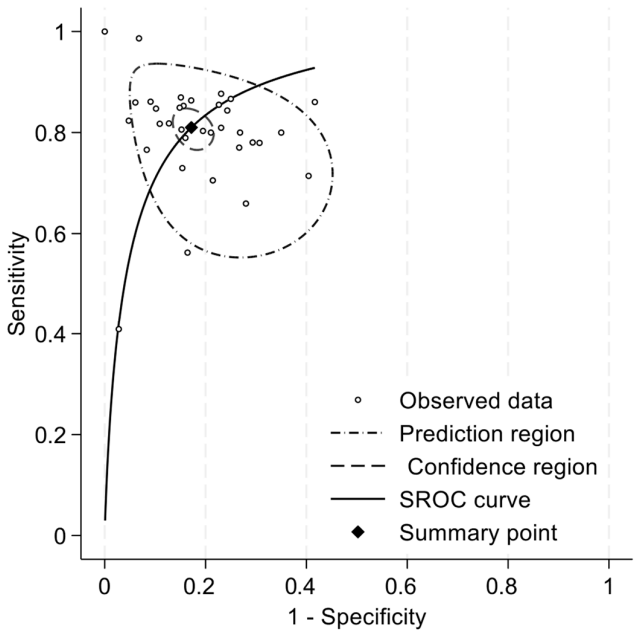

Figure 3. Summary ROC curve of sensitivity and specificity for the diagnosis of mild cognitive disorders.

3.4.2. Subgroup Analysis

We analyzed the performance of the tests according to their procedures and device characteristics (duration, type of administration, type of touchscreen and mobility of the device) using the chi-2 test. Pooled sensitivity and specificity of these subgroups are presented in Figure 4 and the corresponding forest plots with the individual studies are shown in Appendix A (Figures A2–A5) and sections below.

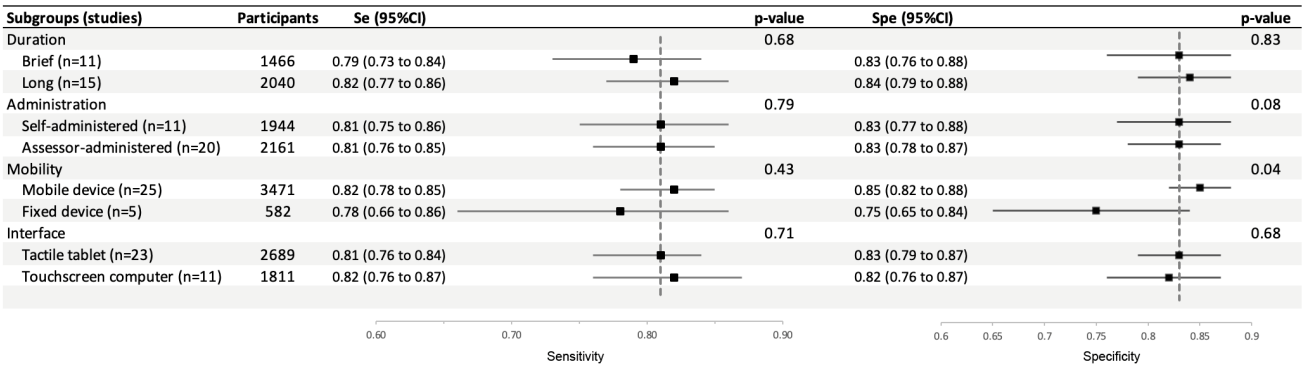

Figure 4. Subgroup analysis of pooled sensitivity and specificity of touchscreen cognitive tests for the diagnosis of mild cognitive disorders.

Duration: Brief Test vs. Longer Test

Sensitivity and specificity in studies using brief tests (0.79; 95%CI: 0.73 to 0.84 and 0.83; 95%CI: 0.76 to 0.88, respectively) were not significantly different from those of studies using longer tests (0.82; 95%CI: 0.77 to 0.86, $p = 0.68$, and 0.84; 95%CI: 0.79 to 0.88, $p = 0.83$) (Figure A2).

Type of Administration: Self or Assessor Administered

Sensitivity and specificity in studies using assessor-administered tests (0.81; 95%CI: 0.76 to 0.85 and 0.83; 95%CI: 0.78 to 0.87, respectively) were not significantly different compared to those using self-administered tests (0.81; 95%CI: 0.75 to 0.86, $p = 0.79$, and 0.83; 95%CI: 0.77 to 0.88, $p = 0.08$) (Figure A3).

Mobility: Fixed or Mobile Device

Sensitivity in studies using a mobile device were not significantly different from that of studies using a fixed device (0.82; 95%CI: 0.78 to 0.85 and 0.78; 95%CI: 0.66 to 0.86, $p = 0.43$). Conversely, specificity in studies using a mobile device was significantly different higher than in studies using a fixed device (0.85; 95%CI: 0.82 to 0.88 and 0.75; 95%CI: 0.65 to 0.84, $p = 0.04$) (Figure A4).

Type of Interface: Touchscreen Computer or Tactile Tablet

Sensitivity and specificity in studies using a tactile tablet (0.81; 95%CI: 0.76 to 0.84 and 0.83; 95%CI: 0.79 to 0.87, $p = 0.71$) were not significantly different from those of studies using a touchscreen computer (0.82; 95%CI: 0.76 to 0.87, and 0.82; 95%CI: 0.76 to 0.87, $p = 0.68$) (Figure A5).

The cognitive tests with the highest combined sensitivity and specificity are summarized in the table below (Table 1).

Table 1. Cognitive tests with the highest pooled sensitivity and specificity.

Authors Year	Cognitive Testings	Duration (min)	Administration Mode	Cognitive Domains Assessed	Diagnostic Performance
An 2024 [76]	Seoul Digital Cognitive Test	30	NS	Attention, language, visuospatial function, memory, executive function	se: 0.81 spe: 0.89
Cheah 2022 [34]	Rey-Osterrieth Complex Figure	-	Assessor-administered	Visuospatial constructional capabilities and visual memory function (immediate and recall), copying	se: 0.85 spe: 0.91
Curiel 2016 [36]	Miami Test of Semantic Interference and Learning	8–10	NS	Semantic memory, categorization	se: 0.85 spe: 0.84
Garre-Olmo 2017 [28]	7 tasks: figure copying (simple spiral, 3D house, crossed pentagons), clock drawing test, sentence copying, writing a dictated sentence and a spontaneous sentence	10–15	Assessor-administered	Kinesthetic, visuospatial function, motor features	For the task writing a dictated sentence: se: 1.00 spe: 1.00
Li 2024 [74]	Drawing and Dragging Tasks	15	Self-administered	Orientation, selective and sustained attention, visual memory and reconstruction, visuospatial organization, and hand motor skills	se: 0.86 spe: 0.91
Park 2018 [51]	Mobile cognitive function test system for screening mild cognitive impairment	10	Assessor-administered	Memory, orientation, attention, visuospatial ability, language, executive function, reaction time	se: 0.99 spe: 0.93
Rodrigues-Salgado 2021 [54]	Brain Health Assessment	10	Assessor-administered	Memory, processing speed and executive function, visuospatial ability, language	se: 0.87 spe: 0.85
Saxton 2009 [21]	Computer Assessment of Mild Cognitive Impairment	20	Self-administered	Verbal and visual memory, attention, psychomotor speed, language, spatial and executive functioning	se: 0.86 spe: 0.94
Wu 2023 [63]	Efficient Online MCI Screening System	10	Self-administered	Memory, visual attention, flexibility, visuospatial and executive function, cognitive proceeding speed	se: 0.85 spe: 0.85

NS: Not specified.

4. Discussion

This review and meta-analysis showed that cognitive tests on touchscreen tools are appropriate to diagnose mNCD in older adults. A large variety of digital devices give satisfactory results in screening for mNCD/MCI. Although imperfect, the overall performance of touchscreen cognitive tests is similar to that of the MoCA, the reference clinical test to screen for mNCD, and several touchscreen cognitive tests outperformed it. However, the heterogeneity of methods and tools makes it difficult to compare studies, precluding any conclusion as to which one is the most effective.

The high degree of heterogeneity among the studies led us to examine test performance based on their main characteristics in a subgroup analysis. It is interesting to note that tests that are short, self-administered and conducted on a touchscreen tablet perform as well as longer tests administered by an assessor or on a fixed device. The former characteristics are very appealing for devices in clinical use, as they are simple, require little professional time and can be used on easily accessible systems.

Through our review, several tools appeared to us to be attractive, due to their good performance in diagnosing mild cognitive disorders (Table 1). Rodríguez-Salgado [54] developed the tool that combines the most practical clinical features and performance, namely the Brain Health Assessment (BHA). It consists of 4 tests: Favorites (associative memory), Match (processing speed and executive function), Line Orientation (visuospatial skills), and Animal Fluency (language). It is a brief, tablet-based cognitive battery validated in English and Spanish, administered by an assessor. Garre-Olmo [28] reported very good results in terms of sensitivity and specificity for the detection of MCI with the Cambridge Cognitive Examination Revised (CAM-COG-R). This is part of a bigger test and consists of 7 tasks assessing cognitive, kinesthetic, visuospatial and motor features on a touchscreen tablet. It can be obtained by purchasing the CAMDEX-DS-II (A Comprehensive Assessment for Dementia in People with Down Syndrome and Others with Intellectual Disabilities) and is available in English and Dutch. The current version is administered by a professional. Park worked on a promising application that revealed the particularities of people with cognitive impairments in their daily use of the telephone keypad [80]. One might imagine downloading this module, which would evaluate keyboard use over several hours or days, taking much of the stress out of traditional exams. Another approach is home assessment, as tested by Thompson with the Mobile Monitoring of Cognitive Change (M2C2) [81], which measures visual working memory, processing speed and episodic memory. The M2C2 is a self-administered test, performed completely remotely, and the episodic memory task demonstrated good ability to distinguish Aß PET status among study participants.

This systematic review and meta-analysis have several limitations. First, it is likely to be affected by publication bias, as studies with null or negative results may be underrepresented. In addition, patient selection in the included studies limits generalizability. Indeed, many of the studies recruited highly selected or convenience samples, which may inflate performance estimates. The predominance of case–control study designs also introduces selection biases that could overestimate diagnostic accuracy compared to prospective cohort study designs. In order to limit potential bias, we excluded 13 articles that we rated, on an ad hoc basis, as having a high risk of bias according to the QUADAS-2 scale, which may also be considered a limitation of our meta-analysis. We also encountered some difficulties with the term "touchscreen device", which is broad and unclear, as pointed out in Nurgalieva's review about touchscreen devices. Indeed, devices are not often described in detail, and technology has undergone rapid development in recent years [82]. To address this challenge, we include several terms in our search equation intended to obtain a broad selection of articles and render our screening sensitive (see Table A1 in Appendix A). Nurgalieva's review also highlights the heterogeneity of older people, and the need to

categorize them according to the sensory or cognitive limitations they encounter, in order to be able to propose adapted tools.

5. Conclusions

Touchscreen devices can be used to detect mNCD, but their development has yet to be validated by real-life studies. Further efforts are warranted to harmonize assessment methods, although initial results are promising.

In future works, there should be methods for standardizing test procedures so that tools can be compared more easily. It would be of interest for clinical studies to describe their methods accurately and in detail, as well as the manner in which the formal diagnosis was made, in order to fully understand what is being evaluated. Results relating to tool performance are important for the purposes of comparison and should be published in all articles. Touchscreen-based tools need to be evaluated in real-life conditions with people being diagnosed with cognitive disorders, and the results compared.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/diagnostics15182383/s1. Reference [83] is cited in the supplementary materials.

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Abbreviations

The following abbreviations are used in this manuscript:

MCI	Mild Cognitive Impairment
NCD	Neuro Cognitive Disorder
NINCDS-ADRDA	National Institute of Neurological and Communicative Disorders and Stroke/Alzheimer's Disease and Related Disorders Association
NIAAA	National Institute on Aging-Alzheimer's Association
MoCA	Montreal Cognitive Assessment
MMSE	Mini Mental State Examination

Appendix A

Table A1. MeSH terms used for the database query.

Themes	MeSH Terms
Age factor	elderly, elder, aged, older adult, geriatrics
Screening/diagnostic	Diagnosis, diagnose, screening, assessment, evaluation, testing, detection
Neurocognitive condition	neurodegenerative diseases, cognitive disorders, neurocognitive disorders, dementia, Alzheimer disease
Touchscreen device	handheld computer, numeric tablet, smartphone, mobile applications, cell phone, touch screen, computer device, mobile technology, computer, electronic device, tablet, tablet computer, mobile device, web app

Table A2. Characteristics of studies using a tactile tablet or smartphone.

Author Year, Country	Participants *n* (age ± SD)	Name of the Touchscreen Test Language	Functions Assessed	Self-Administration	Touchscreen Test Duration	Mobility	Reference Diagnostic Criteria	Neuropsychological Testing for Reference Diagnosis
Alegret 2020 [29], Spain	61 MCI (67.74 ± 7.93) 154 control (67.98 ± 7.92)	FACEmemory® Spanish	Memory, recognition	yes	30	yes	NINCDS/ADRDA	NS
An 2024 [76], Korea	126 MCI (70.2 ± 7.8) 55 SCD (69.7 ± 7.2)	Seoul Digital Cognitive Test Korean	Memory, attention, language, visuospatial	NS	30	yes	Petersen	SNSB-II
Berron 2024 [84], Germany and USA	25 MCI (69.2 ± 6.8) 78 control (68.2 ± 5.5)	Remote Digital Memory Composite English and German	Memory, discrimination, Recognition	yes	NS	yes	NINCDS/ADRDA	MMSE, CERAD and neuropsychological battery tests
Boz 2019 [31], Turkey	37 MCI (70.4 ± 7.3) 52 control (67.6 ± 6.0)	Virtual Supermarket Turkish	Visual and verbal memory, executive function, attention, spatial navigation	no	25	yes	Petersen	MMSE and neuropsychological battery tests
Cheah 2022 [34], Taïwan	59 MCI (67.5 ± 6.3) 59 control (62.6 ± 5.9)	Rey-Osterrieth Complex Figure Taiwanese	Visuospatial, memory, organization skills, attention, visuomotor coordination	no	NS	yes	Jak et al.	Rey-Osterrieth Complex Figure (paper)
Chin 2020 [35], Korea	42 MCI (71.7 ± 7.3) 26 control (68.5 ± 6.3)	Inbrain Cognitive Screening Test Korean	Attention, language, visuospatial, memory and executive function	yes	30	yes	Petersen	MMSE and Seoul Neuropsychological Screening Battery
Freedman 2018 [37], Canada	50 MCI 57 control	Toronto Cognitive Assessment English	Memory, orientation, visuospatial, attention, executive control, language	no	34	yes	NIA-AA	Neuropsychological battery tests

Table A2. *Cont.*

Author Year, Country	Participants *n* (age ± SD)	Name of the Touchscreen Test Language	Functions Assessed	Self-Administration	Touchscreen Test Duration	Mobility	Reference Diagnostic Criteria	Neuropsychological Testing for Reference Diagnosis
Garre-Olmo 2017 [28], Spain	12 MCI (63.5 ± 6.5) 17 control (70.2 ± 7.4)	7 tasks Spanish	Cognitive, kinesthetic, visuospatial, motor features	no	10–15	yes	Petersen	Cambridge Cognitive Examination Revised
Gielis 2021 [39], Belgium	23 MCI (80.0 ± 5.2) 23 control (70.0 ± 5.4)	Klondike Solitaire Dutch	Cognitive skills, spatial and temporal function	yes	79	yes	Petersen	MoCA, MMSE and CDR
Ishikawa 2019 [27], Japan	25 MCI (75.9 ± 5.3) 36 control (70.0 ± 5.0)	Five drawing tasks Japanese	Memory, visuospatial, executive function	no	NS	yes	Petersen	MMSE
Kobayashi 2022 [43], Japan	65 MCI (74.5 ± 4.9) 52 control (72.6 ± 3.8)	Five drawing tasks Japanese	Memory, visuospatial, executive function	yes	NS	yes	NIA-AA	MMSE and neuropsychological battery tests
Kubota 2017 [20], USA	4 MCI 6 control	Virtual Kitchen Challenge English	Executive function, memory, attention, processing speed	yes	NS	yes	NS	Neuropsychological battery tests
Li 2025 [77], China	93 MCI (73.1 ± 4.8) 88 control (72.2 ± 5.1)	BrainNursing Chinese	Memory, language, attention, visuospatial, executive and fine motor functions	yes	25	yes	NS	MoCA, MMSE and a neuropsychological battery test
Li 2024 [74], China	108 MCI (71.3 ± 4.5) 99 control (70.1 ± 4.0)	Drawing and Dragging Tasks Chinese	Memory, attention, orientation, visuospatial, hand motor performance	yes	15	yes	NINDS-ADRDA	MoCA, MMSE and a neuropsychological battery test
Li 2023 [44], China	61 MCI (71.0 ± 5.8) 59 control (67.9 ± 6.2)	Digital cognitive tests + data from a smartwatch Chinese	Verbal fluency, memory, attention, listening, visuospatial and executive function	yes	NS	yes	Petersen	MMSE and MoCA

Table A2. *Cont.*

Author Year, Country	Participants *n* (age ± SD)	Name of the Touchscreen Test Language	Functions Assessed	Self-Administration	Touchscreen Test Duration	Mobility	Reference Diagnostic Criteria	Neuropsychological Testing for Reference Diagnosis
Li 2023 [45], China	30 MCI (69.2 ± 5.9) 30 control (66.1 ± 7.9)	Fingertip interaction handwriting digital evaluation Chinese	Memory, orientation, optimal decision-making, fingertip executive dynamic abilities	no	NS	yes	NIA-AA	MMSE
Li 2022 [26], China	43 MCI (61.9 ± 9.6) 12 control (58.3 ± 14.6)	Tree drawing test Chinese	Feature extraction of the drawing	yes	NS	yes	NS	MMSE
Libon 2025 [19], USA	17 MCI (74.8 ± 7.1) 23 control (70.0 ± 8.7)	Digital neuropsychological protocol English	Memory, executive function, language	yes	10	yes	NS	Neuropsychological battery tests
Müller 2019 [47], Germany	138 MCI (70.8 ± 8.4) 137 control (69.6 ± 7.8)	Digital Clock Drawing Test German	Visual perception and encoding, attention, anticipatory thinking, motor planning and executive functions	NS	4	yes	Petersen	CERAD
Müller 2017 [48], Germany	30 MCI (65.3 ± 6.6) 20 control (66.9 ± 9.4)	Digitizing visuospatial construction task German	Visuospatial construction, movements kinematics, fine motor control, coordination	yes	<1	yes	Petersen and NIA-AA	CERAD (German)
Na 2023 [49], Korea	93 MCI 73 control	Inbrain Cognitive Screening Test Korean	Visuospatial skills, attention, memory, language, orientation, executive function	yes	NS	yes	Petersen	CERAD (Korean)

Table A2. *Cont.*

Author Year, Country	Participants *n* (age ± SD)	Name of the Touchscreen Test Language	Functions Assessed	Self-Administration	Touchscreen Test Duration	Mobility	Reference Diagnostic Criteria	Neuropsychological Testing for Reference Diagnosis
Rigby 2024 [78], USA	62 MCI (72.1 ± 6.8) 96 control (69.0 ± 6.4)	NIH Toolbox Cognition Battery English and Spanish	Memory, executive function, processing speed	no	30	yes	NACC	National Alzheimer's Coordinating Center Unified Data set version 3
Robens 2019 [53], Germany	64 MCI (67.9 ± 11.2) 67 control (65.9 ± 10.3)	Digitized Tree Drawing Test German	Visuospatial and planning abilities, semantic memory and mental imaging	yes	4	yes	Petersen and McKhan	CERAD (German) and Clock Drawing test
Rodríguez-Salgado 2021 [54], Cuba	46 MCI (72.7 ± 7.5) 53 control (70.4 ± 5.9)	Brain Health Assessment Cuban-Spanish	Memory, processing speed, executive function, visuospatial skills, language	yes	10	yes	NS	MoCA, CERAD, BHA and neuropsychological battery tests
Simfukwe 2022 [22], Korea	22 MCI (67.2 ± 6.0) 22 control (53.0 ± 1.5)	Digital Trail Making Test-Black and White English and Korean	Attention, mental flexibility, visual scanning	yes	5	yes	NS	Trail Making Test-Black and White
Sloane 2022 [58], USA	21 MCI (71.1) 65 control (70.2)	Miro Health English	Movements, speech, language	yes	5 to 60	yes	American Academy of Neurology	MMSE, Telephone Interview for Cognitive Status; Geriatric Depression Scale
Suzumura 2018 [59], Japan	15 MCI (74.3 ± 6.0) 48 control (73.6 ± 8.3)	JustTouch screen Japanese	Finger motor skills	yes	NS	yes	Petersen	MMSE
Um Din 2024 [72], France	49 mNCD (79.5 ± 6.0) 47 control (78.2 ± 8.5)	Digital Clock Drawing Test French	Visuospatial, memory, planification	no	5	yes	DSM-V	Neuropsychological battery tests and paper CDT

Table A2. *Cont.*

Author Year, Country	Participants *n* (age ± SD)	Name of the Touchscreen Test Language	Functions Assessed	Self-Administration	Touchscreen Test Duration	Mobility	Reference Diagnostic Criteria	Neuropsychological Testing for Reference Diagnosis
Wu 2023 [63], China	73 MCI 175 control	Efficient Online MCI Screening System Chinese	Memory, attention, flexibility, visuospatial and executive function, cognitive proceeding speed	yes	10	yes	Petersen and American Academy of Neurology	MoCA-C, IADL, AD8 questionnaire
Yamada 2022 [65], Japan	67 MCI (74.1 ± 4.5) 46 control (72.3 ± 3.9)	Five drawing tasks Japanese	Visuospatial, planification	yes	NS	yes	McKhann, McKeith and Petersen	MMSE
Ye 2022 [66], USA	22 MCI (73.5 ± 5.9) 35 control (67.8 ± 9.6)	BrainCheck battery V4.0.0 English	Memory, inhibition, attention, flexibility	yes	15 to 37	yes	Alzheimer's Disease International	Neuropsychological battery tests
Yu 2019 [71], Taiwan	14 MCI (74.9 ± 5.2) 18 control (75.8 ± 5.8)	Graphomotor tasks: two graphic and two handwriting tasks Chinese	Fine motor function	no	NS	yes	Petersen	CDR and neuropsychological battery tests
Zhang 2024 [75], China	38 MCI (67.5 ± 7.2) 26 control (64.6 ± 7.0)	Tablet's Geriatric Complex Figure Test Chinese	Memory, visuospatial, planning, attention, fine motor coordination	no	23	yes	NIA-AA	Neuropsychological battery tests
Zygouris 2015 [68], Greece	34 MCI (70.3 ± 1.2) 21 control (66.6 ± 1.2)	Virtual Supermarket Test Greek	Memory, executive function, attention, spatial navigation	no	10	yes	Petersen	MoCA and MMSE
Zygouris 2020 [69], Greece	47 MCI (67.9 ± 0.8) 48 SCD (66.0 ± 0.6)	Virtual Supermarket Test Greek	Visual and verbal memory, executive function, attention, spatial navigation	yes	30	yes	Petersen	MMSE, MoCA

NS: not specified; SCD: Subjective Cognitive Decline. NIA-AA: National Institute on Aging-Alzheimer's Association; NINCDS-ADRDA: National Institute of Neurological and Communicative Disorders and Stroke/Alzheimer's disease and related Disorders Association; NACC: National Alzheimer's Coordinating Center; MoCA: Montreal Cognitive Assessment; CERAD: Consortium to Establish a Registry for Alzheimer's Disease neuropsychological test battery; CDT: Clock Drawing Test; SNSB: Seoul Neuropsychological Screening Battery.

Table A3. Characteristics of the studies using a computer touchscreen.

Author Year, Country	Participants *n* (age ± SD)	Name of the Touchscreen Test Language	Functions Assessed	Self-Administration	Touchscreen Test Duration	Mobility	Reference Diagnostic Criteria	Neuropsychological Testing for Reference Diagnosis
Ahmed 2012 [23], England	15 MCI (80.9 ± 7.2) 20 control (77.4 ± 4.0)	Computer-Administered Neuropsychological Screen for Mild Cognitive Impairment English	Memory, language, executive functions	yes	30	no	Petersen	ACE-R, MoCA
Cabinio 2020 [32], Italy	32 MCI (76.7 ± 5.3) 107 control (76.5 ± 3.0)	The Smart Aging Serious Game Italian	Executive function, attention, memory and orientation	yes	NS	NS	NIA-AA, DSM-5	MoCA, FCSRT, TMT A&B
Curiel 2016 [36], USA	34 MCI (77.6 ± 6.3) 64 control (74.0 ± 7.3)	The Smart Aging Serious Game English	Memory, categorization	NS	10	NS	NS	MMSE and the Loewenstein-Acevedo Scales for Semantic Interference and Learning
Fukui 2015 [38], Japan	41 MCI (75.3 ± 6.5) 75 control (75.1 ± 6.1)	Touch-panel screening test: flipping cards, finding mistakes, arranging pictures and beating evils Japanese	Memory, attention and discrimination, memory, judgment	NS	NS	no	ADNI	MMSE, HDS-R
Inoue 2005 [18], Japan	22 MCI (72.0 ± 9.6) 55 control (72.6 ± 7.3)	Six tests: age and year of birth, 3 words memory test, time orientation test, 2 modified delayed-recall test, visual working memory test Japanese	Memory, orientation, visual working memory	yes	5	no	Petersen	Neuropsychological tests, neuroimaging examination and medical checks

Table A3. *Cont.*

Author Year, Country	Participants *n* (age ± SD)	Name of the Touchscreen Test Language	Functions Assessed	Self-Administration	Touchscreen Test Duration	Mobility	Reference Diagnostic Criteria	Neuropsychological Testing for Reference Diagnosis
Isernia 2021 [41], Italy	60 MCI (74.2 ± 5.0) 74 control (75.5 ± 2.7)	Smart Aging Serious Game: 5 tasks of functional activities of everyday life Italian	Memory, spatial orientation, executive functions, attention	yes	30	NS	NINCDS-ADRDA	MoCA and neuropsychological battery
Liu 2023 [73], China	74 MCI (66.3 ± 10.1)	Computerized cognitive training Chinese	Memory, attention, perception, executive function	NS	NS	NS	Petersen	MoCA, MMSE, CDR
Memória 2014 [46], Brasil	35 MCI (73.8 ± 5.5) 41 control (71.7 ± 4.6)	Computer-Administered Neuropsychological Screen for Mild Cognitive Impairment Portuguese	Executive function, language, memory	yes	30–50	NS	Petersen	MoCA
Noguchi-Shinohara 2020 [50], Japan	94 MCI (75.8 ± 4.1) 100 control (75.0 ± 3.2)	Computerized assessment battery for Cognition Japanese	Time orientation, recognition, memory	yes	5	no	International Working Group	MMSE
Park 2018 [51], Korea	74 MCI (74.4 ± 6.5) 103 control (74.9 ± 7.0)	Mobile cognitive function test system for screening mild cognitive impairment English and Korean	Orientation, memory, attention, visuospatial ability, language, executive function, reaction time	no	10	yes	Petersen	MoCA-K
Porrselvi 2022 [25], India	18 MCI (71.0 ± 5.4) 100 control (66.3 ± 7.8)	Tamil computer-assisted cognitive test Battery Tamil	Attention, memory, language, visuospatial skills and spatial cognition, executive function, processing speed	NS	150	yes	Petersen	MoCA, CDR Scale, MMSE, and neuropsychological battery

Table A3. *Cont.*

Author Year, Country	Participants *n* (age ± SD)	Name of the Touchscreen Test Language	Functions Assessed	Self-Administration	Touchscreen Test Duration	Mobility	Reference Diagnostic Criteria	Neuropsychological Testing for Reference Diagnosis
Saxton 2009 [21], USA	228 MCI (75.2 ± 6.8) 296 control (71.8 ± 5.9)	Computer Assessment of Mild Cognitive Impairment English	Memory verbal and visual, attention, psychomotor speed, language, spatial and executive functioning	yes	20	yes	Criteria of the University of Pittsburgh Alzheimer Disease Research (ADRC)	MMSE and neuropsychological battery
Wang 2023 [24], China	46 MCI (70.0) 46 control (68.0)	Smart 2-Min Mobile Alerting Method Chinese	Fingertip interaction, spatial navigation, executive process	no	2	yes	NIA-AA	MMSE
Wong 2017 [62], China	59 MCI (78.2 ± 8.1) 101 control (70.5 ± 8.6)	Computerized Cognitive Screen English	Memory, executive functions, orientation, attention and working memory	yes	15	no	NS	MoCA
Wu 2017 [64], France	129 MCI (76.5 ± 7.5) 112 control (74.7 ± 6.9)	Tablet-based cancelation test French	Attention, visuospatial, psychomotor speed, fine motor coordination	yes	3	yes	Petersen	K-T cancelation test

NS: not specified. NIA-AA: National Institute on Aging-Alzheimer's Association; NINCDS-ADRDA: National Institute of Neurological and Communicative Disorders and Stroke/Alzheimer's disease and related Disorders Association; ADNI: Alzheimer's Disease in neuroimaging initiative; CDR: Clinical Dementia Rating Scale.

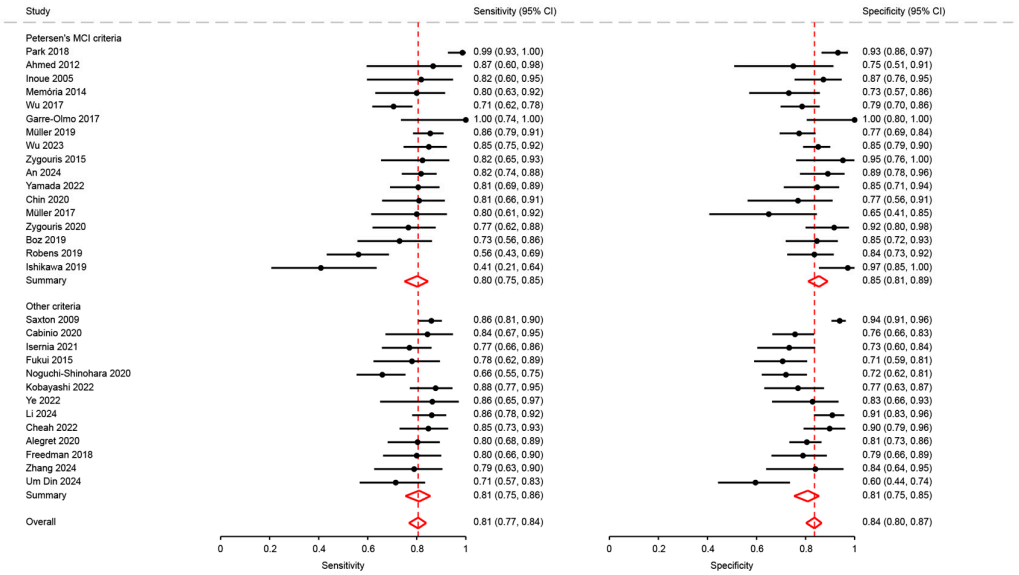

Figure A1. Analysis of sensitivity of studies using Petersen's MCI criteria with others [18,21,23,27–29,31,32,34,35,37,38,41,43,46–48,50,51,53,63–66,68,69,72,74–76].

Table A4. Results of the quality assessment of the articles by the QUADAS-2.

Study	Risk of Bias				Applicability Concerns			Decision
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard	
Ahmed 2012 [23]	☺	☺	☺	☺	☺	☺	☺	included
Alegret 2020 [29]	☺	☺	☺	☺	☺	☺	☺	included
An 2024 [76]	☺	☺	☺	☺	☺	☺	☺	included
Bergeron 2020 [30]	☺	?	☹	☺	☹	☺	☹	excluded
Boz 2020 [31]	☺	☺	☺	☺	☺	☺	☺	included
Cabinio 2020 [32]	☺	☺	☺	☺	☺	☺	☺	included
Cerino 2021 [33]	?	?	☺	?	☺	☺	☺	excluded
Cheah 2022 [34]	?	☺	?	☺	?	☺	☺	included
Chin 2020 [35]	☺	☺	☺	☺	☺	☺	☺	included
Curiel 2016 [36]	☺	☺	☺	☺	☺	☺	☺	included
Freedman 2018 [37]	☺	☺	☺	☺	☺	☺	☺	included
Fukui 2015 [38]	☺	☺	☺	☺	☺	☺	☺	included
Garre-Olmo 2017 [28]	☺	☺	☺	?	☺	☺	☺	included
Gielis 2021 [39]	☺	☺	☺	☺	☺	☺	☺	included
Groppell 2019 [40]	?	☺	☹	☺	?	☺	☹	excluded
Inoue 2005 [18]	☺	☺	☺	☺	☺	☺	☺	included
Isernia 2021 [41]	☺	☺	☺	☺	☺	☺	☺	included
Ishikawa 2019 [27]	☺	☺	☺	☺	☺	☺	☺	included
Ishiwata 2014 [42]	☹	☹	☹	☹	☹	☺	☺	excluded
Kobayashi 2022 [43]	☺	☺	☺	☺	☺	☺	☺	included
Kubota 2017 [20]	?	☺	NA	☺	☹	☺	NA	included
Li 2024 [74]	?	☺	☺	☺	☺	☺	☺	included
Li 2025 [77]	?	☺	☺	☺	☺	☺	?	included
Li 2023 [44]	☺	☺	☺	☺	☺	☺	☺	included
Li 2022 [26]	☺	☺	?	☺	☺	☺	☺	included
Li 2023 [45]	☺	☺	☺	☺	☺	☺	☺	included
Libon 2024 [19]	☺	☺	☺	☺	☺	☺	?	included
Liu 2023 [73]	☺	☺	☺	☺	☺	☺	☺	included
Memória 2014 [46]	☺	☺	☺	☺	☺	☺	☺	included
Morisson 2016 [70]	?	?	?	?	?	?	?	excluded
Müller 2019 [47]	☺	☺	☺	☺	☺	☺	☺	included
Müller 2017 [48]	☺	☺	☺	☺	☺	☺	☺	included

Table A4. *Cont.*

Study	Risk of Bias				Applicability Concerns			Decision
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard	
Mychajliw 2024 [79]	☺	☺	?	?	?	☺	?	excluded
Na 2023 [49]	?	☺	☺	☺	?	☺	☺	included
Noguchi-Shinohara 2020 [50]	☺	☺	☺	☺	☺	☺	☺	included
Park 2018 [51]	☺	☺	☺	?	☺	☺	☺	included
Porrselvi 2022 [25]	☺	☺	☺	☺	☺	☺	☺	included
Possin 2018 [52]	?	?	☺	?	☺	☺	☺	excluded
Rigby 2024 [78]	☺	☺	☺	☺	☺	☺	☺	included
Robens 2019 [53]	☺	☺	☺	☺	☺	☺	☺	included
Rodríguez-Salgado 2021 [54]	☺	☺	☺	☺	☺	☺	☺	included
Satler 2015 [55]	?	☺	☹	?	☹	☺	?	excluded
Saxton 2009 [21]	☺	☺	☺	☺	☺	☺	☺	included
Scharre 2017 [56]	☹	☺	☹	☺	☺	☺	☺	excluded
Shigemori 2015 [57]	☹	☹	?	?	☹	☹	?	excluded
Simfukwe 2022 [22]	☺	☺	?	☺	☺	☺	☺	included
Sloane 2022 [58]	☺	☺	☺	☺	☺	☺	☺	included
Suzumura 2018 [59]	☺	☺	☺	☺	☺	☺	☺	included
Tamura 2006 [60]	?	☺	?	?	☺	☹	☺	excluded
Um Din 2024 [72]	☺	☺	☺	☺	☺	☺	☺	included
Wang 2023 [24]	☺	☺	☺	☺	☺	☺	☺	included
Wilks 2021 [61]	?	☺	☹	?	☺	?	?	excluded
Wong 2017 [62]	☹	☺	☺	☺	☹	☺	☺	included
Wu 2023 [63]	☺	☺	☺	☺	☺	☺	☺	included
Wu 2017 [64]	☺	☺	☺	☺	☺	☺	☺	included
Yamada 2022 [65]	☺	☺	☺	☺	☺	☺	☺	included
Ye 2022 [66]	☺	☺	?	☹	☺	☺	☹	included
Yu 2019 [71]	☺	?	☺	☺	☺	?	☺	included
Zhao 2019 [67]	?	?	?	?	☺	☺	☺	excluded
Zhang 2024 [75]	☺	☺	☺	☺	☺	☺	☺	included
Zygouris 2015 [68]	☺	☺	☺	☺	☺	☺	☺	included
Zygouris 2020 [69]	☺	☺	☺	☺	☺	☺	☺	included

☺ Low Risk; ☹ High Risk; ? Unclear Risk.

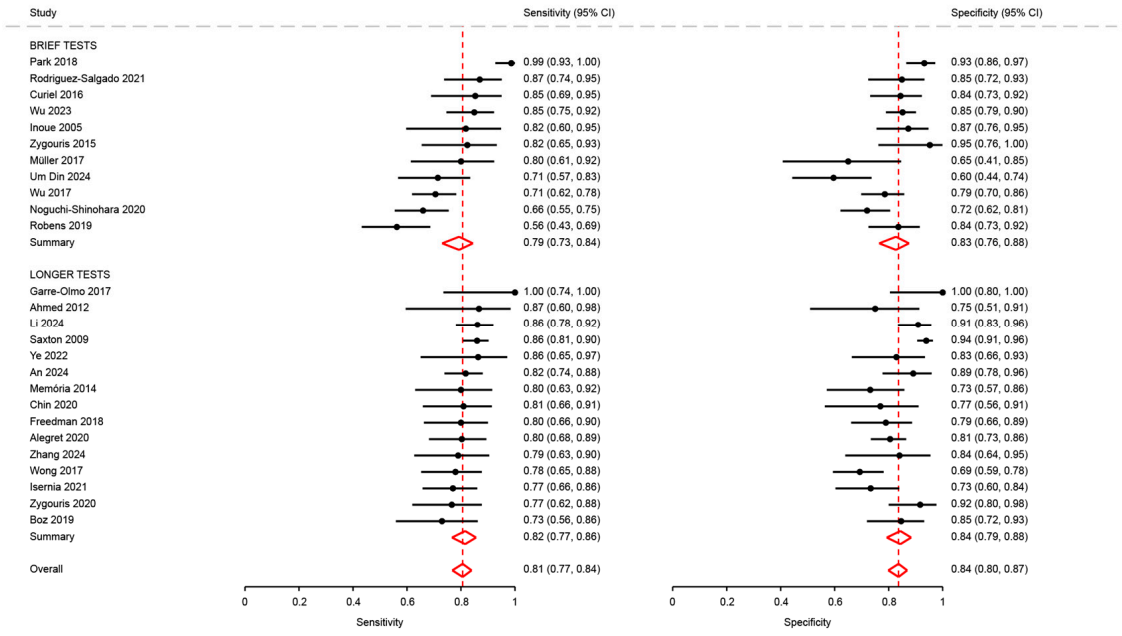

Figure A2. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders by test duration [18,21,23,28,29,31,35–37,41,46,48,50,51,53,54,62–64,66,68,69,72,74–76].

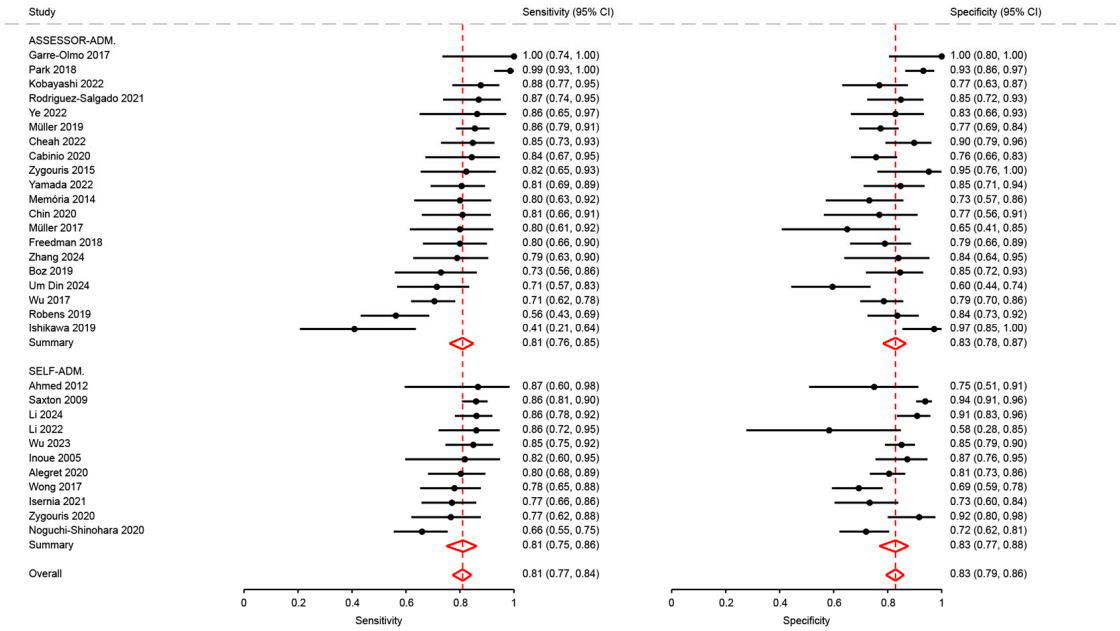

Figure A3. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders by modality of assessment [18,21,23,26–29,31,32,34,35,37,41,43,46–48,50,51,53,54,62–66,68,69,72,74–76].

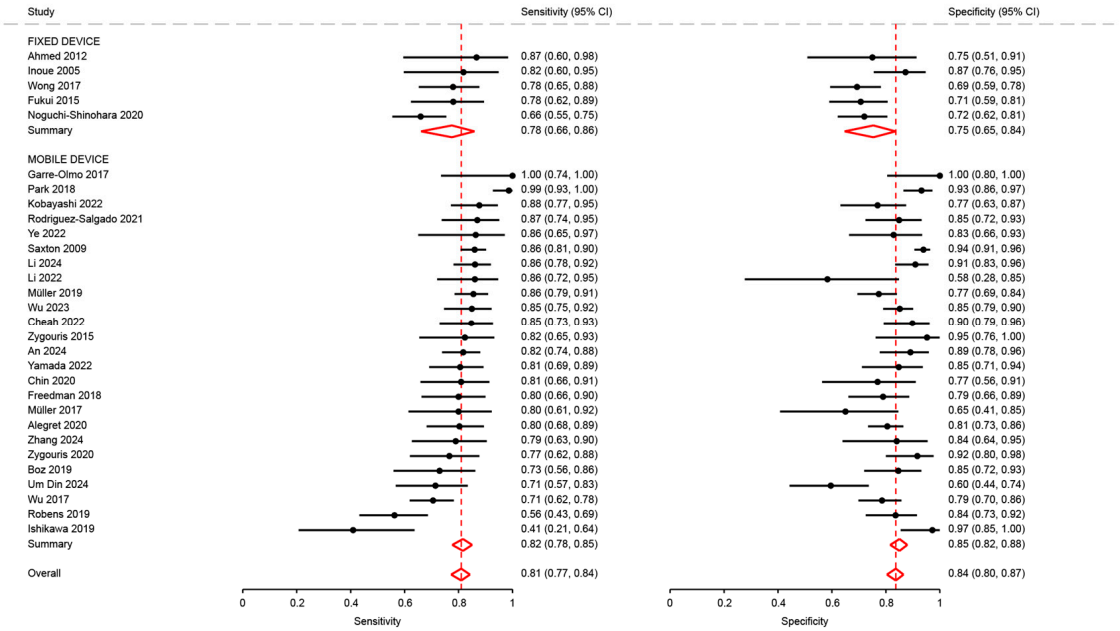

Figure A4. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders by type of mobile device [18,21,23,26–29,31,34,35,37,38,43,47,48,50,51,53,54,62–66,68,69,72,74–76].

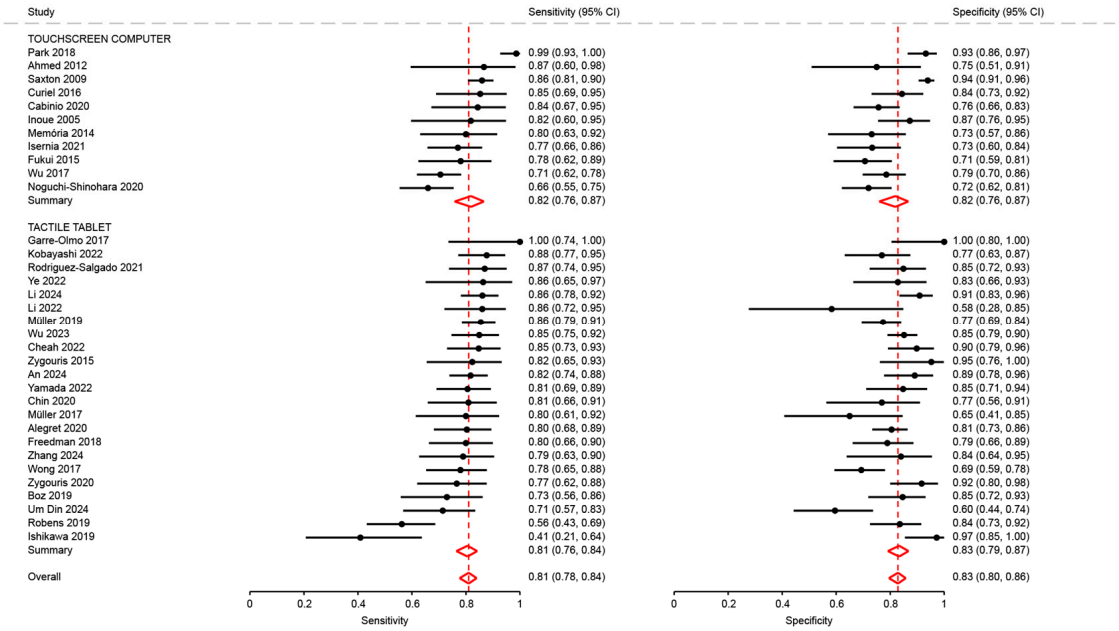

Figure A5. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders by type of touchscreen device [18,21,23,26–29,31,32,34–38,41,43,46–48,50,51,53,54,62–66,68,69,72,74–76].

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