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Titre : Faisabilité et utilité des évaluations cognitives sur tablette tactile pour le repérage des troubles neurocognitifs

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Vieillir en beauté c'est vieillir avec son cœur
Sans remords, sans regrets, sans regarder l'heure
Aller de l'avant, arrêter d'avoir peur
Car, à chaque âge, se rattache un bonheur.

Felix Leclerc, La Vieillesse

Résumé

Un trouble neurocognitif correspond à une altération des fonctions cognitives. Ces troubles cognitifs peuvent être liés à des maladies neurocognitives comme la maladie d'Alzheimer. La prévalence de ces maladies augmente avec le vieillissement de la population. Leur diagnostic requiert une batterie de tests nécessitant l'expertise d'une équipe médicale et paramédicale spécialisée. Des outils de repérage de ces maladies existent mais présentent des résultats hétérogènes, et restent difficiles à utiliser pour un médecin de soins primaires. Les outils numériques, dont les écrans tactiles sont plus faciles à utiliser par les personnes âgées, pourraient aider au repérage des maladies et à leur orientation à bon escient vers un centre spécialisé. L'objectif de cette thèse est d'étudier l'intérêt de tests réalisés sur une tablette tactile dans l'aide au repérage des troubles neurocognitifs chez les personnes âgées en combinant des données mixtes issues d'un questionnaire médical, de tâches cognitives et de tâches de motricité fine. Pour cela, nous avons mené deux méta-analyses sur les outils d'évaluation cognitive sur écran tactile dans le repérage des troubles neurocognitifs pour décrire et analyser les caractéristiques des outils existants et de comparer leurs performances. Ces travaux ont mis en avant une excellente faisabilité et des résultats similaires entre les tests auto-administrés et ceux administrés par un professionnel ; et également des performances similaires entre les tests brefs et les longs. Nous avons ensuite élaboré un outil intégrant ces caractéristiques afin d'identifier par une étude clinique les éléments pertinents qui contribueraient au repérage de ces maladies et proposer un outil réunissant toutes ces connaissances. L'exploration du jeu de données ainsi constitué a mis en évidence un nombre restreint de variables indépendantes et pertinentes qui pourront entrer dans la constitution d'un dispositif numérique pour identifier les troubles neurocognitifs. En conclusion, le développement des tests cognitifs sur écran tactile semble être une solution intéressante et performante dans le repérage des troubles neurocognitifs chez les personnes âgées.

Mots clés : personnes âgées – repérage – diagnostic – aide à la décision – recherche clinique – santé numérique – usabilité et acceptabilité – motricité fine – tablette tactile

Abstract

A neurocognitive disorder is an impairment of cognitive functions. These cognitive disorders may be related to neurocognitive diseases such as Alzheimer's disease. The prevalence of these diseases increases with the aging of the population. Their diagnosis requires a battery of tests that require the expertise of a specialized medical and paramedical team. Tools for detecting these diseases exist but vary in effectiveness and remain difficult for primary care physicians to use. Digital tools with touchscreens that are easier for older people to use could help screen for diseases and refer them to the right specialized center. The objective of this thesis is to study the benefits of tests performed on a touchscreen tablet in helping to identify neurocognitive disorders in older adults by combining mixed data from a medical questionnaire, cognitive tasks, and fine motor skills tasks. For this purpose, we conducted two meta-analyses on touchscreen cognitive assessment tools for identifying neurocognitive disorders in order to describe and analyze the characteristics of existing tools and compare their performance. This work has demonstrated excellent feasibility and similar performance between self-administered tests and those administered by a professional, as well as similar performance between short and long tests. We then developed a tool incorporating these characteristics in order to identify, through a clinical study, the relevant elements that would contribute to the detection of these diseases and propose a tool combining all this knowledge. Exploration of the resulting dataset revealed a limited number of independent and relevant variables that could be used to develop a digital tool for identifying neurocognitive disorders. In conclusion, the development of touchscreen cognitive tests appears to be an interesting and effective solution for identifying neurocognitive disorders in older adults.

Keywords: older adults – screening – diagnosis – decision support – clinical research – digital health – usability and acceptability – fine motor – touchscreen tablet

Abréviations

AUC	Area Under the Curve
CDR	Clinical Dementia Rating Scale
EVA-13	Echelle de Vulnérabilité des Ainés-13
MA	Maladie d'Alzheimer
MCI	Mild Cognitive Impairment
MIS	Memory Impairment Screen
MMSE	Mini-Mental State Examination
MoCA	Montreal Cognitive Assessment
OMS	Organisation Mondiale de la Santé
PROMs	Patient-Reported Outcome Measures
ROC	Reveiver Operating Characteristic
Se	Sensibilité
Spe	Spécificité
TNC	Trouble Neurocognitif
TNC-L	Trouble Neurocognitif Léger
TNC-M	Trouble Neurocognitif Majeur
VES-13	Vulnerable Elders Survey – 13

I. Introduction

Les maladies neurocognitives et le trouble neurocognitif majeur

Les maladies neurocognitives chroniques sont un groupe de maladies du cerveau dont l'évolution conduit à un déclin de l'indépendance fonctionnelle, en altérant progressivement la mémoire, le langage, le raisonnement ou le comportement. La plus fréquente d'entre elles est la maladie d'Alzheimer qui entraîne une altération des fonctions cognitives et notamment des troubles de la mémoire portant sur le rappel de faits récents. Elle altère aussi le langage, les fonctions exécutives, l'orientation temporo-spatiale, l'humeur. Reisberg et al. ont décrit 7 stades de la maladie (1) : les stades 1, 2 et 3 sont les stades de pré-démence où la personne peut avoir de légers troubles cognitifs sans que cela ne la dérange ; le stade 4 est le stade de la démence légère avec un déclin cognitif modéré, c'est souvent à ce stade que le diagnostic est posé ; le stade 5 est le stade de démence modérée où la personne a besoin d'une aide pour les activités de la vie quotidienne, c'est-à-dire les activités nécessaires pour prendre soin de son propre corps ; le stade 6 est la démence modérément sévère où la personne ne peut plus s'habiller seule, faire sa toilette et peut avoir des troubles du comportement ; le stade 7 est la démence sévère, c'est le dernier stade de la maladie où la personne ne peut plus marcher, présente une rigidité généralisée et des troubles du langage importants. En recherche, le questionnaire d'évaluation clinique de la démence (« *Clinical Dementia Rating Scale* ») (2) est utilisé pour identifier la sévérité de la maladie, il évalue de manière globale 6 domaines (mémoire, orientation, jugement et résolution des problèmes, position dans la communauté, foyer et passe-temps, hygiène personnelle). Cette échelle est notée de 0 à 3 : 0 correspondant à

l'absence de trouble, 0,5 aux troubles incertains, 1 aux troubles légers, 2 aux troubles modérés et 3 aux troubles sévères.

Les maladies neurocognitives sont une source de préoccupation majeure pour la santé publique. En 2020, plus de 50 millions de personnes vivaient avec un trouble neurocognitif majeur (TNC-M) dans le monde selon l'*Alzheimer's Disease International* (3). Le nombre de personnes atteintes de maladies neurocognitives a augmenté au cours des dernières décennies en raison du vieillissement de la population (4,5) avec environ 1,2 million de personnes en France (6). Les projections démographiques prévoient une très forte croissance au cours des prochaines décennies et le *Global burden of disease* estime que la prévalence mondiale des TNC-M sera de 152,8 millions en 2050 (5). L'Organisation Mondiale de la Santé (OMS) évalue le coût des maladies neurocognitives à 1,3 mille milliards de dollars dans le monde (7). Ces coûts comprennent les coûts médicaux directs, les coûts sociaux directs, et la moitié concerne les coûts des soins informels. Ils sont surtout engendrés par la dépendance associée dont la sévérité augmente avec la progression de la maladie (8). Le retentissement de ces maladies concerne les personnes malades, mais aussi leurs proches qui les accompagnent et les aident au quotidien pendant toute la durée de la maladie. Afin de faire face à ces préoccupations de santé publique, l'OMS a mis en place un plan d'action global (*Global action plan on the public health response to dementia 2017-2025*) pour améliorer la qualité de vie des personnes touchées à travers le monde. Ses domaines d'actions concernent notamment l'information autour de la maladie, la réduction des risques, le diagnostic, le traitement, les soins, le soutien aux aidants, la recherche et l'innovation (9).

Le trouble neurocognitif (TNC) est une réduction acquise, significative et évolutive des capacités dans un ou plusieurs domaines cognitifs. Le manuel diagnostique et statistique des troubles mentaux, dont la 5ème édition est parue en 2013 (*Diagnostic and Statistical Manual of Mental Disorders,* DSM-5) (10) fournit des critères précis de ces TNC. Il distingue d'une part le trouble neurocognitif majeur (TNC-M) qui affecte plusieurs domaines cognitifs dont la mémoire, et qui implique une perte d'autonomie pour les actes de la vie quotidienne, et d'autre part le trouble neurocognitif léger (TNC-L) qui peut ne concerner qu'un seul domaine cognitif et qui n'implique pas de perte d'indépendance. Les termes TNC-M et TNC-L, définis par le DSM-5, ont remplacé progressivement les termes de démence et de *mild cognitive impairment* respectivement, utilisés auparavant par les praticiens et les chercheurs. Dans notre travail, par souci de simplification, nous utiliserons systématiquement le terme TNC-M en décrivant les publications qui utilisent le terme de démence. De même, nous utiliserons le terme TNC-L pour décrire celles qui utilisent le terme *mild cognitive impairment*.

Quelques concepts concernant le diagnostic des troubles neurocognitifs

Pour le diagnostic des TNC, le parcours de soin recommandé dans les guides de bonne pratique consiste en 1) un repérage en soins primaires souvent réalisé par un médecin généraliste, 2) puis un adressage en centre spécialisé qui 3) aboutira à un diagnostic après mobilisation de praticiens pluridisciplinaires et d'examens complémentaires. Voici les concepts liés au diagnostic résumés dans le tableau ci-dessous (Tableau 1) :

Tableau 1. Concepts concernant le diagnostic des troubles neurocognitifs

Repérage/screening	S'adresse à des personnes ayant déjà des problèmes de santé (ici difficultés de mémoire, chute, dépendance, …) et les tests ont pour objectif de savoir si ces personnes peuvent avoir un TNC. Le repérage aide à organiser le parcours de soin et à proposer d'adresser ou non l'individu à un centre spécialisé.
Dépistage organisé	S'adresse à des personnes qui n'ont pas de symptômes, et vise à identifier une maladie chez des personnes en apparente bonne santé. Le dépistage organisé des TNC en population générale n'est pas recommandé dans les bonnes pratiques car les thérapeutiques disponibles ont une efficacité faible.
Diagnostic des troubles neurocognitifs	Est porté à l'aide des critères diagnostiques (ceux du DSM-5 ou d'autres organisations) par des praticiens ayant l'expérience des maladies neurocognitives, le plus souvent des neurologues ou des gériatres en centres spécialisés (consultations mémoire).
Diagnostic précoce du TNC-M	Consiste à faire le diagnostic des TNC avant que le déclin cognitif soit à un stade évolué, c'est-à-dire au stade de TNC-L ou de TNC-M débutant.
Dépistage opportuniste	Il a lieu en dehors d'un programme de dépistage organisé et il est proposé au cas par cas chez des patients demandeurs ou bien en raison de facteurs de risque.

Le diagnostic des troubles neurocognitifs

Les critères diagnostiques des TNC-M basés sur le DSM-5, requièrent un déclin de la mémoire et de l'apprentissage et d'au moins un autre domaine cognitif (il en existe six au total : attention complexe, fonctions exécutives, apprentissage et mémoire, langage, perception-motricité et cognition sociale) ainsi qu'une interférence avec les activités de la vie quotidienne (activités instrumentales de la vie quotidienne ou activités de base de la vie quotidienne) (10). Lorsque les TNC n'ont pas de retentissement dans les actes de la vie quotidienne, il s'agit d'un trouble neurocognitif léger (TNC-L) ou encore *Mild Cognitive Impairment* (MCI). Le MCI comprend obligatoirement les plaintes concernant la mémoire, concept qui a évolué en TNC-L avec une considération plus globale des troubles cognitifs incluant l'attention, les fonctions exécutives, l'apprentissage, la mémorisation, le langage, la perception motrice et la cognition sociale. La présence ou l'absence de plaintes concernant la mémoire n'intervient plus dans les critères diagnostiques (11). Le TNC-L regroupe des

situations cliniques très hétérogènes notamment du point de vue de leur évolution : il peut rester stable tout au long du vieillissement ; il peut régresser jusqu'à retrouver l'état cognitif normal ; mais il peut aussi évoluer vers un TNC-M, et pour ce dernier cas, il s'agit d'une maladie neurocognitive en cours d'installation.

Le diagnostic actuel des TNC est basé sur un examen médical et une batterie de tests neuropsychologiques. La recherche de biomarqueurs, examens d'imagerie cérébrale ou tests biologiques, est réalisée pour trouver les maladies responsables de TNC. Les investigations conduisant au diagnostic de TNC sont réalisées par une équipe pluridisciplinaire disponible dans des centres spécialisés : infirmier, neuropsychologue, gériatre/psychiatre ou neurologue. Le délai entre l'apparition des premières plaintes mnésiques et l'annonce d'un diagnostic peut être long avant une prise en soin. Au sein de l'Union européenne, le délai moyen global entre l'apparition d'une plainte mnésique et l'établissement d'un diagnostic est de 2 ans (12). Cette errance diagnostique peut être causée par le délai important entre l'apparition d'un symptôme et sa considération. La personne est susceptible de cacher ses difficultés, compenser ses troubles cognitifs débutants de manière consciente ou non, puis l'entourage peut mettre du temps avant de prendre conscience de ces troubles et convaincre la personne à aller consulter un médecin. Selon une enquête de la Fondation Médéric Alzheimer, le délai d'attente pour une première consultation est de 71 jours en moyenne et varie selon les établissements (13).

Les TNC-M et notamment de la maladie d'Alzheimer sont très largement sous-diagnostiqués, pour des raisons complexes comme le déni des personnes malades ou de leur entourage, des craintes de stigmatisation, au manque de formation des

professionnels et notamment des médecins généralistes (12,14) et aussi à l'accessibilité au diagnostic en général (12).

Il a longtemps été pensé qu'un diagnostic précoce avait peu d'intérêt du fait du manque de solutions, mais désormais les recommandations de bonne pratique soulignent son importance (14). Ce diagnostic est d'autant plus important qu'il permet d'accompagner le patient et ses proches, d'apporter une écoute et répondre aux interrogations, de donner des conseils adaptés, de proposer des aides et un accompagnement juridique, de maintenir une bonne qualité de vie. Il permet aussi de mettre en place des interventions de stimulations cognitives et physiques rapidement, de traiter les symptômes, de retarder l'institutionnalisation, et de développer la recherche clinique (14,15). Enfin, cela permet de mettre la personne au centre de la démarche en soin, de prendre des décisions éclairées, d'organiser et planifier sa vie future. Une enquête auprès de professionnels et de patients a mis en avant les bénéfices bien plus importants que les risques, ce qui conforte l'idée de développer et changer les mentalités sur le sujet (16). La revue de De Levante soulève le fait que les croyances et attitudes des médecins sont une barrière majeure à lever (17).

Les outils de repérage conventionnels

Les outils de repérage sont nombreux, et comportent des propriétés différentes (18). Les plus connus, validés en français, et utilisés en clinique sont ceux présentés dans le tableau ci-dessous (Tableau 2). Ces tests sont validés et utilisés en version papier.

Tableau 2. Principaux outils de repérage conventionnels des troubles neurocognitifs et leur performance

Tests	Sensibilité		Spécificité		Remarques
	TNC-L	TNC-M	TNC-L	TNC-M	
Mini Mental State Examination (19)	0,62	0,78	0,87	1,00	Sensible à l'âge et niveau socio-éducatif. Bonne détection des troubles de la mémoire et du langage
Montreal Cognitive Assessment (20)	0,89	1,00	0,75	0,87	Sensible à l'âge et niveau socio-éducatif. Évaluation plus fine des capacités visuo-spatiales et des fonctions exécutives. Plus sensible au changement.
Codex (21)	-	0,92	-	0,85	Mémoire et test de l'horloge simplifiée.
5 mots de Dubois (22)	-	0,91	-	0,87	Mémoire uniquement. Différencie troubles de l'encodage et de la récupération.
Memory Impairment Screen (23)	0,45	0,60	0,89	0,88	Pas d'influence du niveau éducatif. Ne détecte pas bien les TNC-L.
Rappel libre-rappel indicé à 16 items du test de Grober-Buschke (24)	-	0,79	-	0,76	Prend en compte le contexte culturel et linguistique des participants
Test du dessin de l'horloge (25)	0,63	0,85	0,77	0,85	Besoin d'être complété par d'autres évaluations.

Les outils numériques au service du diagnostic

L'essor du numérique dans le domaine de la santé (26) a permis de développer des outils numériques faciles à implémenter et à utiliser, ce qui en font des outils intéressants pour faciliter l'accès aux outils numériques pour les populations isolées géographiquement des lieux de soins. Le plan d'action 2017-2025 de l'OMS (9) encourage l'utilisation des technologies auprès des personnes atteintes de TNC-M à tous les stades ainsi qu'à leurs aidants, que cela soit pour informer, recenser ou pour développer des outils numériques à leur usage. La connaissance de la santé numérique chez les personnes âgées devient un enjeu important pour les années à venir car elle va rapidement devenir un indicateur à prendre en compte pour l'adhérence à ces outils et des comportements favorables à la santé (27).

Les outils numériques pourraient permettre un diagnostic rapide, simple, précoce pour les professionnels de santé et les personnes âgées (16). L'intérêt grandissant des écrans tactiles pour les personnes âgées peut s'expliquer par leur facilité d'utilisation et leur interaction intuitive pour des personnes n'ayant pas l'habitude d'utiliser des

technologies (28). D'autre part, les écrans tactiles sont une interface intéressante car ils permettent une grande liberté de création pour les concepteurs ce qui augmente les possibilités d'élaboration et les modalités d'évaluation. Il faut également prendre en compte l'hétérogénéité des personnes âgées en termes de familiarité avec les technologies mais également les limitations normales liées à l'avancée en âge (baisse de la vision, baisse de l'audition, toucher) qui ne permettent plus les mêmes interactions. La difficulté dans l'élaboration de nouveaux outils réside dans le fait de tenir compte de ces limitations sans pour autant créer des outils trop différents et stigmatisants, qui ne seraient pas adoptés par les usagers. L'étude de Nurgalieva et al. pointe que les personnes âgées sont souvent considérées comme un groupe homogène par les concepteurs d'application, qui n'ont pas d'idées claires sur les compétences et limitations de cette population, ce qui engendre des produits inadaptés et donc inutilisés. Malgré des outils de screening avec des performances correctes, ils ne sont pas ou peu utilisés en clinique, les causes peuvent être multiples comme les tests auto-administrés sur tablette qui nécessitent une connaissance technologique même basique pour la mise à jour des outils et leur utilisation (29).

L'informatique au service du domaine médical

L'apprentissage automatique (*machine learning*) est un domaine de l'informatique qui vise à développer des systèmes ou des machines capables d'effectuer des tâches qui requièrent normalement l'intelligence humaine ; ces tâches comprennent l'apprentissage, le raisonnement, la résolution de problèmes, le traitement du langage naturel et la prise de décision (30,31). Il comprend des techniques supervisées et des techniques non supervisées. Les techniques supervisées ont pour objectif de prévoir la valeur spécifique d'un résultat plutôt que de classer les données. Les plus utilisées

sont les régressions linéaires, les régressions logistiques, les méthodes d'ensemble et la régression par vecteurs de support. Les techniques non supervisées ont pour objectif d'analyser de grandes quantités de données non étiquetées avec un apprentissage non linéaire et en utilisant des paramètres de modèles complexes. L'apprentissage automatique a permis d'améliorer la prédiction et la classification des maladies grâces aux données issues des patients, notamment les dossiers médicaux électroniques qui sont une base précieuse pour ces techniques qui ont besoin de nombreuses données pour s'affiner en permanence. Les cliniciens ont rapidement compris son intérêt et les collaborations avec les ingénieurs sont nombreuses (32).

Dans l'ère de la médecine de précision (ou médecine personnalisée) - qui consiste à utiliser des outils diagnostiques et de traitements ciblés sur les besoins de chaque patient en fonction de ses caractéristiques génétiques, psychosociales ou de ses biomarqueurs (33) - l'apprentissage automatique a fait ses preuves dans de nombreux domaines médicaux (34) : en oncologie (35,36) et spécifiquement dans le cancer du sein (37) ; en cardiologie (38) et en imagerie médicale (39). La gériatrie aussi bénéficie de son utilisation, avec une majorité d'études sur les TNC et quelques-unes sur la prédiction du risque de survenue d'un événement ou d'une maladie (40). Parmi les différentes thématiques nous retrouvons la prédiction de la durée du séjour des patients âgés atteints de maladies chroniques au moment de l'admission en établissement (41), la détection et la prévention des chutes (42), la prédiction de la confusion postopératoire (43), la prédiction de la fragilité (44), mais ces travaux demandent encore à être développés et ne permettent pas à ce jour de tirer des connaissances généralisables pour la pratique clinique. Les méthodes supervisées et non supervisées sont utilisées en médecine et présentent chacune des forces et

faiblesses, il convient alors de choisir celles plus adaptées aux données qui sont à notre disposition, aux tâches et aux ressources disponibles (30).

Contribution du travail de thèse

Cette thèse vise à élaborer un outil d'aide au repérage des troubles neurocognitifs, non invasif, accessible grâce à une tablette tactile, et réalisable par des professionnels non spécialisés dans les soins primaires. Les résultats des tests cognitifs conventionnels et les approches des données neurobiologiques semblent satisfaisants, c'est pourquoi nous avons élaboré un outil combinant des données mixtes, c'est-à-dire des données qualitatives et quantitatives issues de différents types d'évaluation (questionnaire, épreuves), pour éventuellement obtenir un repérage plus rapide et précis, qui pourrait être indépendant du niveau socio-culturel, ce qui fait souvent défaut lors des évaluations cognitives classiques.

Cette thèse pourrait contribuer à la recherche sur le repérage des TNC, à étudier l'apport du numérique dans cette évaluation, et aider à différencier les TNC-L qui sont plus difficiles à détecter que les TNC-M. Nous souhaitons par ce travail montrer l'intérêt des données mixtes par une approche d'apprentissage automatique en utilisant des variables plus précises et peut être plus pertinentes que nous permet la technologie actuelle.

Ce travail s'inscrit donc dans l'esprit des travaux de Qiu et al. (45), qui cherche à classer des personnes ayant des TNC à partir de données mixtes : données démographiques, antécédents médicaux, évaluations fonctionnelles, imagerie médicale et résultats des tests neuropsychologiques. Nous souhaitons utiliser des données mixtes issues d'exercices plus classiques, moins coûteux, dans une optique d'utilisation en soin primaire. Le travail de la thèse consistera à élaborer un outil de

repérage des TNC sur une tablette tactile, et d'identifier les variables d'intérêts les plus pertinentes pour la classification. Pour ce faire, une étude clinique a été réalisée, avec le recueil de données auprès des participants, puis l'exploration du jeu de données pour la recherche des combinaisons pertinentes au moyen des méthodes statistiques et de l'informatique médicale. La constitution du jeu de données sera la base de plusieurs travaux de la thèse, avec une recherche des variables pertinentes et des caractéristiques des tests à favoriser selon les données de la littérature.

Questions de recherche

Est-ce que des données issues de différentes évaluations réalisées au moyen d'une tablette tactile augmentent la performance des tests de repérages des troubles neurocognitifs ? Quelle serait la meilleure combinaison de variables qui permettrait un repérage rapide et performant de ces troubles neurocognitifs chez les personnes âgées ?

Nous proposons dans un premier chapitre un état de la littérature sur lequel le travail de la thèse est basé, sur l'utilisation d'outils à écrans tactiles dans le diagnostic des TNC, qui a donné lieu à la publication de deux revues systématiques et méta-analyses sur le diagnostic des troubles neurocognitifs par des tests cognitifs sur tablette tactile auprès des personnes âgées. Ce travail vise à contribuer à la recherche en identifiant les outils de repérage des TNC existants, d'en relever les caractéristiques et les comparer au diagnostic de référence, de pointer les limites dues aux méthodes hétérogènes des études et des propositions d'amélioration. Dans un second chapitre, nous présenterons comment les outils de la tablette ont été élaborés et validés, avec un travail de préparation en vue de l'étude clinique, avec la publication d'un article de

validation d’une échelle numérique de la fragilité sur tablette, d’un article de congrès sur la numérisation et la comparaison des performances des horloges numériques et d’un poster publié sur la preuve de concept des exercices sur tablette. Ce travail vise à contribuer à la recherche en proposant des outils validés numériquement, qui peuvent être utilisés par des cliniciens. Dans la partie finale nous présenterons l’aboutissement de ce travail par l’étude clinique qui aura été la ligne directrice et le cœur de la thèse. Ce travail aura pour but de contribuer à la recherche par la proposition d’une combinaison de variables pour la création d’un outil d’aide au repérage des TNC.

II. Revue systématique de la littérature

Dans cette première partie, nous avons réalisé un état des lieux des outils numériques les plus développés sur écran tactile dans le repérage des TNC chez les personnes âgées pour guider notre travail. L'objectif était d'avoir une vue d'ensemble des outils existants, de lister et de comparer les caractéristiques précises des différents outils pour pouvoir déterminer ceux qui réuniraient une balance satisfaisante entre praticité et performance dans une optique d'utilisation par des cliniciens.

Les principaux points méthodologiques sont les suivants. Le protocole a été enregistré auprès du « International Prospective Register of Systematic Review » (PROSPERO numéro CRD42022358725) et les articles suivent les lignes directrices du PRISMA-DTA (*Preferred Reporting Items for Systematic reviews and Meta-Analyses*) (46,47). Nous avons questionné 4 bases de données, deux étant plutôt orientées médecine et deux orientées vers l'informatique médicale : PubMed, Embase, IEEE Xplore and Web of Science. Face au grand nombre d'articles retenus après les différentes étapes de sélection, nous avons choisi de scinder la revue systématique selon les diagnostics pour une meilleure compréhension : une revue systématique sur les TNC-L et une autre sur les TNC-M. Nous avons utilisé les termes MeSH (*Medical Subject Headings*) relatifs au dépistage/diagnostic, aux personnes âgées, aux maladies neurocognitives, aux écrans tactiles. Les résultats ont fait l'objet d'une analyse descriptive et d'une méta-analyse en sous-groupes, basée sur les différentes caractéristiques : la durée, le type d'administration, la mobilité de l'outil, le type d'interface, et le type de maladie pour les TNC-M.

Le premier article sur le repérage des TNC-M a été publié dans la revue *Age and Ageing* en 2025 sous la référence :

Um Din N, Maronnat F, Zolnowski-Kolp V, Otmane S, Belmin J. Diagnosis accuracy of touchscreen-based testings for major neurocognitive disorders: a systematic review and meta-analysis. Age Ageing. 2025 Jul 1;54(7):afaf204. doi: 10.1093/ageing/afaf204. PMID: 40742248; PMCID: PMC12312100.

Le deuxième article sur le repérage des TNC-L a été publié dans la revue *Diagnostics* en 2025 sous la référence :

Um Din N, Maronnat F, Oquendo B, Pariel S, Lafuente-Lafuente C, Badra F, Belmin J. Diagnostic Accuracy of Touchscreen-Based Tests for Mild Cognitive Disorders: A Systematic Review and Meta-Analysis. Diagnostics (Basel). 2025 Sep 18;15(18):2383. doi: 10.3390/diagnostics15182383. PMID: 41008755; PMCID: PMC12468971.

Article 1. Diagnosis accuracy studies of touchscreen-based testings for major neurocognitive disorders: a systematic review and meta-analysis.

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SYSTEMATIC REVIEW

Diagnosis accuracy of touchscreen-based testings for major neurocognitive disorders: a systematic review and meta-analysis

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Abstract

Facing an increasing prevalence, diagnosis and management of dementia has become a global health challenge. While most cognitive assessments are based on paper tests, the current trend is to digitise them, using new technologies. We aimed to achieve a systematic review on touchscreen-based assessments for neurocognitive disorders. A search on four databases (PubMed, Embase, IEEE Xplore and Web of Science) was performed. Two investigators independently selected the articles and assessed their quality using the QUADAS-2 tool. We included articles whose participants were over 65 years, classified according to the presence/absence of major neurocognitive disorder (M-NCD) determined by conventional assessment of cognition, examined with a novel tool using a touchscreen device (tablet or smartphone). We finally retained 35 articles for the systematic review and 24 for the meta-analysis. Of the 35 articles included in the systematic review, participants had Alzheimer's disease, Parkinson's disease, vascular dementia, Lewy body disease or any type of dementia. Pooled sensitivity and specificity were 0.89 (95% CI: 0.86–0.91) and 0.88 (95% CI: 0.82–0.92), respectively. Performances of self-administered or brief assessment testings were similar to those of assessor-administered or longer duration testings. The major limitation of this review and meta-analysis is the multiplicity and diversity of methods (tools, cognition assessment and type of M-NCD), which make the comparison difficult. We conclude that brief and self-assessment touchscreen-based cognitive tests are appropriate and simple tools to screen major cognitive disorders that can be used in primary care. The study was registered in Prospero (CRD42022358725).

Keywords: older adults; major neurocognitive disorder; dementia; touchscreen; diagnosis; digital tools—systematic review

Key Points

- Touchscreen-based testings are innovative tools for assessing cognitive functions.
- There is a wide range of research work, with heterogeneous tools and methods, and their performance in screening major neurocognitive disorders is diverse.
- This systematic review and meta-analysis found that touchscreen-based testings enable reliable screening for major neurocognitive disorders, particularly those related to Alzheimer's disease.
- Self-administered or brief assessment testings, using tactile tablets or mobile devices are appropriate, with performances similar to assessor administered or longer duration testings, and those using touchscreen computers or fixed devices.

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Introduction

In 2020, around 50 million people worldwide were affected by dementia, and this is expected to rise to 152 million by 2050 [1]. Faced with rising costs, managing dementia is a global public health issue both for high- and low-income countries. Among all causes, Alzheimer's disease (AD) is the first one (60%–70%) and is defined by specific criteria [2]. Other neurodegenerative diseases can lead to dementia, such as Parkinson's disease or Lewy body disease. AD has an insidious onset and a slow, gradual progression. After an asymptomatic clinical phase lasting several years, the first signs are a moderate deterioration in performance in one or more cognitive domains, such as memory, attention, planning or other mental faculties. Clinically, it's a mild neurocognitive disorder caused by Alzheimer's disease, also known as mild cognitive impairment (MCI). These symptoms inevitably evolve into major neurocognitive disorder (M-NCD) or dementia, defined by multidomain cognitive dysfunction responsible for loss of autonomy in activities of daily living. M-NCDs are the cause of impaired quality of life, psychological and behavioural disorders, falls and hospitalisations. They represent a considerable burden for families and often lead to admission in nursing homes.

Early diagnosis of M-NCD is widely recommended to inform patients and their families, so that they can be aware of what is at stake and make the necessary decisions [1, 3]. The challenge of early detection of the disease is to propose interventions before the dementia stage. It is a favourable period for cognitive stimulation to maintain the person's abilities. Currently, the diagnosis of M-NCD is based on detailed cognitive and clinical assessment realised in memory clinics by dementia specialists. In order to optimise referral to these centers, screening of these conditions in primary care is recommended by clinical guidelines. Indeed, early management could allow patients and their carers to organise themselves and put appropriate measures in place. Unfortunately, access to diagnosis remains limited, and many cases are underdiagnosed. The development of brief tools in primary care seems to be an essential step in improving access to early diagnosis, by facilitating patients' referral to a specialised centre by primary care practitioners.

Several authors have proposed digital programs to enhance and maintain cognitive functions [4, 5] using new technologies such as immersive virtual reality [6]. Beyond rehabilitation, digital cognitive assessments have also been studied on computers, touchscreen computers, tactile tablets, smartphones [7, 8] or in virtual reality [6]. In rehabilitation, these new cognitive evaluations could be appropriate by allowing assessments at home, in an ecological environment, rather than in specialised places such as memory centres. These new approaches could also be faster and more relevant for professionals, like touchscreens that don't require additional equipment to be installed. What's more, touchscreens are more intuitive, nonstigmatising and don't require to learn an additional tool like a mouse or a keyboard on a computer. Faced with the profusion of new technologies designed for cognitive assessment, we wanted to focus on systems using tactile interfaces, as these are of particular interest to older adults, especially those with cognitive disorders [5]. Indeed, technologies using keyboard- or mouse-based interfaces seem more complex to use with this population, and using them is already a cognitive task in itself [9]. To our knowledge, there has been no systematic review of this type of cognitive assessment to date. Nevertheless, each author has developed their digital assessment, either created new tests or drawn inspiration from classical tests [10]. This variety of evaluations associated with small populations reduces the possibilities of current utilisation. Each test should be evaluated and standardised before generalised use.

In this context, we aimed to examine in depth current knowledge about innovative tactile tools such as touch tablets and smartphones for screening cognitive impairment in people with M-NCD. To achieve this goal, we undertook a systematic review and meta-analysis to produce a comprehensive synthesis of tested and validated digital tools and to determine their performance in identifying M-NCD.

Methods

The protocol of this systematic review and meta-analysis has been registered in the International Prospective Register of Systematic Review (PROSPERO, CRD42022358725) and its report with the PRISMA guidelines [11].

Search strategy

We conducted searches on four electronic databases: PubMed, Embase, Web of Science and IEEE Xplore. Initially, we searched for articles published up to 31 December 2023, then extended the search period to 31 December 2024, during the revision process (amendment of our protocol). We used MeSH (Medical Subject Headings) terms relating to screening/diagnosis, older adults, neurocognitive diseases, tablets and smartphones (see Appendix 1 in the Supplementary Data section for the full details of the search strategy). The references of review articles cited were manually searched to retrieve relevant studies. Only articles in English were selected.

Selection criteria

We included articles whose participants: (i) were over 65 years of age, (ii) were classified according to the presence/absence of M-NCD determined using a conventional assessment of cognition (standardised neuropsychological test) (see Appendices 2 and 3 for further details about the conventional assessments used) and (iii) were examined using a novel tool, using a touchscreen digital device (touch tablet or smartphone).

Data extraction

Two authors (N.U.D. and F.M.) independently selected relevant articles from the references provided by databases queries on PubMed, Embase, Web of Science and IEEE

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Xplore. Any discrepancies have been discussed among the evaluators, and a consensus has been reached. If compromises between the two evaluators could not be reached, a third person (J.B.) was involved, and a meeting was organised to re-examine the articles as a group and resolve any points of divergence. Articles management was performed using Zotero® (version 6.0.30) and Excel 2013®. All remaining duplicates were individually checked by the two authors. Each investigator passed the study selection criteria independently. The reason for exclusion was noted on the Zotero label, and discrepancies were discussed to reach an agreement.

The descriptive data for each article were collected jointly by the two authors. We wanted to analyse the selected articles in as much detail and precision as possible, and we collected the information available in all the articles. This included: the country, the publication's year, the inclusion period of the participants, the mean ages of the population, the reference diagnostic criteria, the diagnosis and type of dementia, the neuropsychological testing for reference diagnosis, the name of the touchscreen test and the cognitive functions assessed. We also collected data on touchscreen characteristics: the type of the device, the modality of administration, whether it was an assessor- or a self-administered test, the duration of the novel testings and the mobility of the device. Sensitivity, specificity and contingency table were also recorded for performance analysis. For all data, when it was missing or unclear for both investigators, we decided to note it as 'not specified' (NS) in the table. When the contingency table was not available in the article, we calculated the number of true positives, false positives, true negatives and false negatives with sensitivity and specificity.

Assessment of bias and quality

The quality of the selected articles was assessed by two authors (N.U.D., F.M.) using the Quality Assessment of Diagnostic Accuracy Studies 2 instrument (QUADAS-2) [12] which evaluates the risk of bias and applicability of diagnostic accuracy studies. A third author (J.B.) was involved to resolve any discrepancies. It contains four key domains: patient selection, index test, reference standard, flow and timing. Each domain is considered by the risk of bias and the applicability, if they are high, low or unclear.

Meta-analysis

We retrieved information on the performance of the tools tested: we looked for information on true-positive, false-positive, true-negative and false-negative cases. If the information did not appear in an article, we contacted the corresponding author to obtain it.

We performed the analysis with the METADTA program of STATA software (version 16.1). We carried out sub-group analyses according to the diagnosis (Alzheimer's disease, vascular dementia or dementia any type), the mobile device used (touchscreen computer or tactile tablet) and if it was a fixed or a mobile device, the type of questionnaire (assessor-administered or self-administered) and the duration of the test (brief test for <10 minutes and longer test for >10 minutes).

Results

Included studies

Database queries provided 6517 articles. Additional articles were identified through readings and articles references. After search for duplicates, title and abstract analysis, 202 articles were retained for full text analysis. We excluded 167 articles after full reading: 20 articles were purely descriptive with no analysis or performance evaluation; 40 articles did not use a touchscreen in the evaluation; 13 articles were feasibility studies with no evaluation of their tool; 7 articles had no clearly established diagnosis or the diagnostic criteria were too poor; 50 articles concerned another cognitive disease; 1 article did not include patients; 13 articles did not evaluate cognition; 19 articles had no control or comparison group; and 4 articles were in a language other than English. Finally, 35 articles were included in the systematic review and 24 in the meta-analysis (Figure 1).

Study characteristics

Study characteristics are presented in the supplementary data (see Appendix 2 for studies that used tactile tablets and Appendix 3 for those that used a touchscreen computer). These articles were published between 2009 [13] and 2024 [14] and emanated from 15 countries located in Europe, Asia, America and Africa.

Participants and settings

The studies included 5127 participants including 1914 men and 2705 women (in three studies, participants' gender was missing). The number of participants by study varied from 23 [15] to 610 [16] with an average of 146. Participants' mean age was 74 years, ranging from 65 to 90 years [17, 18] and was missing in two studies. They were recruited from memory centres ($n = 16$), community ($n = 1$), both memory centers and community ($n = 4$), general hospitals ($n = 7$), both general hospital and community ($n = 1$), both psychiatry departments and community ($n = 2$) and from research programs ($n = 2$). Two studies did not precise their recruitment methods.

Reference diagnosis (index)

The reference diagnosis (presence/absence of M-NCD) was determined by specialised professionals using reference criteria and tests or parts of tests validated and accepted by the scientific community, such as the Mini Mental Status Examination (MMSE), The Montreal Cognitive Assessment (MoCA) or The Alzheimer's Disease Assessment Scale–Cognitive Subscale (ADAS-Cog), and are detailed in Supplementary data (see Appendices 2 and 3). The aetiology of M-NCDs varied between studies and was Alzheimer's disease ($n = 19$), Alzheimer's disease or Lewy body disease

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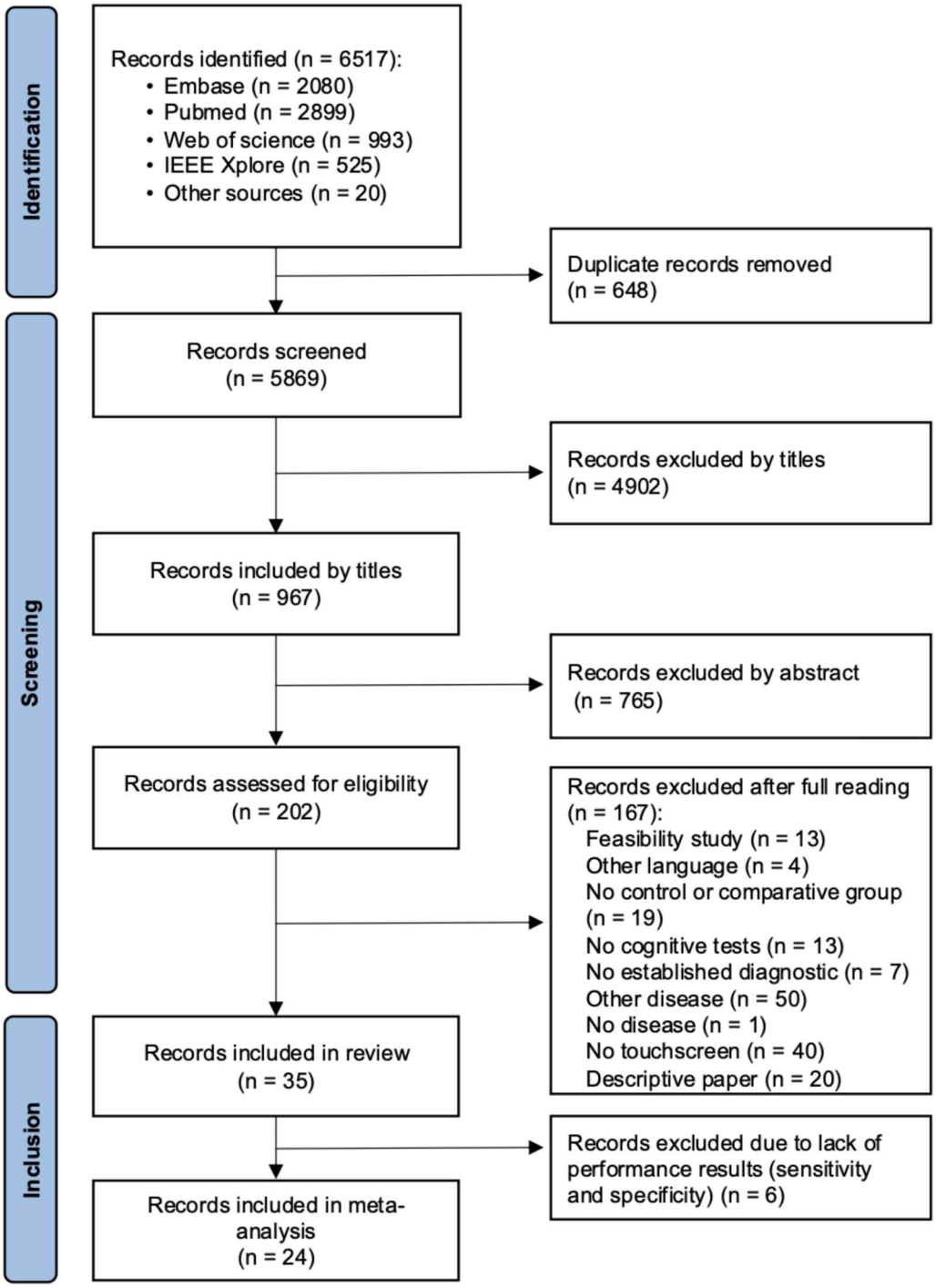

Figure 1. Flow chart.

($n = 1$), Alzheimer's disease or dementia ($n = 1$), vascular dementia ($n = 1$), Parkinson's disease ($n = 1$) and any type of dementia ($n = 12$).

Touchscreen testing procedures

A phase of learning and familiarisation with the digital tool has been described in 10 studies and was not specified in the other.

Digital test times ranged from 3 minutes [19] to unlimited [17]. The time needed to complete the testings was <5 minutes in 18 studies, between 10 and 15 minutes for 2 studies, between 15 and 30 minutes for 9 studies, between 30 and 60 minutes for 1 study and >1 hour for 1 study.

Twenty-five studies used a self-administered assessment (71%), 6 were assessor-administered (17%) and 4 studies (11%) did not report this information. The professionals

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involved were health practitioners or researchers trained in the assessments required.

The studies used tactile tablets ($n = 24$), touchscreen computers ($n = 10$) and both tactile tablets and computers ($n = 1$).

Twenty-nine of these devices were mobile (83%) versus 2 fixed (6%), while 4 studies did not specify the characteristics of their tool (11%).

Performance results and side-effects

Twenty-four have measured the performance of their digital tests by calculating the sensitivity and specificity of their conclusion using reference diagnosis. Sensibility score ranged from 0.80 (95% CI: 0.56–0.94) to 1.00 (95% CI: 0.84–1.00) [20, 21]. Specificity score ranged from 0.57 (95% CI: 0.40–0.72) to 0.97 (95% CI: 0.90–1.00) [20, 22, 23]. No side effects were reported in the studies and touchscreen.

Quality assessment

Overall quality of the studies assessed by QUADAS-2 was good [7, 13–46] (see Appendix 4). One study had a single item rated with risk of bias [24], one had two items rated with risk of bias [25] and four studies had items with unclear risk of bias [15, 17, 26, 27]. A third author intervened to resolve the disagreement over six articles.

Meta-analysis

Main results

Pooled sensitivity and specificity were 0.89 (95% CI: 0.86–0.91) and 0.88 (95% CI: 0.82–0.92), respectively. Heterogeneity coefficient (I2) was 0.27 and 0.75 for sensitivity and specificity, respectively, indicating that the studies were homogeneous according to sensitivity but heterogeneous regarding specificity. We also analysed the performance of the touchscreen testings presented according to the M-NCD aetiology: Alzheimer's disease, vascular dementia and dementia of any type (Figure 2). Pooled sensitivity and specificity for Alzheimer's disease were 0.89 (95% CI: 0.86–0.91) and 0.90 (95% CI: 0.85–0.93), respectively. In the single study done on vascular dementia, sensitivity and specificity were 0.74 (95% CI: 0.54–0.89) and 0.99 (95% CI: 0.93–1.00). Pooled sensitivity and specificity for dementia of any type were 0.89 (95% CI: 0.85–0.93) and 0.76 (95% CI: 0.64–0.86), respectively. Sensitivity of testings in Alzheimer's dementia studies were not significantly different from those in dementia of any type ($P = 0.39$), but specificity was significantly worse in dementia of any type ($P < .001$) (Figure 3).

Subgroup analysis

We analysed the effects of test procedures and device characteristics (duration and administration modalities, tablet/-computer and mobile/fixed device) on their performance. We performed the analyses using the data available in the 24 articles. Data were complete for outcome and type of touchscreen, but there were still some missing data that were not included in the analysis. For duration, data were not available for six articles, for administration, modality data were not available for two articles, and for mobility data were not available for two articles. The pooled sensitivity and specificity for these subgroups of studies are presented in Figure 3. The heterogeneity was calculated by the I^2 statistics. Detailed corresponding forest plots with the individual studies are shown in the supplementary material (see Appendices 5–8), and the results obtained are described in the sections below.

Duration: brief test or longer test

Sensitivity and specificity in studies using brief tests (0.89; 95% CI: 0.85–0.92 and 0.83; 95% CI: 0.74–0.90, respectively) were not significantly different from those of studies using longer tests (0.88; 95% CI: 0.82–0.92, $P = .81$, and .90; 95% CI: 0.80–0.95, $P = .24$) (see Appendix 5).

Type of administration

Sensitivity and specificity in studies using a self-administered questionnaire (0.89; 95% CI: 0.86–0.92 and 0.89; 95% CI: 0.83–0.93, respectively) were not significantly different from those administered by an assessor (0.85; 95% CI: 0.77–0.91, $P = .21$ and 0.81; 95% CI: 0.61–0.93, $P = .29$, respectively) (see Appendix 6).

Type of interface: touchscreen computer or tactile tablet

Sensitivity and specificity in studies using a touchscreen computer (0.87; 95% CI: 0.82–0.91 and 0.88; 95% CI: 0.75–0.95, respectively) were not significantly different from studies using a tactile tablet (0.89; 95% CI: 0.86–0.92, $P = .45$, and 0.88; 95% CI: 0.81–0.92, $P = .92$, respectively) (see Appendix 7).

Mobility: fixed or mobile device

Testing specificity in studies using a mobile device (0.89; 95% CI: 0.87–0.91) was significantly better than studies using a fixed device (0.62; 95% CI: 0.35–0.83, $P = .03$), but the corresponding sensitivity was not significantly different (0.89; 95% CI: 0.87–0.91 and 0.84; 95% CI: 0.79–0.89, $P = .08$) (see Appendix 8).

Discussion

This systematic review and meta-analysis found that the touchscreen testings on digital tools are appropriate to screen and diagnose M-NCD in older adults. We found a wide variety of existing numerical tools, and most of them had a high sensitivity to screen this condition. However, their specificity varies from one tool to another, as evidenced by the wide heterogeneity between studies. This is due to the fact that the tools used were not the same and did not necessarily

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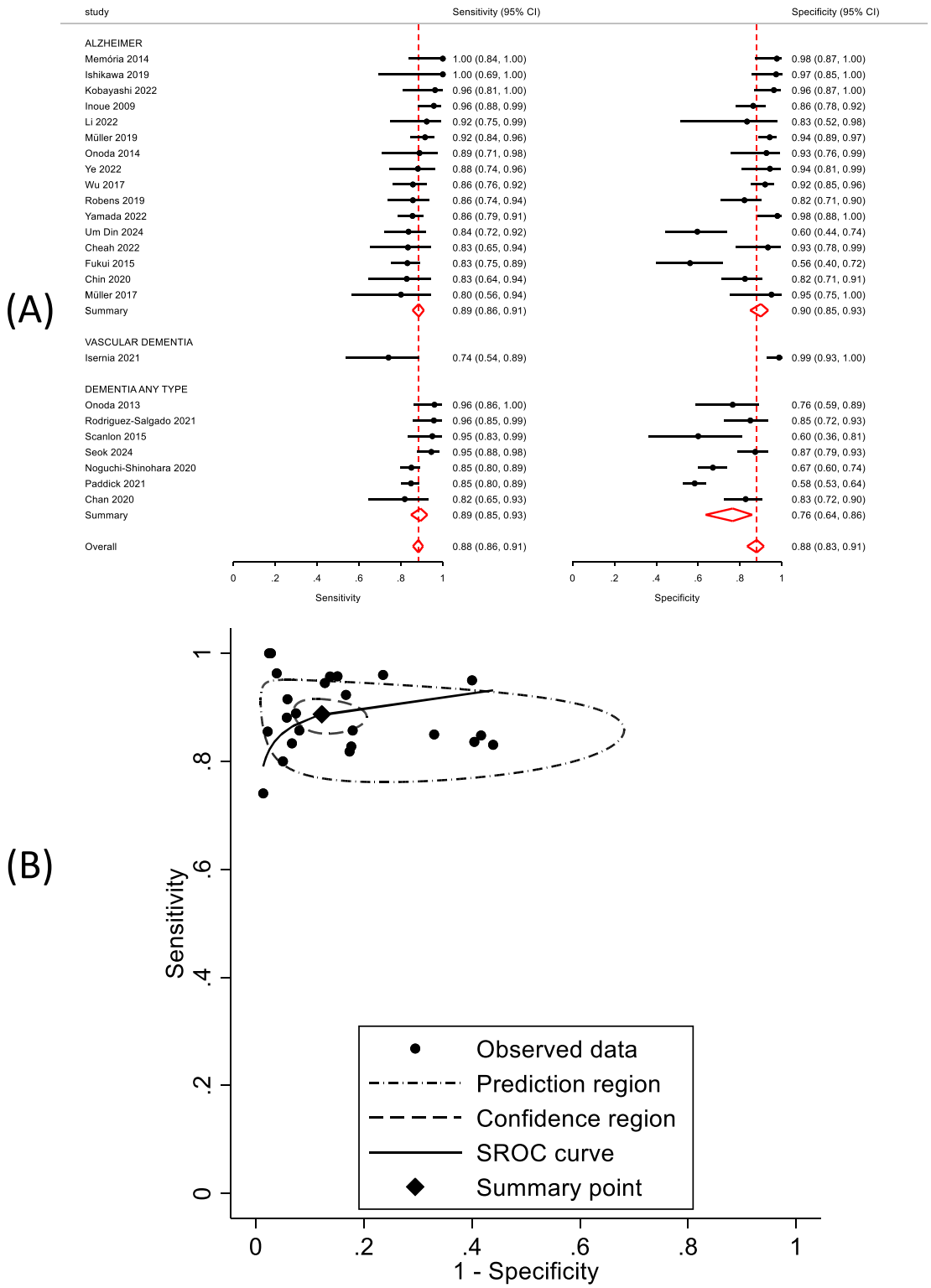

Figure 2. Analysis of sensitivity and specificity for the diagnosis of the M-NCD by type of dementia.

assess the identical cognitive functions. The digital testings with the lowest specificity (0.57) [22] included a large number of cognitive tasks (memory, attention, discrimination, processing and judgement), which may be a little too broad and would not allow good discrimination. The digital testings with the best specificity (0.97) [23, 28] involved fine

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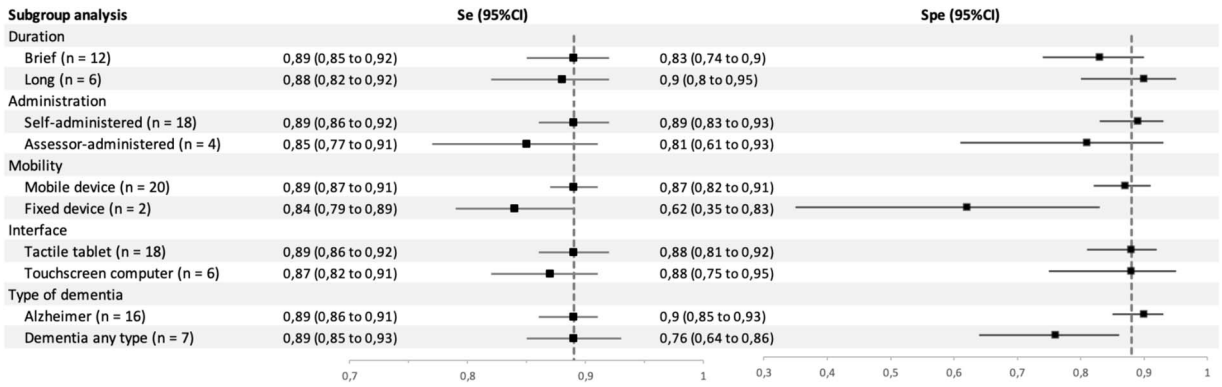

Figure 3. Subgroup analysis of pooled sensitivity and specificity of touchscreen cognitive testings for the diagnosis of M-NCD.

motor tasks for two of them, and one of the tools was designed to diagnose mild cognitive disorders [20]. Interestingly, we found that several simple tools, brief and self-administered, had appropriate performances to be used by clinicians [25, 29, 30].

Among the tools that combine diagnostic performance and simplicity, we have identified several. The Five drawing and writing test, designed by Kobayashi *et al*., uses a touchscreen tablet and a smart pencil. The Cognitive Assessment for Dementia iPad version (CADi2), developed by Onoda *et al*., consists of 10 simple questions from existing tests digitised on a touchscreen tablet. A free iOS app is available in English and Japanese. The BrainCheck battery of cognitive tests, developed by Ye *et al*., consists of a combination of existing tests adapted to a touchscreen tablet and is commercially available online. It evaluates memory, attention, executive function, mental flexibility and processing speed within 15 minutes and has already been validated in the United States as a class II of medical device by the FDA. All these tools are self-administered and have shown excellent sensitivity and specificity, and they might be useful to screen older adults for M-NCD.

To our knowledge, we have conducted the first meta-analysis of the diagnosis of neurocognitive disorders on a touchscreen device. Our work complements two recent systematic reviews on the subject. In 2021, Chan *et al*. [7] evaluated all types of digital tools for cognitive diagnosis and concluded that digital versions of the tests had a diagnostic performance comparable or even better than traditional paper-and-pencil cognitive ones. In 2022, Giaquinto *et al*. [31] focused on the use of tactile devices for cognitive diagnosis in primary care and assessed their feasibility across populations with cultural, linguistic and educational diversity. We found similar results about the performance of digital tools and centred our research on touchscreen devices and completed our work with subgroup meta-analysis to detail diagnostic performance according to tool characteristics.

Our study suffers from publication bias, a problem inherent in systematic reviews and meta-analyses, as people working on these subjects don't always publish their results, especially when they are negative. The other limitation of our study is the multiplicity and diversity of methods (tools, conventional assessments, cognition assessment and type of M-NCD), which makes it more difficult to compare studies. This certainly explains the heterogeneity observed for the specificity of these tools. However, despite the diversity of models, we noted good homogeneity for sensitivity, which indicates that the global approach is interesting for dementia screening. Even the term 'touch tablet' was the subject of a wide variety of terms used to describe it, making it difficult to find out what it means. Efforts to harmonise methods appear to be necessary if results are to be comparable. Further work is needed on translating assessments and applications into several languages. For high-quality diagnosis, clinical studies must calculate and publish the sensitivity and specificity of their tools, in comparison with one or more reference tests. The tools that correspond to the efficacy criteria highlighted by our meta-analysis and that deserve more widespread clinical use are the Five drawing and writing test, the CADi2 and the BrainCheck battery. They should be more widely deployed and cross-culturally validated in several languages to facilitate dissemination.

The biggest challenge now is to promote the use of these tools in order to gain real-life clinical experience. Potential barriers to widespread adoption include clinicians' scepticism of new technologies, patients' familiarity with them and cost considerations. Since touchscreen tablets are widely available for healthcare professionals, digital tools for cognitive screening might become a new approach to screen and diagnose M-NCD in primary care. We should take advantage of the ease and practicality of digital tools. Short and self-administered digital testings could be more widely used for cognitive screening, e.g. in the waiting room before a medical visit, with usage modalities similar to those for patient-reported outcome measures. It would be interesting to be able to combine a fun time of self-assessment with a debriefing with the doctor at a later stage, making the assessment less stressful for patients and perhaps closer to their abilities. Many studies have been carried out in diagnosed groups, but it would be valuable to develop studies in real clinical practice without having the classification in advance.

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Supplementary Data

Title: Diagnosis accuracy studies of touchscreen-based testings for major neurocognitive disorders: a systematic review and meta-analysis.

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Appendix 1. MeSH terms used for databases queries

ALT TEXT: table of database queries terms by main topic (screening/diagnostic, age factor, neurocognitive disorder, touchscreen device).

Screening/diagnostic		Age factor		Neurocognitive disorder		Touchscreen device
diagnosis		aged		neurodegenerative diseases		handheld computer
diagnose(s)		elderly		cognitive disorders		numeric tablet
screening		elder		cognition disorders		smartphone
assessment		older adult		neurocognitive disorders		mobile applications
evaluation		geriatrics		dementia		cell phone
testing	AND		AND	Alzheimer disease	AND	touch screen
detection						computer device
						mobile technology
						computer
						electronic device
						tablet
						tablet computer
						mobile device
						web app

Pubmed

("diagnos*" OR "screening" OR "assessment" OR "evaluation" OR "testing" OR "detection") AND ("aged" OR "elder*" OR "older adult*" OR "geriatrics") AND ("neurodegenerative disease*" OR "cognitive disorder*" OR "cognition disorder*" OR "neurocognitive disorder*" OR "dementia" OR "Alzheimer disease") AND ("handheld computer" OR "smartphone" OR "mobile applications" OR "cell phone" OR "touch screen" OR "computer device" OR "mobile technology" OR "computer" OR "electronic device" OR "tablet" OR "mobile device" OR "web app")

Embase

('diagnosis'/exp OR 'screening'/exp OR 'assessment'/exp OR 'testing'/exp OR 'detection'/exp) AND ('aged'/exp OR 'older adult*'/exp OR 'geriatric*'/exp) AND ('degenerative disease'/exp OR 'cognitive defect'/exp OR 'disorders of higher cerebral function'/exp OR 'dementia'/exp OR 'Alzheimer disease'/exp) AND ('personal digital assistant'/exp OR 'mobile application'/exp OR 'smartphone'/exp OR 'mobile phone'/exp OR 'touchscreen'/exp OR 'mobile technology'/exp OR 'computer'/exp OR 'electronic device'/exp OR 'web application'/exp)

IEEE Xplore

("diagnos*" OR "screening" OR "assessment" OR "evaluation" OR "testing" OR "detection") AND ("aged" OR "elder*" OR "older adult*" OR "geriatrics") AND ("neurodegenerative disease*" OR "cognitive disorder*" OR "cognition disorder*" OR "neurocognitive disorder*" OR "dementia" OR "Alzheimer disease") AND ("handheld computer" OR "smartphone" OR "mobile applications" OR "cell phone" OR "touch screen" OR "computer device" OR "mobile technology" OR "computer" OR "electronic device" OR "tablet" OR "mobile device" OR "web app")

Web Of Science

("diagnos*" OR "screening" OR "assessment" OR "evaluation" OR "testing" OR "detection") AND ("aged" OR "elder*" OR "older adult*" OR "geriatrics") AND ("neurodegenerative disease*" OR "cognitive disorder*" OR "cognition disorder*" OR "neurocognitive disorder*" OR "dementia" OR "Alzheimer disease") AND ("handheld computer" OR "smartphone" OR "mobile applications" OR "cell phone" OR "touch screen" OR "computer device" OR "mobile technology" OR "computer" OR "electronic device" OR "tablet" OR "mobile device" OR "web app")

Appendix 2. Characteristics of studies using a tactile tablet or smartphone

ALT TEXT: table of the characteristics of the studies using a tactile tablet or a smartphone included in the systematic review. The data collected concerns author's name, year of publication, country, number and age of the participants, name of the test, functions assessed, type of administration, language of the testings, test duration, criteria used for the diagnosis and the testings for the reference diagnosis.

Author, year (Country)	Participants n (age ± SD)	Name of the touchscreen test	Functions assessed	Self-administration	Language	Test duration (min)	Reference diagnostic criteria	Testings for reference diagnosis
Ben-Sadoun, 2024 (France)	45 MCI (84.2 ± 6.0) 56 moderate NCD (86.4 ± 5.7) 10 severe NCD (89.9 ± 5.5) 24 control (84.4 ± 4.1	Digitrack: digit-tracking technique	Eye-tracking exploration	yes	French	5	DSM-V	MMSE, "Autonomie, Gérontologie, Groupe Iso Ressources" (AGGIR) grid
Chan, 2020 (Hong Kong)	33 DEM (78.6 ± 7.1) 37 MCI (76.1 ± 6.3) 75 control (70.2 ± 8.1)	EC-Screen: Electronic Cognitive Screen	Executive functions, visuospatial abilities, mental flexibility, memory	yes	Chinese/ English	5	MCI: Peterson DEM: International Classification of Disease version 10	HK-MoCA
Cheah, 2022 (Taïwan)	30 AD (77.7 ± 7.0) 59 MCI (67.5 ± 6.3) 59 control (62.6 ± 5.9)	ROCF: Rey-Osterrieth Complex Figure	Visuospatial abilities, visual episodic memory, organization skills, attention, visuomotor coordination	no	NS	NS	MCI: Jak et al AD: American Alzheimer's Association	Rey-Osterrieth Complex Figure (ROCF) paper-and-pencil based
Chin, 2020 (Korea)	29 AD (73.6 ± 8.7) 42 MCI (71.7 ± 7.3) 26 control (68.5 ± 6.3)	Inbrain CST: Inbrain Cognitive Screening Test	Attention, language, visuospatial, memory and executive function	yes	Korean	30	AD: NINCDS-ADRDA MCI: Peterson	Seoul Neuropsychological Screening Battery (SNSB-II): Digit Span test forward and backward, Controlled Oral Word Association Test, Korean version of the Boston Naming Test, Rey-Osterrieth Complex Figure Test (RCFT), Seoul Verbal Learning Test-Elderly version (SVLT-E), K-TMT-E, K-MMSE
Ishikawa, 2019 (Japan)	10 AD (76.7 ± 6.0) 25 MCI (75.9 ± 5.3) 36 control (70.0 ± 5.0)	Five drawing tasks	Memory, visuospatial, executive function	no	Japanese	NS	AD: NIA-AA MCI: Peterson	MMSE
Kim, 2020 (Korea)	17 AD (65.0 ± ?) 17 control (73.0 ± ?)	Simplified Version of the Rey-Osterrieth Complex Figure Test	Visuoconstruction and visual memory function	no	NA	NS	NINCDS-ADRDA	Backward digit span and letter cancellation tests, Korean version of the Boston Naming Test, RCFT, Seoul Verbal Learning Test, phonemic and semantic Controlled Oral Word Association Test, Stroop word/color reading test, MMSE and Clinical Dementia Rating test
Kobayashi, 2022 (Japan)	27 AD (75.1 ± 7.5) 65 MCI (74.5 ± 4.9) 52 control (72.6 ± 3.8)	Five drawing tasks	Memory, visuospatial, executive function	yes	Japanese	NS	NIA-AA	MMSE, Frontal Assessment Battery (FAB), immediate and delayed recall of Logical Memory Story A from the Wechsler, Memory Scale-Revised (LM- immediate and LM-delayed), TMT (TMTA&B), CDT

Li, 2022 (China)	26 AD (65.8 ± 8.2) 43 MCI (61.9 ± 9.6) 12 control (58.3 ± 14.6)	TDT: Tree drawing test	Feature extraction of the drawing	yes	Chinese	NS	NS	MMSE
Müller, 2019 (Germany)	106 AD (71.4 ± 8.4) 138 MCI (70.8 ± 8.4) 137 control (69.6 ± 7.8)	dCDT: digital Clock Drawing Test	Visual perception and encoding, attention, anticipatory thinking, motor planning and executive functions	NS	German	4	AD: NINCDS-ADRDA MCI: Petersen	CERAD
Müller, 2017 (Germany)	20 AD (69.6 ± 6.1) 30 MCI (65.3 ± 6.6) 20 control (66.9 ± 9.4)	Digitizing visuospatial construction task	Visuospatial construction, movements kinematics, fine motor control, coordination	yes	German	< 1	AD: NINCDS-ADRDA MCI: Petersen and NIA-AA	German version of the CERAD
Onoda, 2013 (Japan)	50 DEM (75.9 ± 5.6) 34 control (70.7 ± 5.0)	CADi: Cognitive Assessment for Dementia, iPad version	Memory, recognition, categorization, visuospatial skills	yes	Japanese	10	Diagnostic and Statistical Manual of Mental Disorders Fourth Edition (DSM-IV)	MMSE, Frontal Assessment Battery (FAB), and Clinical Dementia Rating scale
Onoda, 2014 (Japan)	27 AD (78.1 ± 4.4) 27 control (76.0 ± 3.0)	CADi: Cognitive Assessment for Dementia, iPad version	Memory, recognition, visuospatial skills, orientation	yes	Japanese	< 5	NINCDS-ADRDA and Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV)	MMSE, Frontal Assessment Battery (FAB), verbal fluency task (VFT), Clock Drawing test, Trail Making test, Wechsler memory scale concise version
Paddick, 2021 (Tanzania)	201 DEM 324 control	IDEA cognitive screen: Identification and Intervention for Dementia in Elderly Africans	Abstraction, orientation, long term memory, categorical verbal fluency, visuoconstruction	no	Kiswahili	19	Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V)	NS
Robens, 2019 (Germany)	56 AD (72.7 ± 9.2) 64 MCI (67.9 ± 11.2) 67 control (65.9 ± 10.3)	dTDT: digitized Tree Drawing Test	Visuospatial and planning abilities, semantic memory and mental imaging	yes	NA	4	MCI: Peterson and McKhan AD: NINCDS-ADRDA	German version of the modified CERAD, Clock Drawing test
Rodríguez-Salgado, 2021 (Cuba)	47 DEM (74.1 ± 5.9) 46 MCI (72.7 ± 7.5) 53 control (70.4 ± 5.9)	BHA: Brain Health Assessment	Memory, processing speed, executive function, visuospatial skills, language	yes	Cuban-Spanish	10	NS	MoCA, BHA, CERAD, backward digit span task, Stroop Interference Task, lexical fluency task, Delis-Kaplan Executive Function System Design Fluency subtest, Modified Trails test, Visual Object and Space Perception Battery (VOSP), Number Location subtest, copy of the Benson Complex Figure, Multilingual Naming Test (MINT)
Scanlon, 2016 (Ireland)	40 DEM (76.5 ± 12.5) 20 control (72.2 ± 12.0)	CCS: Computerised Cognitive Screening	Memory, concentration, visuospatial functioning	yes	English	4	DSM-IV	MoCA
Seok, 2024 (South Korea)	91 DEM (77.9 ± 6.4) 94 control (74.1 ± 4.3)	Hellocog	Memory, language, attention, and executive function	yes	Korean	15	DSM-IV, NINCDS-ADRDA	MMSE, CERAD-K, Neuropsychiatric Interview

Staffaroni, 2024 (USA)	47 FTLD 55 control	ALLFTD Mobile App	Memory, executive functions	yes	English	25-35	Criteria from international group: Gorno-Tempini and Brooks	MoCA, CDR, NACC-FTLD SB score
Suzumura, 2018 (Japan)	31 AD (74.2 ± 6.3) 15 MCI (74.3 ± 6.0) 48 control (73.6 ± 8.3)	JustTouch screen	Finger motor skills	yes	Japanese	NS	AD: NIA-AA MCI: Peterson	MMSE
Um Din, 2024 (France)	49 MCI (79.5 ± 6.0) 61 Major NCD (82.3 ± 7.0) 47 control (78.2 ± 8.5)	dCDT: digital Clock Drawing Test	Visuospatial and planning cognitive abilities, semantic memory and mental imaging	no	French	NS	DSM-V	Clock Drawing Test paper version
Yamada, 2022a (Japan)	47 AD (73.2 ± 6.6) 27 LBD (75.1 ± 5.0) 49 control (72.3 ± 3.8)	Five drawing tasks	Complex activity drawing (visuospatial, planification)	yes	Japanese	NS	AD: NIA-AA MCI: Peterson LBD: McKeith	MMSE, Frontal Assessment Battery, immediate and delayed recall of Logical Memory Story A from the Wechsler Memory Scale- Revised, the Trail Making Test parts A and B (TMT-A and TMT-B), and the Clock Drawing Test (CDT)
Yamada, 2022b (Japan)	32 DEM (74.3 ± 6.7) 67 MCI (74.1 ± 4.5) 46 control (72.3 ± 3.9)	Five drawing tasks	Complex activity drawing (visuospatial, planification)	yes	Japanese	NS	McKhann, McKeith and Peterson	MMSE
Ye, 2022 (USA)	42 AD (71.5 ± 9.0) 22 MCI (73.5 ± 5.9) 35 control (67.8 ± 9.6)	BrainCheck battery V4.0.0	Immediate and delayed recognition, digit symbol substitution, Flanker, Stroop test, TMT	yes	English	15 to 37	Alzheimer's Disease International	NS
Zhang, 2024 (Canada)	50 Parkinson (67.6 ± 9.2) 29 control (69.0 ± 7.2)	PDMotion	Tremor tests, finger and foot tapping, and gait assessment, micrographia and bimanual coordination, tapping tests, tracing/drawing tests and accelerometer-related tests. Tapping tests include single tapping test, alternative tapping test, and target test for finger tapping, and foot tapping test	yes	English	NS	Hoehn and Yahr Scale MDS-sponsored Revision of the Unified Parkinson's Disease Rating Scale	MoCA, MDS-sponsored Revision of the Unified Parkinson's Disease Rating Scale

NS: not specified
NIAAA: 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
FTLD: Fronto temporal lobar degeneration
MMSE: Mini-Mental State Examination
MoCA: Montreal Cognitive Assessment
CERAD: Consortium to Establish a Registry for Alzheimer's Disease

Appendix 3. Characteristics of studies using a touchscreen computer

ALT TEXT: table of the characteristics of the studies using a touchscreen computer included in the systematic review. The data collected concerns author's name, year of publication, country, number and age of the participants, name of the test, functions assessed, type of administration, language of the testings, test duration, criteria used for the diagnosis and the testings for the reference diagnosis.

Author, year (Country)	Participants n (age ± SD)	Name of the touchscreen test	Functions assessed	Self-administration	Language	Test duration (min)	Reference diagnostic criteria	Testings for reference diagnosis
Isernia, 2021 (Italy)	27 VascD (74.2 ± 3.4) 60 MCI (74.2 ± 5.0) 74 control (75.5 ± 2.7)	SASG: Smart Aging Serious Game	Memory, spatial orientation, executive functions, divided and selective attention	yes	Italian	20 to 40	MCI due to AD: Albert's et al MCI due to VCI: Hachinski Both with the NINCDS-ADRDA	MoCA, Free and Cued Selecting Reminding Test (FC SRT), Trail Making Test (TMTA&B)
Memória, 2014 (Brasil)	21 AD (76.1 ± 5.0) 35 MCI (73.8 ± 5.5) 41 control (71.7 ± 4.6)	CANS-MCI: Computer-Administered Neuropsychological Screen for Mild Cognitive Impairment	Namely executive function (mental control and spatial ability), language fluency, memory	yes	Portuguese	30 to 50	AD: NINCDS-ADRDA MCI: Petersen	MoCA, Rey Auditory Verbal Learning Test (RAVLT), semantic verbal fluency (VF), and Digit Symbol and Digit Span (Weschler Adult Intelligence Scale)
Fukui, 2015 (Japan)	124 AD (75.6 ± 5.9) 75 control (75.1 ± 6.1)	Touch-panel screening test	Memory, attention, discrimination, processing, judgment	NS	Japanese	NS	MCI and AD: AD neuroimaging initiative (ADNI)	MMSE, Revised Hasegawa's Dementia scale (HDS-R), ADL score, Abe's behavioral and psychological symptoms of dementia (ABS), Apathy Scale (AS)
Inoue 2011 (Japan)	34 AD (79.2 ± 7.9)	TDAS: Touch Panel-type Dementia Assessment Scale	Orientation, visuospatial perception, recognition, money calculation, clock time recognition, memory	yes	Japanese	30	AD: NINCDS-ADRDA	Alzheimer's Disease Assessment Scale - Cognitive (ADAS-cog)
Inoue, 2009 (Japan)	72 AD (80.0 ± 5.1) 102 control (77.1 ± 5.8)	Computerized Test Battery	Memory, temporal orientation, visuospatial perception	yes	Japanese	< 4 min	NINCDS-ADRDA	NS
Liu 2024 (China)	74 MCI (66.3 ± 10.1) 42 DEM (66.5 ± 9.3)	CCT: Computerized cognitive training	Perception, attention, memory, and executive function	NS	Chinese	NS	Petersen, Diagnostic	MMSE, MoCA
Noguchi-Shinohara, 2020 (Japan)	233 DEM (76.0 ± 3.5) 94 MCI (75.8 ± 4.1) 100 control (75.0 ± 3.2)	C-ABC: Computerized Assessment Battery for Cognition	Orientation, recognition, memory, arithmetic problem, attention	yes	Japanese	5	DEM: Diagnostic and Statistical Manual of Mental Disorders, third edition, revised (DSM-III-R) MCI: International Working Group	MMSE

Song, 2020 (Korea)	113 DEM (70.7 ± 9.3)	Co-Wis: Computer-Based Dementia Assessment Contents	Attention, memory, language, visuospatial and executive function	no	Korean	NS	DSM-5	K-MMSE + SNSB-II
Vallejo, 2017 (Switzerland)	18 AD (77.8 ± 6.2) 20 control (74.6 ± 5.9)	Serious game of 6 tasks	Episodic memory, prospective memory, visuo-spatial orientation, executive functions, attention and general processing speed	yes	German	16	International Classification of Diseases 10th revision	NS
Wu, 2017 (France)	84 AD (76.5 ± 5.9) 129 MCI (76.5 ± 7.5) 112 control (74.7 ± 6.9)	e-CT: tablet-based cancellation test	Selective attention, visuospatial search, psychomotor speed, fine motor coordination	yes	French	3	AD: NINCDS-ADRDA MCI: Peterson	K-T cancellation test (K-T)
Zorluoglu, 2015 (Turkey)	14 DEM (72.5 ± 9.9) 9 control (81.8 ± 4.8)	Mobile Cognitive Screen battery	Arithmetic, orientation, abstraction, attention, memory, language, visual and executive function	NS	Turkish	NS	NS	MoCA

NS: not specified
NIAAA: 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
MMSE: Mini-Mental State Examination
MoCA: Montreal Cognitive Assessment
CERAD: Consortium to Establish a Registry for Alzheimer's Disease

Appendix 4. Results of the quality assessment of the articles by the QUADAS-2

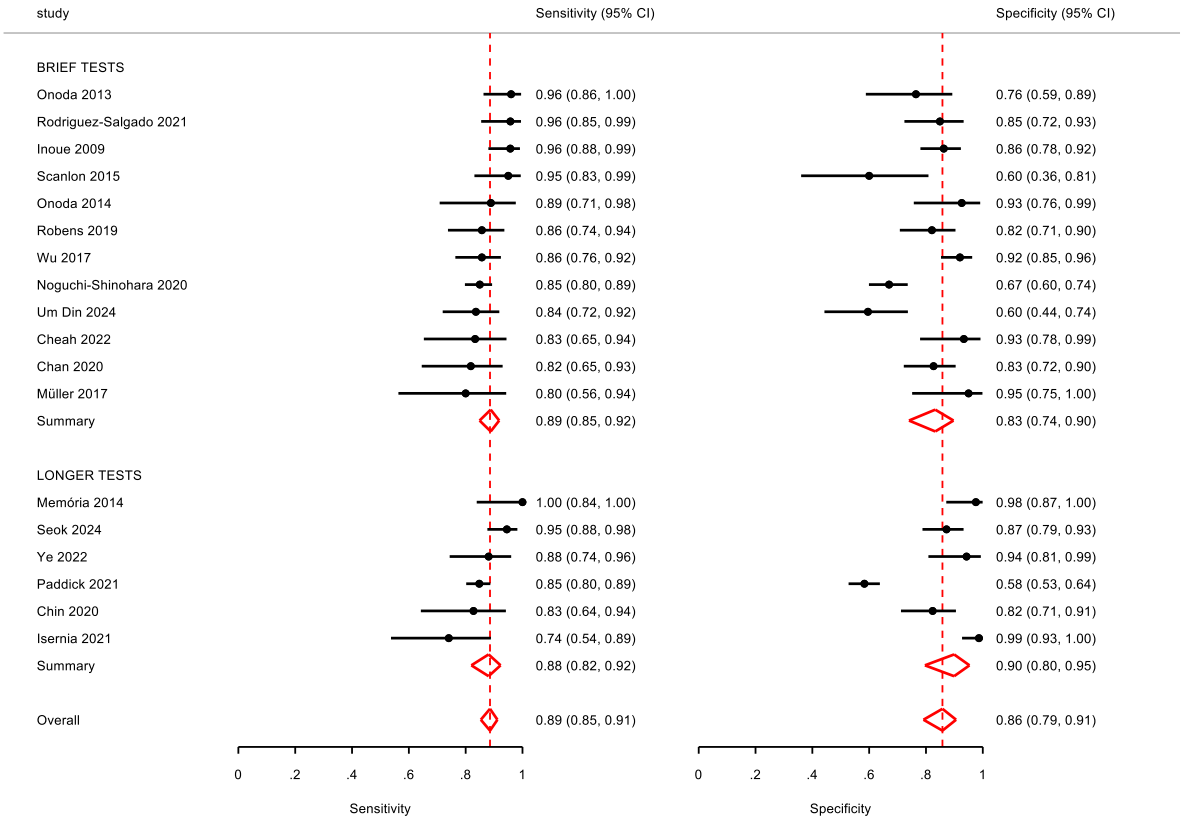
ALT TEXT: table of the quality assessment of the articles included in the systematic review. It contains 4 items for the risk of bias and 3 items for the applicability.

Study	RISK OF BIAS				APPLICABILITY CONCERNS		
	PATIENT SELECTION	INDEX TEST	REFERENCE STANDARD	FLOW AND TIMING	PATIENT SELECTION	INDEX TEST	REFERENCE STANDARD
Ben-Sadoun, 2024	☺	☺	☺	☺	☺	☺	☺
Chan, 2020	☺	☺	☺	☺	☺	☺	☺
Cheah, 2022	?	☺	?	☺	?	☺	☺
Chin, 2020	☺	☺	☺	☺	☺	☺	☺
Fukui, 2015	☺	☺	☺	☺	☺	☺	☺
Inoue, 2009	☺	☺	☺	☺	☺	☺	☺
Inoue, 2011	☺	☺	☺	☹	☺	☺	☺
Isernia, 2021	☺	☺	☺	☺	☺	☺	☺
Ishikawa, 2019	☺	☺	☺	☺	☺	☺	☺
Kim, 2020	☺	☺	☺	☺	☺	☺	☺
Kobayashi, 2022	☺	☺	☺	☺	☺	☺	☺
Li, 2022	☺	☺	?	☺	☺	☺	☺
Liu, 2024	☺	☺	☺	☺	☺	☺	☺
Memória, 2014	☺	☺	☺	☺	☺	☺	☺
Müller, 2017	☺	☺	☺	☺	☺	☺	☺
Müller, 2019	☺	☺	☺	☺	☺	☺	☺
Noguchi-Shinohara, 2020	☺	☺	☺	☺	☺	☺	☺
Onoda, 2013	☺	☺	☺	☺	☺	☺	☺
Onoda, 2014	☺	☺	☺	☺	☺	☺	☺
Paddick, 2021	☺	☺	☺	☺	☺	☺	☺
Robens, 2019	☺	☺	☺	☺	☺	☺	☺
Rodríguez-Salgado, 2021	☺	☺	☺	☺	☺	☺	☺
Scanlon, 2015	?	☺	☺	☺	☺	☺	☺
Seok, 2024	☺	☺	☺	☺	☺	☺	☺
Song, 2020	☺	☺	☺	☺	☺	☺	☺
Staffaroni, 2024	☺	☺	☺	☺	☺	☺	☺
Suzumura, 2018	☺	☺	☺	☺	☺	☺	☺
Um Din, 2024	☺	☺	☺	☺	☺	☺	☺
Vallejo, 2017	☺	☺	☺	☺	☺	☺	☺
Wu, 2017	☺	☺	☺	☺	☺	☺	☺
Yamada, 2022a	☺	☺	☺	☺	☺	☺	☺
Yamada, 2022b	☺	☺	☺	☺	☺	☺	☺
Ye, 2022	☺	☺	?	☹	☺	☺	☹
Zhang, 2024	☺	☺	☺	☺	☺	☺	☺
Zorluoglu, 2015	?	☺	☺	☺	☺	☺	☺

☺ Low risk
☹ High risk
? Unclear risk

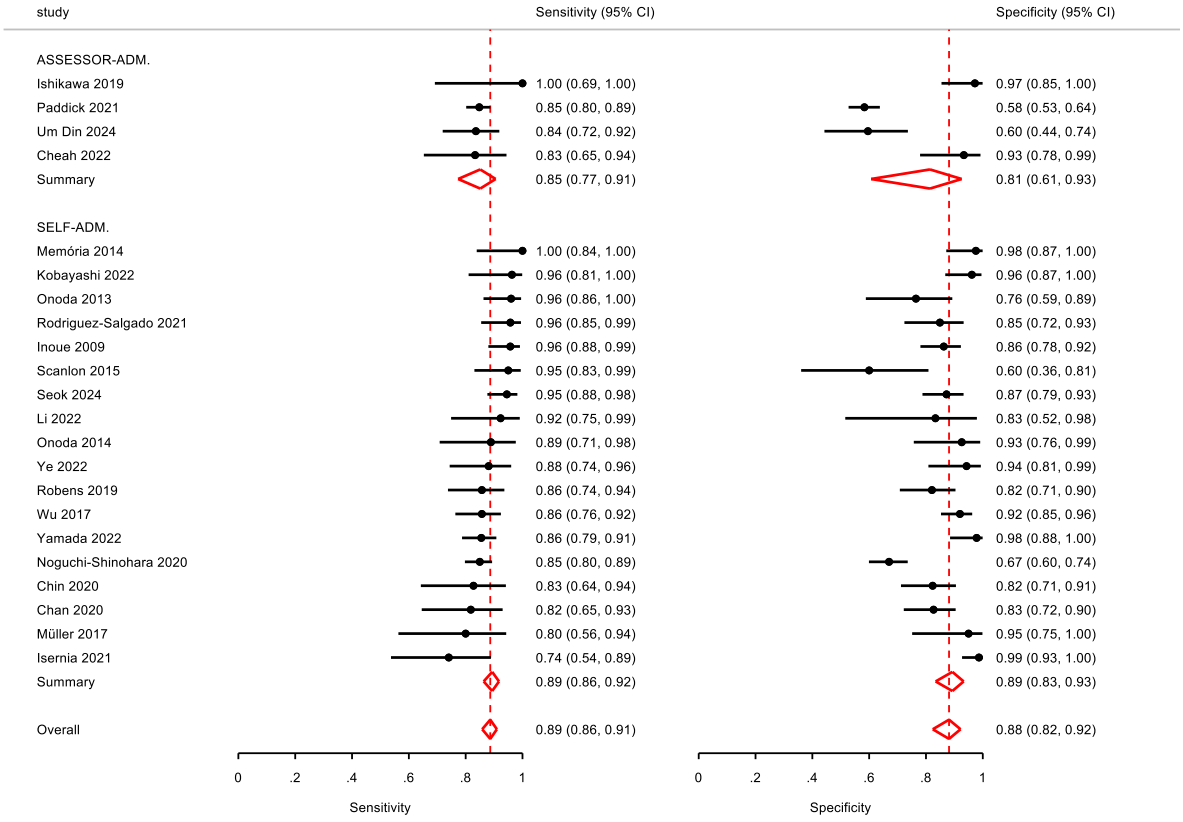
Appendix 5. Analysis of sensitivity and specificity for the diagnosis of the M-NCD by test duration

ALT TEXT: forest plot of sensitivity and specificity of each study included in the meta-analysis grouped by test duration (brief or long).



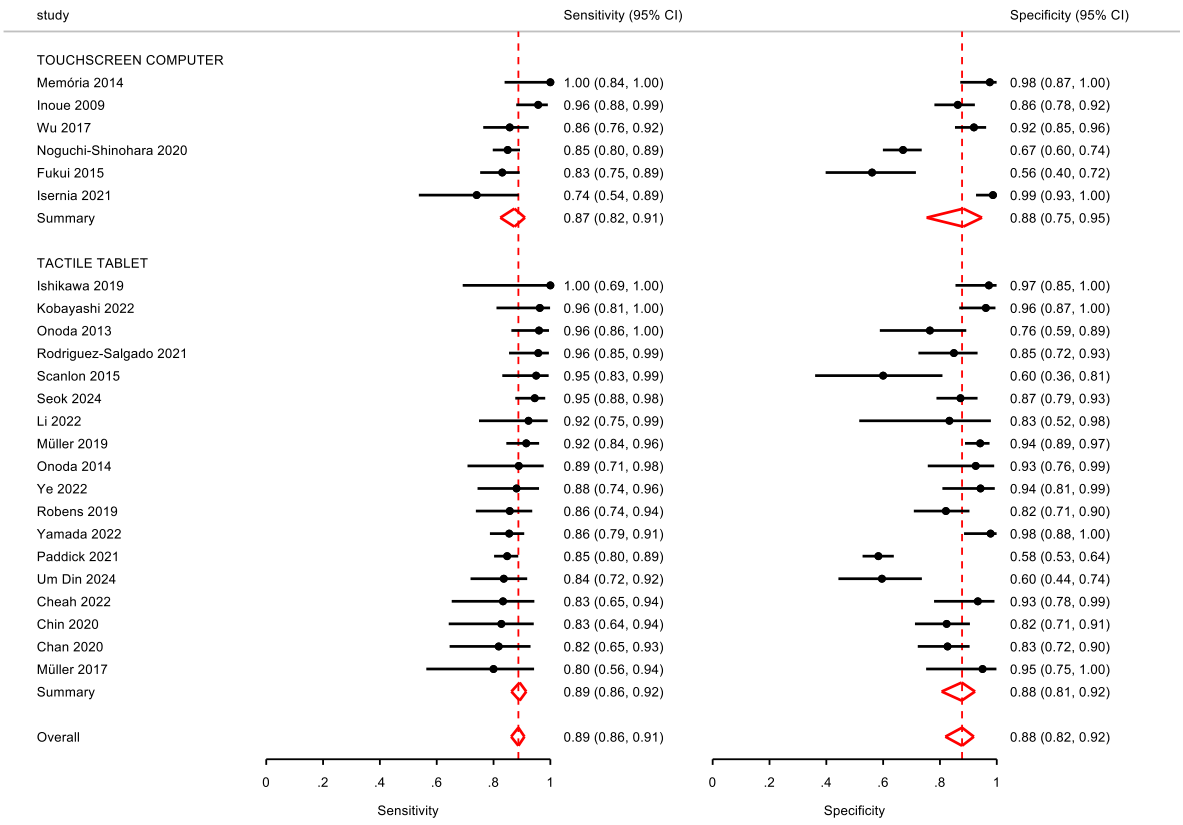
Appendix 6. Analysis of sensitivity and specificity for the diagnosis of the M-NCD by modality of assessment

ALT TEXT: forest plot of sensitivity and specificity of each study included in the meta-analysis grouped by type of administration (assessor-administered or self-administered).



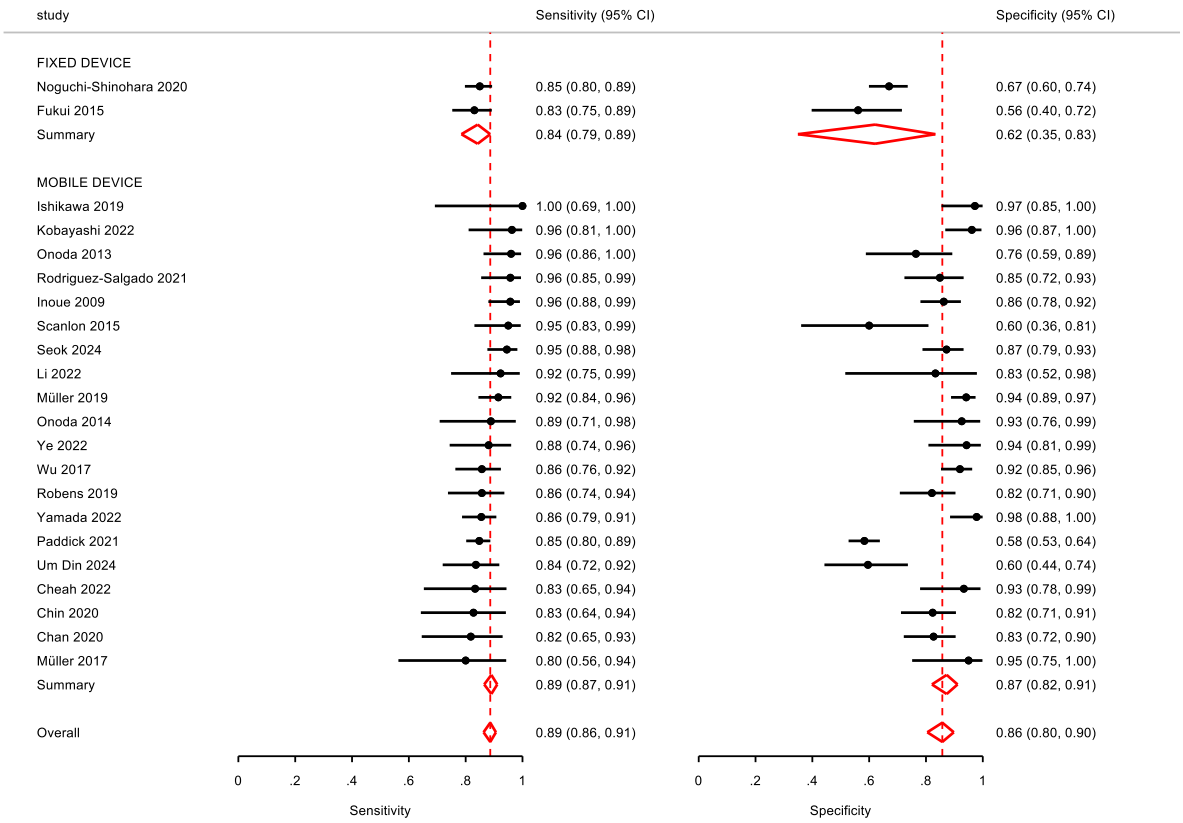
Appendix 7. Analysis of sensitivity and specificity for the diagnosis of the M-NCD by type of touchscreen device

ALT TEXT: forest plot of sensitivity and specificity of each study included in the meta-analysis grouped by interface used (touchscreen computer or tactile tablet).



Appendix 8. Analysis of sensitivity and specificity for the diagnosis of the M-NCD by type of mobile device

ALT TEXT: forest plot of sensitivity and specificity of each study included in the meta-analysis grouped by the mobility of the device (fixed or mobile).



PRISMA 2020 Main Checklist

Topic	No.	Item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist	below
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	page 4
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	page 5
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	page 6
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	page 5-6
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	pages 5-6
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	page 6
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	pages 5-6
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	page 5
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	page 5
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	page 7
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	-
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item 5)).	page 6
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	-
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	page 8
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	page 7
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	page 7
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	page 7
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	page 7
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	page 7
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	page 7

Topic	No.	Item	Location where item is reported
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	page 7
Study characteristics	17	Cite each included study and present its characteristics.	page 8
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	page 9
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	page 9
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	page 9
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	page 10
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	page 10
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	pages 10 to 12
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	na
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	pages 10 to 12
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	page 12
	23b	Discuss any limitations of the evidence included in the review.	page 13
	23c	Discuss any limitations of the review processes used.	page 13
	23d	Discuss implications of the results for practice, policy, and future research.	pages 13-14
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	page 14
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	page 14
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	page 14
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	page 14
Competing interests	26	Declare any competing interests of review authors.	page 14
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	page 14

PRIMSA Abstract Checklist

Topic	No.	Item	Reported?
TITLE			
Title	1	Identify the report as a systematic review.	Yes
BACKGROUND			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Yes
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Yes
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	Yes
Synthesis of results	6	Specify the methods used to present and synthesize results.	No
RESULTS			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Yes
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Yes

Topic	No.	Item	Reported?
DISCUSSION			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision).	Yes
Interpretation	10	Provide a general interpretation of the results and important implications.	Yes
OTHER			
Funding	11	Specify the primary source of funding for the review.	Yes
Registration	12	Provide the register name and registration number.	Yes

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. MetaArXiv. 2020, September 14. DOI: 10.31222/osf.io/v7gm2. For more information, visit: www.prisma-statement.org

Article 2. Diagnostic Accuracy of Touchscreen-Based Tests for Mild Cognitive Disorders: A Systematic Review and Meta-Analysis.

diagnostics

MDPI

Systematic Review

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

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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.

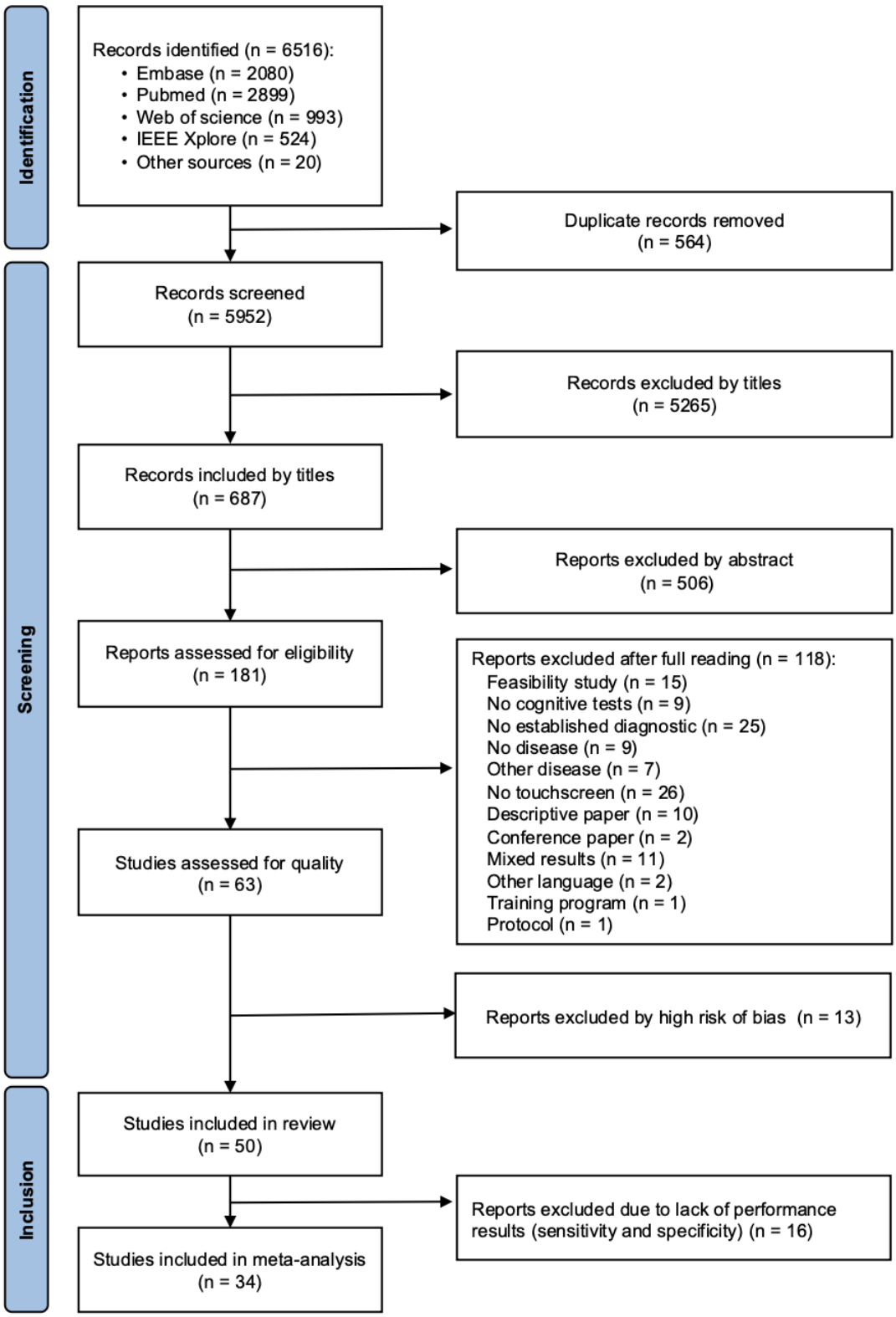

Figure 1. Flow chart of the studies included.

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.

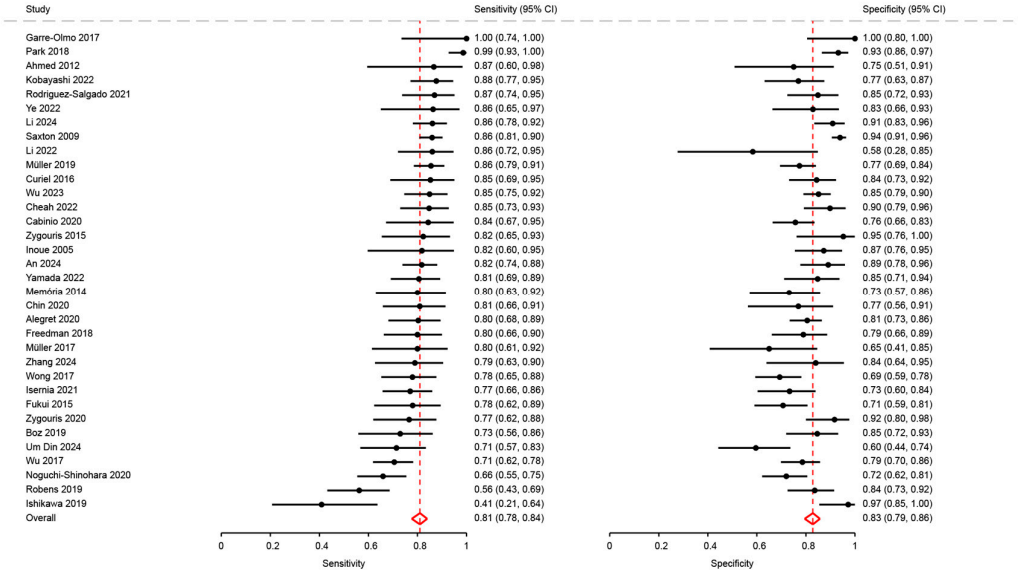

Figure 2. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders [18,21,23,26–29,31,32,34–38,41,43,46–48,50,51,53,54,62–66,68,69,72,74–76].

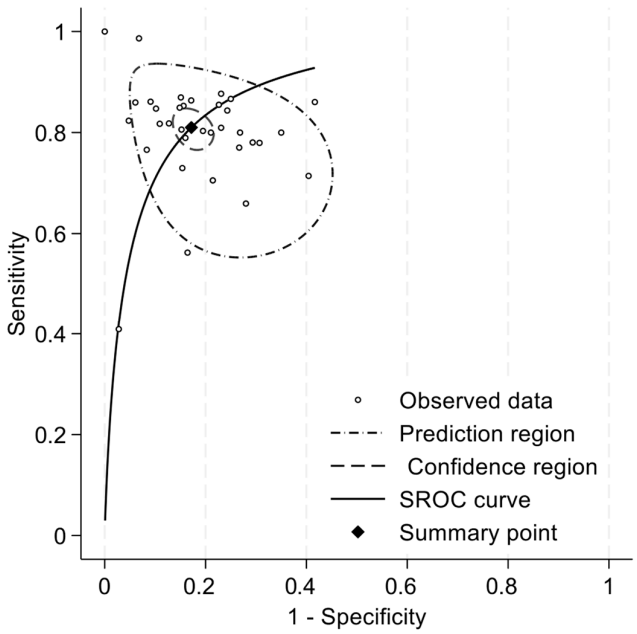

Figure 3. Summary ROC curve of sensitivity and specificity for the diagnosis of mild cognitive disorders.

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.

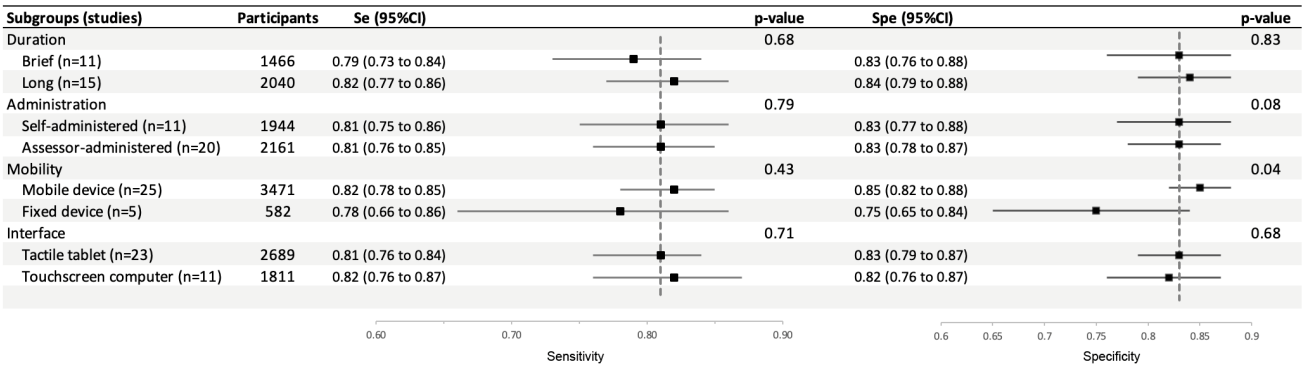

Figure 4. Subgroup analysis of pooled sensitivity and specificity of touchscreen cognitive tests for the diagnosis of mild cognitive disorders.

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.

Author Contributions: Conceptualization, J.B., S.P. and N.U.D.; methodology, J.B., N.U.D., C.L.-L. and F.M.; validation, J.B.; formal analysis, J.B., C.L.-L. and N.U.D.; investigation, N.U.D., F.M. and B.O.; data curation, N.U.D. and F.M.; writing—original draft preparation, N.U.D. and B.O.; writing—review and editing, J.B.; supervision, J.B. and S.P.; project administration, F.B. and J.B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

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.

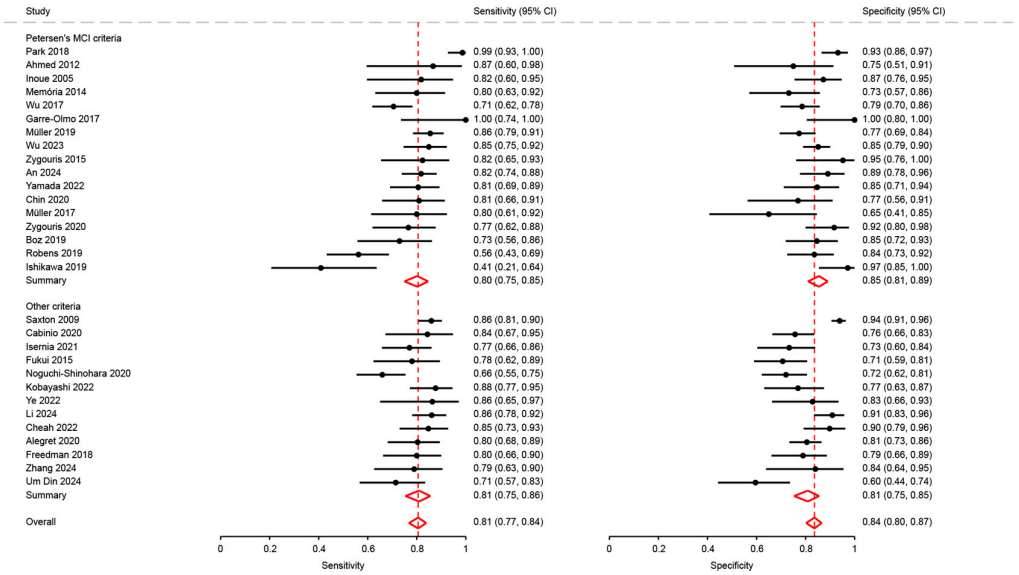

Figure A1. Analysis of sensitivity of studies using Petersen's MCI criteria with others [18,21,23,27–29,31,32,34,35,37,38,41,43,46–48,50,51,53,63–66,68,69,72,74–76].

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.

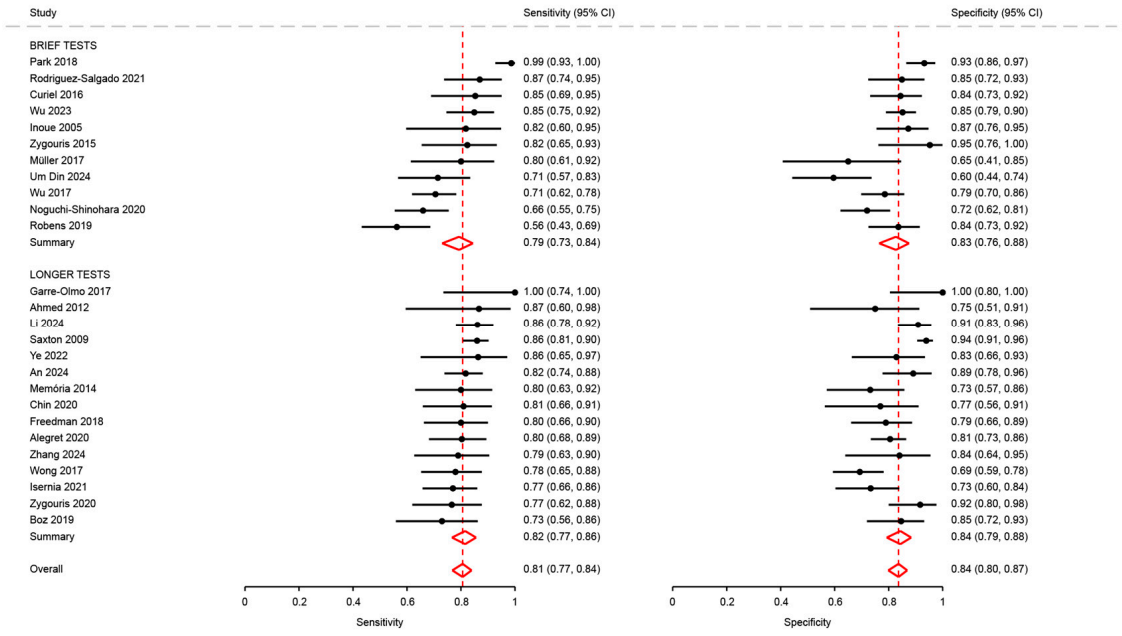

Figure A2. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders by test duration [18,21,23,28,29,31,35–37,41,46,48,50,51,53,54,62–64,66,68,69,72,74–76].

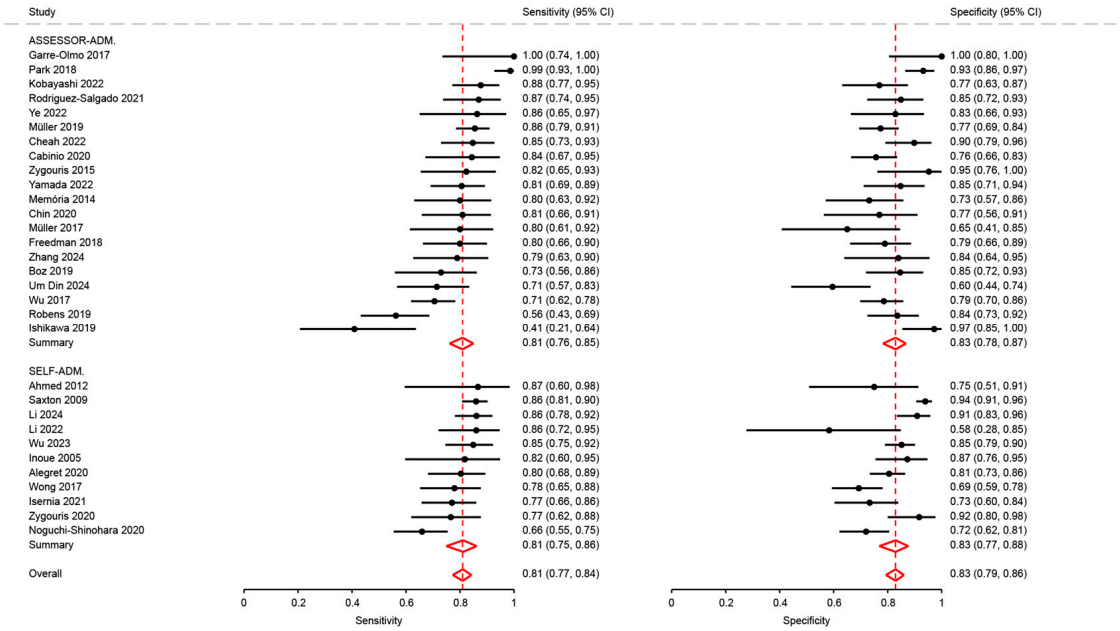

Figure A3. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders by modality of assessment [18,21,23,26–29,31,32,34,35,37,41,43,46–48,50,51,53,54,62–66,68,69,72,74–76].

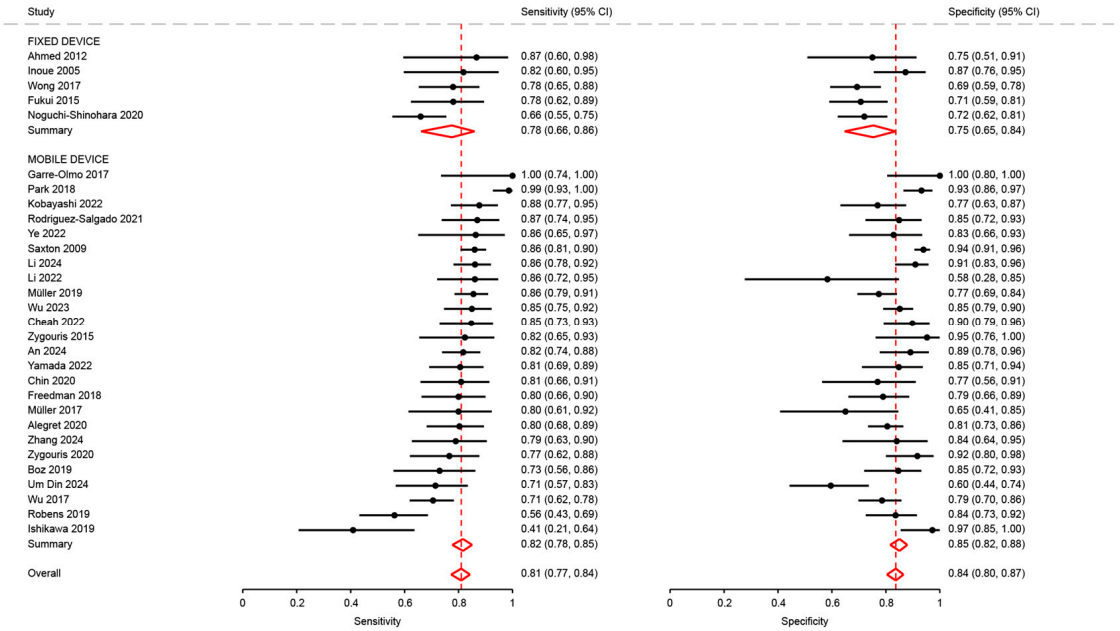

Figure A4. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders by type of mobile device [18,21,23,26–29,31,34,35,37,38,43,47,48,50,51,53,54,62–66,68,69,72,74–76].

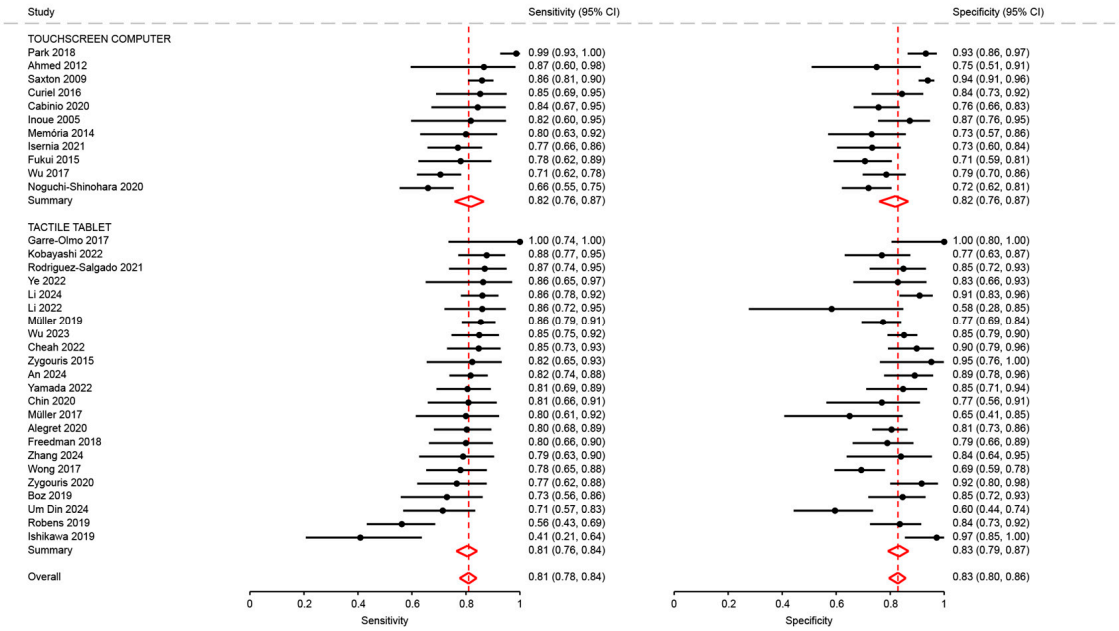

Figure A5. Analysis of sensitivity and specificity for the diagnosis of mild cognitive disorders by type of touchscreen device [18,21,23,26–29,31,32,34–38,41,43,46–48,50,51,53,54,62–66,68,69,72,74–76].

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III. Études cliniques préparatoires

Dans cette seconde partie, nous détaillerons la construction de nos outils d'aide au repérage des TNC et nous présenterons les travaux préliminaires en vue de l'étude clinique principale. Grâce au travail préalable d'analyse de la littérature des tests existants, notre objectif a été de garder l'essentiel pour balayer l'ensemble des domaines à investiguer, et de les rendre les plus courts possibles. Nous avons donc construit un questionnaire médical en sélectionnant des questions issues d'échelles et questionnaires existants d'une part, et des tâches à réaliser évaluant une performance cognitive et de dextérité manuelle d'autre part.

1. Construction du questionnaire médical

Pour créer ce questionnaire médical, nous nous sommes inspirés des PROMs (*patient-reported outcome measures*) qui consistent à interroger directement le patient sur la vision qu'il a de son propre état de santé, sans intervention ou interprétation par un médecin ou un tiers. L'enquête *Patient-Reported Indicator Surveys,* à l'initiative de l'Organisation de coopération et de développement économiques (OCDE), évoque un renforcement du sentiment de bénéficier de soins adaptés à leurs besoins lorsqu'ils utilisent des outils numériques dans le cadre des soins primaires (48).

Nous avons donc relevé les facteurs protecteurs et les facteurs de risque des TNC décrits dans la littérature (4,49), que sont : l'âge, le sexe, l'exercice physique, la vie sociale, le tabagisme, l'hypoacousie et l'appareillage auditif, la dépression, le diabète, l'obésité, l'hypertension, les antécédents neurologiques, l'anxiété, le sommeil, la dépendance, les symptômes cognitifs et la fragilité. Nous avons identifié des évaluations validées de ces facteurs : l'échelle IADL (*Instrumental Activities of Daily Living*) (50), le questionnaire des plaintes cognitives (51), l'échelle de dépression (*Geriatric Depression Scale*) (52), le questionnaire d'anxiété généralisée (*Generalized*

Anxiety Disorder-7) (53), le questionnaire d'auto-évaluation de dépistage de Epworth et l'échelle de vulnérabilité des aînés (*Vulnerable Elders Survey – 13*) (54). Les différents items de chaque échelle et questionnaire ont été passés en revue par un expert gériatre qui en a sélectionné une partie.

Le questionnaire médical créé est composé de 16 questions fermées (oui/non) qui couvrent les domaines des atteintes sensorielles, du mode de vie, du tabagisme, du sommeil, de l'humeur, de l'activité physique, du langage, de la nutrition, de l'autonomie, de la perception de sa santé générale et des maladies annexes (détails dans le tableau 3).

Tableau 3. Description des questionnaires médicaux

N°	Domaine	Question	Type
1	Mode de vie	Pratiquez-vous une ou plusieurs activités physiques chaque semaine ?	Q
2	Mode de vie	Participez-vous à des activités sociales (amicales, associatives) ?	Q
3	Tabagisme	Fumez-vous ?	Q
4	Atteinte sensorielle	Avez-vous une aide auditive ?	Q
5	Atteinte sensorielle	Vous a-t-on proposé un appareil auditif ?	Q
6	Atteinte sensorielle	Faites-vous répéter quand vous êtes avec une autre personne ?	Q
7	Humeur	Pensez-vous être dépressif ?	Q
8	Nutrition	Êtes-vous diabétique ?	Q
9	Nutrition	Êtes-vous en surpoids ?	Q
10	Santé	Avez-vous de l'hypertension ?	Q
11	Humeur	Consommez-vous des somnifères ou tranquillisants tous les jours ?	Q
12	Maladies annexes	Êtes-vous soigné pour les maladies suivantes : maladie de Parkinson, accident vasculaire cérébral, épilepsie, autre maladie du cerveau	Q
13	Autonomie	Avez-vous besoin de l'aide d'une autre personne pour : utiliser le téléphone, faire des courses, préparer vos repas, faire le ménage, laver votre linge, utiliser les transports en commun, préparer et prendre vos médicaments, gérer vos dépenses et votre budget	Q
14	Langage	Avez-vous l'impression de chercher les mots (sauf les noms propres) et d'utiliser d'autres mots, de vous arrêter de parler ou de dire plus souvent "truc" ou "machin" ?	Q
15	Humeur	Au cours des 14 derniers jours, vous est-il arrivé de : - vous sentir nerveux, anxieux ou tendu ? - vous sentir inquiet de façon excessive propos de tout et de rien ? - devenir facilement contrarié ou irritable ?	Q
16	Sommeil	Vous arrive-t-il de vous assoupir dans les situations suivantes : - assis en train de lire, - assis, inactif dans un lieu public, - assis en parlant avec quelqu'un	Q

T : tâche, Q : questionnaire

L'échelle électronique de vulnérabilité des ainés-13 a été reprise dans son ensemble. C'est un auto-questionnaire de moins de 5 minutes qui identifie la fragilité chez les personnes âgées. Elle est composée de 13 questions qui vont donner un score compris entre 0 et 10, avec une fragilité à partir d'un score de 3 (voir l'échelle en annexe). La fragilité est la vulnérabilité associée à l'âge associée à une diminution des réserves fonctionnelles des systèmes physiologiques qui altère les réponses au stress.

2. Construction des outils cognitifs

2.1. Tâches cognitives

Nous avons collaboré avec une équipe d'informaticiens du laboratoire IBISC (Université Évry Paris-Saclay) qui développait un prototype d'évaluation cognitive sur tablette tactile pour un repérage large des TNC-M. Leur équipe a pu tester une partie des exercices auprès de volontaires sains (55). Nous avons décidé de créer un outil commun prenant en compte nos attentes, c'est-à-dire en élargissant le repérage aux TNC-L notamment en proposant des questions et épreuves plus difficiles pour détecter des troubles cognitifs plus subtils. C'est ainsi que nous avons obtenu une première version des tâches cognitives développée sur Unity® réunissant les tâches déjà conçues par leur équipe et les nôtres.

Nous sommes partis des domaines neurocognitifs à explorer selon le DSM-5 : l'apprentissage et la mémoire, le langage, les fonctions perceptivo-motrices, les fonctions exécutives, l'attention et la cognition sociale (56). Pour chaque domaine, des tests de référence étaient identifiés : MMSE (19) (voir annexe 1), MoCA (20) (voir annexe 2), *Memory Impairment Screen* (23), *Addenbrooke's Cognitive Examination* (57), *Six-item Cognitive Impairment Test* (58), test de dépistage de la démence du GP

COG (*General Practitioner-Cognition*) (59), test de Stroop (60) et le *Language Screening Test date* (61). Le choix des items a été réalisé en sélectionnant ceux qui étaient simples à implémenter sur tablette tactile et qui permettaient un enregistrement des résultats. Les différents items choisis ont été revus par un médecin expert qui a pris une partie de chaque test basé sur ses connaissances et son expérience clinique. Au final, les tâches cognitives élaborées concernent : la mémoire immédiate, la mémoire différée, la catégorisation, l'orientation spatiale et temporelle, la reconnaissance du drapeau, le calcul mental. Un message d'encouragement est affiché à la fin de chaque tâche, quelle que soit la réponse. Ce message a pour but de maintenir la motivation de la personne jusqu'à la fin du test. Les consignes des exercices sont à la fois écrites et orales par une voix pré-enregistrée. A l'inclusion, trois écrans sont prévus pour renseigner les informations des participants : centre d'examen, nom, prénom, date de naissance, sexe, lieu de vie, diagnostic (si connu), date du diagnostic, examens complémentaires, traitement et troubles sensoriels. Avant de commencer les exercices, deux tâches d'entraînements sont proposées au participant : un premier symbole s'affiche sur l'écran qu'il est invité à toucher. Ensuite, deux symboles s'affichent et le participant doit toucher le symbole demandé. Si ces tâches sont réussies, les exercices peuvent être initiés. Le participant est assis à une table, sur laquelle est disposée la tablette sur un support. Une touche « Démarrer » est affichée à l'écran, la personne appuie dessus lorsqu'elle est prête à commencer les exercices. Le détail des tâches est décrit dans le tableau ci-dessous (Tableau 4). Le participant a la possibilité de se corriger. S'il met plus de 30 secondes à répondre, la tâche est comptabilisée comme une erreur et la tâche suivante est proposée.

Tableau 4. Résumé des tâches cognitives

Numéro	Description	Type
1	Mémoriser 3 mots écoutés et sélectionner les 3 images correspondantes parmi 8 images	T
2	Sélectionner la bonne horloge parmi 3 horloges, qui indique l'heure demandée par une consigne vocale	T
3	Rappel différé des 3 mots précédemment retenus parmi les 8 images	T
4	Sélectionner le drapeau du pays où nous sommes parmi 8 drapeaux	T
5	Sélectionner la ville parmi 6 panneaux de villes	T
6	Sélectionner l'année parmi 8 années proposées	T
7	Sélectionner la saison en cours	T
8	Sélectionner l'image qui complète une série de 3 objets (catégorisation)	T
9	Sélectionner la catégorie (fruit)	T
10	Sélectionner la catégorie (transport)	T
11	Sélectionner la catégorie (outil)	T
12	Calculer la monnaie à rendre pour des courses	T
13	Calculer la date antérieure de 2 mois	T

T : tâche, Q : questionnaire

2.2. Test de l'horloge

Le test de l'horloge est un test cognitif simple qui consiste à demander à une personne de dessiner le cadran d'une horloge, d'y inscrire les chiffres indiquant les heures au bon endroit puis de dessiner les aiguilles pour représenter une heure précise indiquée par l'examinateur (62). Plusieurs passations et cotations de ce test existent, nous avons choisi deux systèmes de cotations : la cotation du Greco (63) et celle du test Codex (21). Nous avons choisi de réaliser la passation avec un cercle pré-dessiné où nous demandons à la personne d'écrire les nombres sur le cadran de l'horloge puis de dessiner les aiguilles pour indiquer une heure précise (voir Figure 1). La cotation recommandée par le Greco, qui est la cotation qui donne la meilleure sensibilité et spécificité, donne un score sur 10 points qui comprend : la présence des 12 nombres, le bon emplacement des nombres, le positionnement des chiffres, la présence des deux aiguilles, le bon positionnement de l'aiguille des heures, le bon positionnement de l'aiguille des minutes, la différence de taille entre les aiguilles. Un score de 7 ou plus est normal, tout autre score est considéré pathologique. La cotation utilisée dans le test Codex repose sur 4 critères : la présence de tous les nombres, le bon placement

des nombres, la différence de taille entre les aiguilles, la bonne indication de l'heure. L'horloge est considérée normale lorsque les 4 critères sont remplis ; elle est anormale si un ou plusieurs critères ne sont pas remplis. Le test de l'horloge sur tablette a été réalisé au moyen d'une application gratuite de dessin, qui permet d'écrire sur un cercle déjà dessiné. Le participant doit écrire les chiffres du cadran avec un stylet. Puis il doit dessiner les aiguilles pour indiquer 11h10.

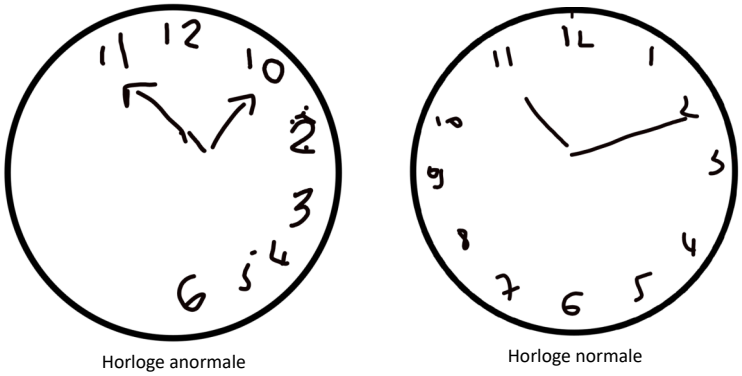

Figure 1. Exemples de dessins de l'horloge

3. Construction des tâches de dextérité manuelle

La revue systématique et méta-analyse de Cooper et al. a trouvé que la dextérité manuelle reflète notre état de santé tout au long de la vie (64) plus précisément qu'une force de préhension plus élevée était associée à une mortalité plus faible. La force de préhension serait un biomarqueur, c'est-à-dire un prédicteur, de future incapacité, de morbidité et de mortalité (65). La revue de Namkoong et Roh (66) a analysé les études sur la fonction de la main chez les patients atteints de TNC-M afin de déterminer la possibilité de l'utiliser comme prédicteur de la MA ou de sa progression. Il a montré que lors de mouvements complexes de la main, les personnes présentant une MA ont une diminution de l'automatisme, du rythme et de la régularité. Ces mouvements complexes pourraient être utilisés pour prédire la transition du TNC-L à la MA et

également la progression d'une démence modérée à une démence sévère. L'étude de Suzumura et al. (67) a trouvé des différences significatives dans les temps de réponse et la durée du contact avec l'outil entre les personnes ayant une MA et ceux avec un TNC-L. Une autre étude (68) a montré l'importance du dysfonctionnement moteur de la dextérité manuelle dans les TNC, avec des profils spécifiques selon les maladies (maladie de Parkinson, MA, TNC-L). Une étude précédente de nos collègues (69) avait trouvé deux types d'altération de la dextérité manuelle chez les personnes âgées : les personnes présentant un déclin cognitif avaient une variation importante de la frappe entre les doigts et une capacité réduite à sélectionner correctement un doigt en réponse à une cible visuelle dans la tâche de frappe multi-doigts, cette altération des performances n'était liée qu'à l'état cognitif et non à l'augmentation de l'âge. Le deuxième constat concernait l'altération de l'indépendance des mouvements des doigts chez les sujets âgés. Ce premier travail a été réalisé avec un outil spécifique, le *Finger Force Manipulandum*. Une autre étude de Darweesh et al. (70), conforte ces résultats en utilisant le *Purdue Pegboard Test* (71) qui est un test évaluant la dextérité manuelle. Ces tâches ont été numérisées sur une tablette tactile afin d'en améliorer l'accessibilité. L'outil a d'abord été utilisé et testée dans un travail de thèse en psychiatrie sur les marqueurs de progression vers la maladie de la schizophrénie (72). Des études cliniques ont également montré que les difficultés de dextérité manuelle progressaient en lien avec l'avancée des TNC (73–75).

L'application Homecare (76) a été développée par l'entreprise Dextrain, avec Pâvel Lindberg et les membres de l'équipe de l'Institut de Psychiatrie et Neurosciences de Paris (Inserm U1266, Université de Paris). Elle consiste en 6 tâches de motricité fine détaillées dans le tableau 5.

Tableau 5. Description des tâches de dextérité manuelle

Tâche	Description	Type
Intégration sensorielle / *Finger recognition*	Une main virtuelle s'affiche sur laquelle apparait une pastille bleue et indique le doigt à lever et à reposer. Il faut sélectionner uniquement le doigt affiché, le plus rapidement possible. La main virtuelle change d'orientation mais la main du participant ne doit pas bouger.	T
Précision temporelle / *Rhythm tapping*	Une pastille bleue apparait de façon périodique et indique le doigt à bouger, la personne doit suivre et maintenir le rythme le plus régulièrement possible. La première partie de la tâche est réalisée accompagnée des bips sonores réguliers, puis les bips s'arrêtent et la personne doit maintenir ce rythme seule.	T
Dissociation des doigts / *Multi finger tapping*	Une ou deux barres bleues apparaissent sous le ou les doigts à lever (jusqu'à 2 doigts). Le participant doit lever et reposer le ou les doigts de façon synchronisée et le plus rapidement possible.	T
Vitesse maximale / *Max tapping*	Une vignette bleue apparaît sous le doigt à lever (index). Au signal sonore, la personne doit réaliser le plus grand nombre de tapes possible dans le temps imparti.	T
Mémorisation de séquence / *Sequence tapping*	Une barre bleue apparaît pour indiquer les doigts à lever et reposer suivant une séquence de 5 tapes. La séquence est répétée plusieurs fois. Le participant doit mémoriser la séquence et la réaliser lui-même après un signal sonore et consigne écrite.	T
Contrôle de trajectoire / *Line tracking*	Une pastille bleue indique l'endroit où poser son doigt. Une trajectoire apparaît au fur et à mesure de l'avancement sur l'écran. La personne doit suivre le plus rapidement et précisément la trajectoire. Durant l'exercice, des symboles et des chiffres peuvent apparaitre sur l'écran, le participant doit ignorer les symboles et soustraire les chiffres en partant de 50 et devra donner la bonne valeur de la soustraction à la fin.	T

T : tâche, Q : questionnaire

Toutes ces tâches sont précédées d'une tâche de familiarisation qui consiste à écouter les consignes de l'exercice en regardant une vidéo, puis, la personne s'entraîne sur une courte durée pour s'approprier l'usage de la tablette. La tablette est positionnée à plat sur la table, les cinq doigts doivent être au contact de l'écran pour être identifiés et amorcer les exercices, sauf le suivi de ligne (*line tracking*) qui ne nécessite que l'index. La position de la main doit être tenue tout au long des exercices avec un contact uniquement de la pulpe des cinq doigts sur l'écran, en évitant l'affaissement de la main ou le contact des ongles ce qui amèneraient à des erreurs de reconnaissance. Les doigts doivent être écartés, tenir dans la largeur de l'écran et sur la moitié basse (voir figure 2).

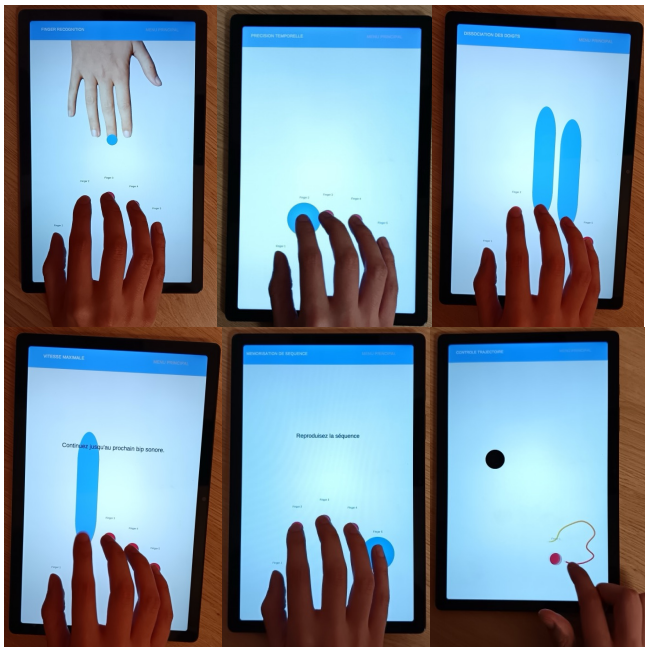

Figure 2. Photos des six exercices de dextérité manuelle. Du haut vers le bas de gauche à droite : finger recognition, rhythm tapping, multi finger tapping, max tapping, sequence tapping et line tracking.

4. Présentation des articles

Dans cette démarche d'utilisation de tests numérisés, nous n'avons pas trouvé d'échelle numérique validée de la fragilité. C'est pourquoi nous avons souhaité réaliser une étude pour vérifier le maintien des performances d'une version numérique de l'échelle de fragilité (VES-13). Nous avons inclus 86 participants dont 40 personnes consultant un hôpital gériatrique et 46 aidants familiaux qui les accompagnaient. Chaque personne a réalisé l'échelle deux fois : une fois en version papier lors d'un entretien en face-à-face ou d'un entretien téléphonique, puis une fois sur tablette tactile. L'ordre des versions de l'échelle était randomisé. Les résultats de cette première étude étaient encourageants, avec une excellente faisabilité et des performances similaires entre les deux versions de l'échelle (77) :

Zolnowski-Kolp V, Um Din N, Havreng-Théry C, Pariel S, Veyron JH, Lafuente-Lafuente C, Belmin J. Assessment of Frailty by the French Version of the Vulnerable

Elders Survey-13 on Digital Tablet: Validation Study. J Med Internet Res. 2023 Aug 2;25:e42017. doi: 10.2196/42017. PMID: 37531175; PMCID: PMC10433029.

Dans la même logique, nous avons cherché à étudier la validation du test de l'horloge numérique, habituellement réalisé et validé en version papier. Et malgré des versions numériques existantes (78), nous n'avions pas trouvé d'étude correspondante à la manière dont nous souhaitions réaliser le test, à savoir placer les chiffres présents sur le cadran d'une horloge et indiquer une heure demandée à partir d'un cercle pré-dessiné, avec une simple consigne et sans demande de reproduction. Nous souhaitions vérifier les performances du test de l'horloge numérique avec celles de la version papier. Dans cette étude, nous avons recruté 257 participants hospitalisés ou consultant un hôpital gériatrique, qui ont réalisé 2 horloges dans un ordre randomisé : une fois en version papier et une fois en version numérique sur une tablette tactile. Nous avons trouvé des résultats équivalents entre les 2 versions, et avec des résultats à considérer avec précaution dans les deux cas (79) :
Um Din N, Maronnat F, Pariel S, Badra F, Belmin J. A Digital Clock Drawing Test on Tablet for the Diagnosis of Neurocognitive Disorders in Older Adults. Stud Health Technol Inform. 2024 Aug 22;316:1878-1882. doi: 10.3233/SHTI240798. PMID: 39176858.

Forts de ces résultats, nous avons réalisé des premières inclusions complètes pour vérifier la faisabilité de nos exercices qui a donné lieu à une première présentation à un congrès de gérontechnologies (80) (poster en annexe 8), montrant une bonne faisabilité et des résultats préliminaires encourageants. Dans un travail plus élaboré, nous avons recruté 122 participants dans un centre mémoire qui ont réalisé les

exercices cognitifs, les questionnaires médicaux et les exercices de motricité fine. Les premiers résultats montrent une faisabilité bonne dans l'ensemble des tâches mais des difficultés de détection dans les exercices de dextérité manuelle. Nous avons modifié les paramètres de ces exercices, principalement l'allongement de la durée des tâches. La faisabilité et l'acceptabilité des exercices de dextérité manuelle étaient bonnes, mais les difficultés liées à la détection des mains des personnes âgées demande un travail approfondi et seront résolus ultérieurement (81) :

Um Din N, Maronnat F, Le Boterff Q, Otmane S, Badra F, Lindberg PG, Belmin J. Contribution of a Tablet-Based Tests to the Diagnosis of Neurocognitive Disorders in Older Adults: A Feasibility Study. Stud Health Technol Inform. 2024 Aug 22;316:1163-1164. doi: 10.3233/SHTI240616. PMID: 39176587.

5. Article 3. Assessment of Frailty by the French Version of the Vulnerable Elders Survey-13 on Digital Tablet: Validation Study.

Original Paper

Assessment of Frailty by the French Version of the Vulnerable Elders Survey-13 on Digital Tablet: Validation Study

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Abstract

Background: Frailty assessment is a major issue in geriatric medicine. The Vulnerable Elders Survey-13 (VES-13) is a simple and practical tool that identifies frailty through a 13-item questionnaire completed by older adults or their family caregivers by self-administration (pencil and paper) or by telephone interview. The VES-13 provides a 10-point score that is also a recognized mortality predictor.

Objective: This study aims to design an electronic version of the Echelle de Vulnérabilité des Ainés-13, the French version of the VES-13 (eEVA-13) for use on a digital tablet and validate it.

Methods: The scale was implemented as a web App in 3 different screens and used on an Android tablet (14.0× 25.6 cm). Participants were patients attending the outpatient clinic of a French geriatric hospital or hospitalized in a rehabilitation ward and family caregivers of geriatric patients. They completed the scale twice, once by a reference method (self-administered questionnaire or telephone interview) and once by eEVA-13 using the digital tablet. Agreement for diagnosis of frailty was assessed with the κ coefficient, and scores were compared by Bland and Altman plots and interclass correlation coefficients. User experience was assessed by a self-administered questionnaire.

Results: In total, 86 participants, including 40 patients and 46 family caregivers, participated in the study. All family caregivers had previously used digital devices, while 13 (32.5%) and 10 (25%) patients had no or infrequent use of them previously. We observed no failure to complete the eEVA-13, and 70% of patients (28/40) and no family caregivers needed support to complete the eEVA-13. The agreement between the eEVA-13 and the reference method for the diagnosis of frailty was excellent (κ=0.92) with agreement in 83 cases and disagreement in 3 cases. The mean difference between the scores provided by the 2 scales was 0.081 (95% CI–1.263 to 1.426). Bland and Altman plots showed a high level of agreement between the eEVA-13 and the reference methods and interclass correlation coefficient value was 0.997 (95% CI 0.994-0.998) for the paper and tablet group and 0.977 (95% CI 0.957-0.988) for the phone and tablet groups. The tablet assessment was found to be easy to use by 77.5% (31/40) of patients and by 96% (44/46) of caregivers. Finally, 85% (39/46) of family caregivers and 50% (20/40) of patients preferred the eEVA-13 to the original version.

Conclusions: The eEVA-13 is an appropriate digital tool for diagnosing frailty and can be used by older adults and their family caregivers. The scores obtained with eEVA-13 are highly correlated with those obtained with the original version. The use of

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health questionnaires on digital tablets is feasible in frail and very old patients, although some patients may need help to use them.

Trial Registration: CNRIPH 20.08.04.58402 RIPH3 HPS, ID RCB: 2020-A02331-38; https://cnriph.sante.gouv.fr/dossier.php?type=detail&id=9305

(J Med Internet Res 2023;25:e42017) doi: 10.2196/42017

KEYWORDS

frailty; Vulnerable Elders Survey-13 (VES-13); elderly; older people; family caregivers; French version; electronic assessment; digital technology; digital health; eHealth; tablet; validity

Introduction

The concept of frailty has been widely studied in aging research for the past decades [1,2]. Frailty is characterized by a vulnerability related to advancing age, along with a reduction in the functional reserves of physiological systems that impairs responses to stress. Older individuals identified as frail are considered vulnerable in terms of their medical and social status, and compared to age-matched nonfrail people, they are more likely to experience geriatric deleterious events in the future [3]. Several studies found that frailty status is a significant predictor of decline in functional independence, onset of geriatric syndromes (such as falls, malnutrition, and depression), but also institutionalization, and even death [4-6]. Thus, the identification of frailty in older adults opens the way to targeted interventions to prevent or delay these geriatric events, whose individual and societal consequences are considerable [7-11]. These issues have been widely emphasized by the World Health Organization, which has initiated proactive programs to promote healthy and active aging [12,13].

The search for frailty is no longer restricted to the field of research, but is becoming part of routine care for an increasing number of geriatric teams, and the question of diagnostic strategies for this condition is clearly raised in these settings and also in primary care. Two instruments, the Fried Frailty Index [2] and the Rockwood Clinical Frailty Scale [14], are reference methods to diagnose frailty in older adults. Many other instruments have been developed to identify frailty in older individuals, and the benefits and limitations of these instruments are under debate [15,16]. However, these are relatively complex tools that are time-consuming and require a high level of geriatric expertise [9], making their use difficult for some geriatric teams and inappropriate for primary care. The Vulnerable Elders Survey-13 (VES-13) is a validated tool to identify frailty in older adults and is a predictor of the risk of functional decline, institutionalization, or mortality [17,18]. This tool is easy-to-use, brief (less than 5 minutes), and can be completed during a face-to-face interview or by telephone with the older individual or with his or her proxy. The scale has 13 simple items or questions, provides a score ranging from 0 to 10, and frailty is diagnosed by a score of 3 or more. The VES-13 can be completed without the need to involve health care staff, and for example, a trained secretary can interview the respondent or supervise the completion of the self-administrated questionnaire. Recently, the original English-language VES-13 has been validated in French, named Echelle de vulnérabilité des aînés-13 (EVA-13), and can now be used to assess frailty in France [19].

With the increasing use of informatics in health care, a number of studies have focused on the design and validation of digital versions of known screening or assessment instruments originally developed on paper. Various electronic media have been used in this research, such as computers, tactile tablets, and smartphones. Digital assessment tools have been developed for pain assessment [20,21], the function of the shoulder joint [22], food intake [23], quality of life measurement [24], dermatological monitoring [25], or erectile function [26]. These studies have documented the reliability of these digital instruments, their equivalence to the original version, and have evaluated the users' experience with the original version. These digital instruments appear to be useful for screening or assessment because of their accuracy of detection, their ecological aspects, and their speed of execution, which saves time for physicians and can have positive effects on health [27]. Few studies have so far evaluated the feasibility and acceptability of a digital assessment tool in an older population.

This study aims to develop an electronic version of the French version of the VES-13 on a digital tablet. To do this, we will compare the results obtained by the original paper version of the French version of the VES-13 and its digital version, named Echelle électronique de vulnérabilité des ainés-13 (eEVA-13), with a population of older people and their caregivers. We wish to measure the reliability of the digital version in detecting frailty, but also its evaluation and acceptability, compared to a scale already used in its paper version in routine care.

Methods

Elaboration of eEVA-13

In this study, eEVA-13 was displayed on an Android tablet with a width of 14.9 cm (5.5 inches), a height of 25.8 cm (10.2 inches), a depth of 1.06 cm (0.42 inches), and a total weight of 515 g. This tablet has a 25.6 cm (10.1 inch) multitouch screen. A secured web application was elaborated to host the data on a personal health data host certified by the Agence Numérique en Santé (Microsoft Azure). It comprised secure web access (strong authentication) through a supervision console [28]. Once the authentication has been successfully completed by the research assistant, he or she identifies the data collector and the latter fills in the questionnaire in accordance with the illustrative input screens provided on the digital tablet. In designing the screens, emphasis was placed on the appearance and clarity of the messages. The answer possibilities are specified for each

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question, with attention paid to the visibility of the proposed answers.

The original scale was organized in 3 screens in eEVA-13. The 2 first questions (age group and health status) were displayed on the first screen (Figure 1), the 6 following questions were displayed on the second screen which requires scrolling (Figure 2), and the 5 last items on the third screen, which also require scrolling. For the items on the third screen inquiring about limitations in some physical activities, an additional question ("is it because of your health?") unfolded for items answered with a limitation. The score was calculated automatically and displayed in a banner at the bottom of the third screen. The cutoff point defining frailty was a score of 3 or higher, as with the paper-and-pencil or telephone interview scales. The research technician prepared the access page for the electronic questionnaire in advance so that when the digital tablet was handed over to the participants, the form was already ready for input. In this access page, the research technician recorded if the respondent was the person assessed or a proxy, and noted an id code for the person assessed and his or her age (years).

Figure 1. Screen print of the first 2 questions of the Echelle électronique de vulnérabilité des ainés-13 (eEVA-13).

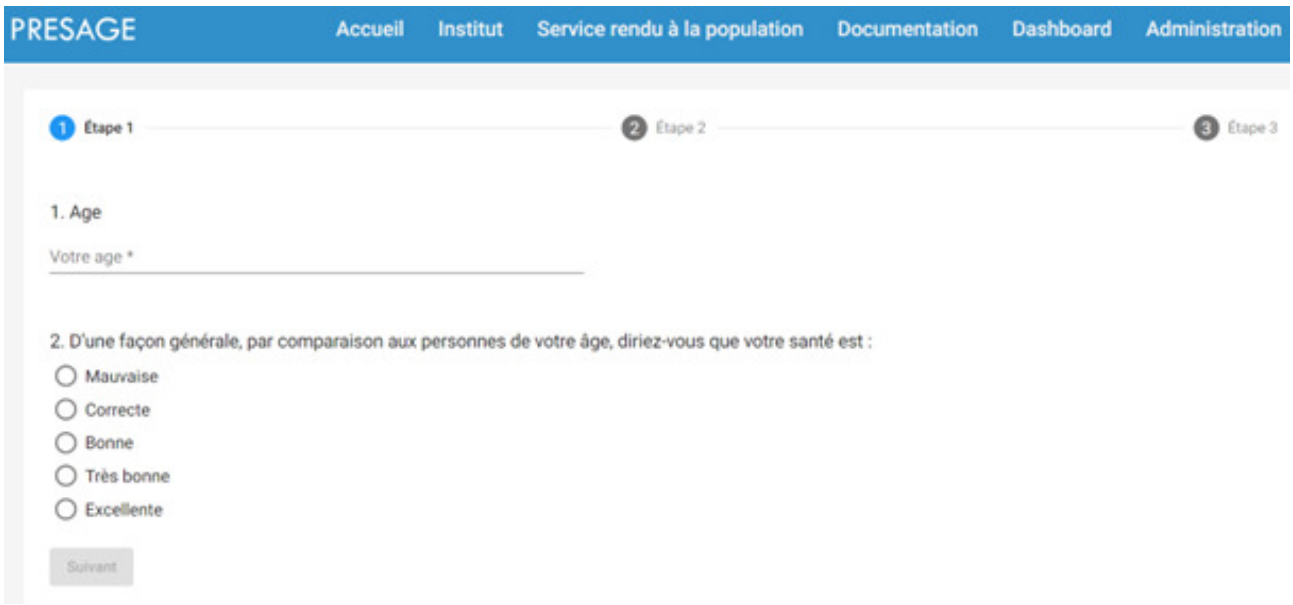
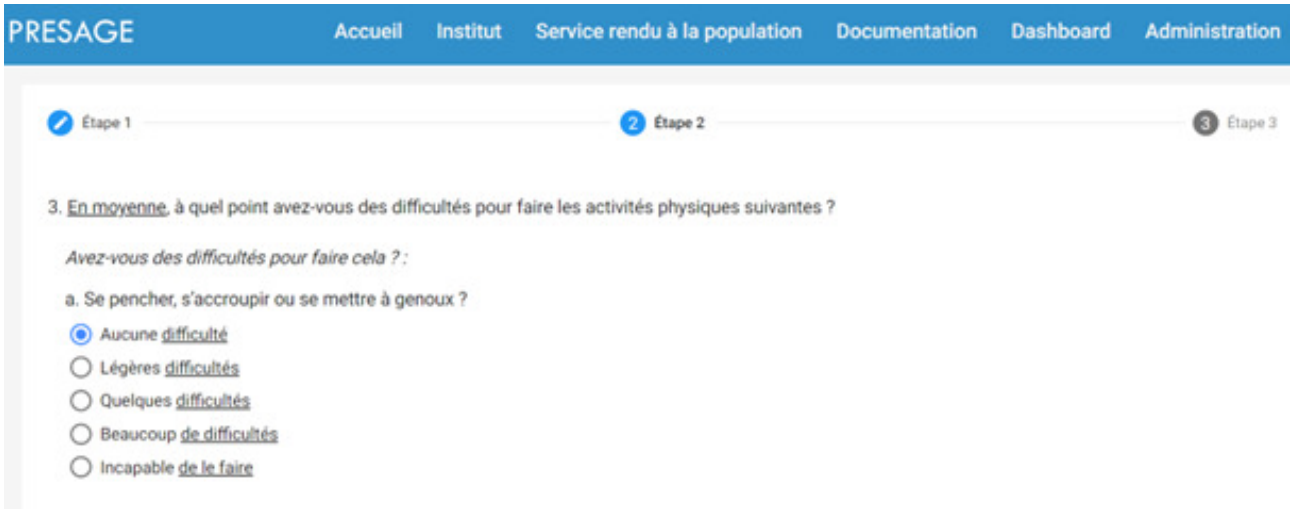


Figure 2. Screen print of the beginning of the next 6 questions of the Echelle électronique de vulnérabilité des ainés-13 (eEVA-13).



Participants and Randomization

Participants were geriatric patients and family caregivers of geriatric patients of the Hôpital Charles Foix, an academic geriatric hospital located near Paris, France. From March 17, 2021, to June 28, 2021, we recruited consecutive patients attending the outpatient geriatric clinic and inpatients admitted to our rehabilitation ward. Eligible patients were included if they did not experience cognitive impairment defined by a Mini Mental Status Examination score above 22 and if they gave their written consent. During the same period, we also recruited a comparable number of family caregivers of geriatric patients attending the outpatient clinic or being hospitalized.

Each participant was assigned to 1 of 2 groups based on a randomization process stratified on the participant's status (patient or caregiver). For the reference scale, participants in group 1 completed the self-administered paper version, and those in group 2 completed the scale as a telephone

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hetero-questionnaire (interview with a research technician). The eEVA-13 and the reference scale were completed within 2 days.

Data Collection

For all participants, we recorded their age, sex, status (patient or family caregiver), previous use of digital devices, and whether they owned a digital device and if so, what type. Participants were considered occasional users if they used a digital device less than once a week, and frequent users if it was more often. All participants completed 2 scales, the eEVA-13 on a digital tablet and the reference scale (self-administered paper questionnaire for group 1 participants, telephone interview for group 2 participants) in random order. Depending on the degree of comfort with the digital device, we also noted if some people required specific support to fill the eEVA-13. User experience was assessed using a self-administered questionnaire that included eight 5-level Likert-type questions, 2 questions about their preference, and 2 multiple choices questions recording positive and negative aspects of the eEVA-13.

Ethics Approval

The research has been approved by the French national ethics committee (Comité de Protection des Personnes Ile de France II; 2020-A02331-38). Written informed consent was obtained from all participants. Data were deidentified and processed in accordance with the European Union General data protection regulation. No compensation was provided to participants.

Statistical Analysis

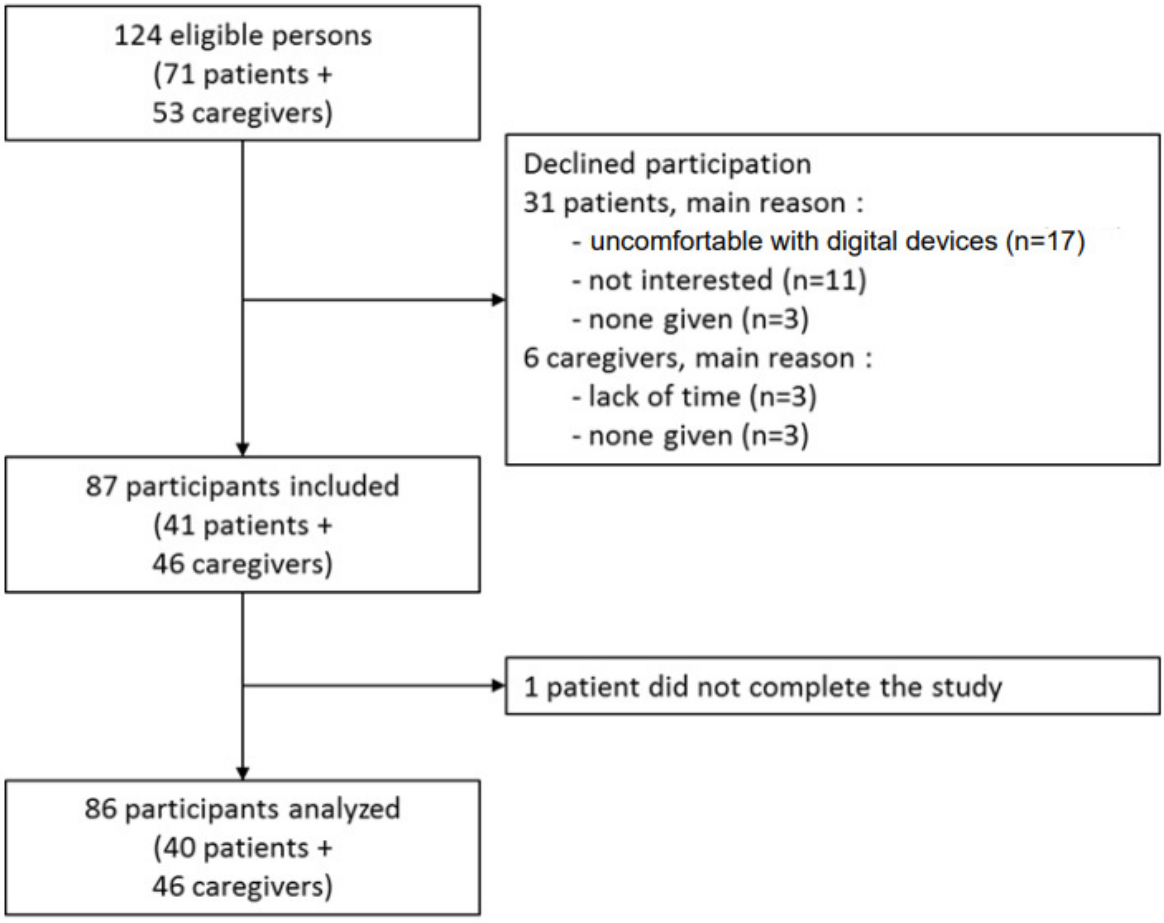
Characteristic of patients and caregivers were compared using the Student *t* test and chi-square test. Agreement for diagnosis of frailty was assessed by the κ coefficient, and scores obtained at the eEVA-13 were compared to that obtained by the reference tools by Bland and Altman plots and interclass correlation coefficients. Statistics were realized using STATA (version 16.1; StataCorp).

Results

Selection and Characteristics of the Participants

During the study period, 124 people were offered the study and 37 of them declined to participate, including 31 patients and 6 family caregivers. Finally, 87 people were included in the study. One of them completed the eEVA-13, but did not complete the reference scale and, therefore, was not included in the analysis. Finally, 86 people completed the study and were included in the analysis. They comprised 40 patients and 46 caregivers (Figure 3).

Figure 3. Flowchart for participants' selection in the study.



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Participants' characteristics are shown in Table 1. Family caregivers were significantly younger than the patients (mean 52.8, SD 11.1 years vs mean 79.9, SD 7.5 years, *P*<.001) and were more frequently owners of digital devices and more frequently users of digital devices. Indeed, all the family caregivers say they use digital devices very regularly. By contrast, among the 40 patients, 13 (32.5%) never used digital devices, 10 (25%) were occasional users and 17 (42.5%) were frequent users. All the caregivers had a smartphone, and 39 (87.9%) had a computer and 27 (67.5%) had a digital tablet. Among the patients, 29 had a smartphone (72.5%), 15 (37.5%) a computer, and 4 had a digital tablet (10%).

Table 1. Participants' characteristics.

	Patients (n=40)	Family caregivers (n=46)	*P* values
Age (years), mean (SD; range)	79.9 (7.5; 65-93)	52.8 (11.1; 22-74)	<.001
Female, n (%)	24 (60)	31 (67.4)	.501
Owns digital devices, n (%)			
Computer	15 (37.5)	39 (84.7)	.005
Digital tablet	4 (10)	27 (67.5)	<.001
Smartphone	29 (72.5)	46 (100)	<.001

Feasibility and Support to Complete the eEVA-13

We observed no failure to complete the eEVA-13. Of the 40 patients, 28 (70%) needed support from the research assistant to complete the eEVA-13, while no caregivers needed support to complete the scale. The support consisted of an explanation of how works the digital tablet (21 cases) and help with navigation from one screen to another (18 cases), scrolling through the screen (23 cases), and selecting answers (24 cases).

Comparison of eEVA-13 With the Reference Scale

Agreement for the diagnosis of frailty was observed in 83 (96.5%) participants and disagreement was observed in 3 (3.5%) participants. The κ coefficient was 0.92, indicating an excellent level of agreement between eEVA-13 and the reference scales (Table 2).

Table 2. Agreement for the diagnosis of frailty provided by the EVA-13[a] scale (reference method) and the eEVA-13[b] used on digital tablet (κ=0.92, indicating excellent agreement).

	EVA-13 (reference method)		
	Nonfrail	Frail	Total
eEVA-13 used on digital tablet			
Nonfrail	27	2	29
Frail	1	56	57
Total	28	58	86

[a]EVA-13: Echelle de vulnérabilité des aînés-13.

[b]eEVA-13: Echelle électronique de vulnérabilité des ainés-13.

The equivalence of the scores obtained by eEVA-13 and those obtained by original EVA-13 was assessed by 2 means. First, the intraclass correlation coefficient between eEVA-13 and paper EVA-13 was 0.997 (95% CI 0.994-0.998) and that between eEVA-13 and telephone interview EVA-13 was 0.977 (95% CI 0.957-0.988; Table 3). These results indicate a high degree of agreement between the different versions. Second, we plotted Bland and Altman graphs that showed that the differences between the scores from eEVA-13 and the original scale were small and were not related to the relative value of the scores (Figure 4). The mean difference between the scores provided by the 2 scales was 0.081 (95% CI –1.263 to 1.426).

Table 3. Assessment of the equivalence of the scores provided by the eEVA[a] scale and the original EVA[b] scale (obtained either by paper questionnaire or by telephone questionnaire).

Comparison	Interclass correlation coefficient (95% CI)	Pearson correlation coefficient	*P* values (Pearson)
Paper versus electronic	0.997 (0.994-0.998)	0.987	<.0001
Telephone versus electronic	0.977 (0.957-0.988)	0.912	<.0001

[a]eEVA-13: Echelle électronique de vulnérabilité des ainés-13.

[b]EVA: Echelle de vulnérabilité des aînés.

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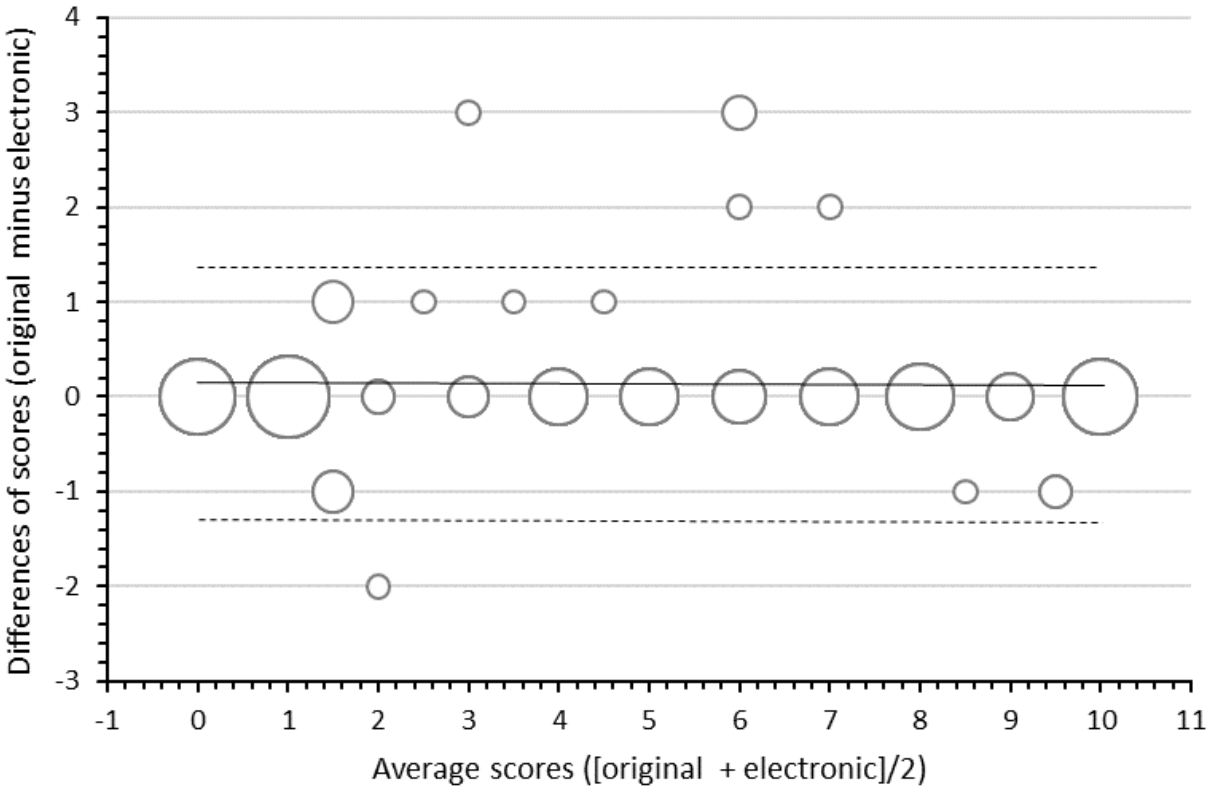
Figure 4. Bland-Altman plot of scores obtained with the Echelle électronique de vulnérabilité des ainés-13 (eEVA-13) and those obtained with the original EVA-13. The solid line represents the bias and the dotted lines the limits of 95% CI.



User's Experience With eEVA-13

User's experience with eEVA-13 assessed by questionnaire is reported in Table 4. The patients who participated in the study agreed overall (85%) that the original version of the instrument and the electronic version was similar, while among family caregivers this rate was 69%. If they were to complete the scale a second time, 85% of the family caregivers would like to do so in electronic form. As for the patients, 50% of them were divided between the electronic and the original mode. The digital version of the scale was considered easy to use overall (96% of caregivers and 77.5% of patients). The electronic version was considered the most pleasant to complete by 74% of the caregivers, while 67.5% of the patients preferred the original version.

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Table 4. Users' experience with the Echelle électronique de vulnérabilité des ainés-13 (eEVA-13). For simplicity, we grouped the responses to the 5 level-Likert scale into 3 levels as described.

Questions	Patients (n=40), n (%)	Caregivers (n=46), n (%)
How did you find the ease of use of the digital tablet?		
Easy or very easy	31 (77.5)	44 (96.0)
Nor easy or difficult	6 (15.0)	1 (2.0)
Difficult or very difficult	3 (7.5)	1 (2.0)
How did you find the ergonomics of the scale on digital tablet?		
Good or very good	28 (70.0)	42 (91.0)
Average	8 (20.0)	3 (7.0)
Poor or very poor	4 (10.0)	1 (2.0)
The size of the tablet was appropriate?		
Agree or fully agree	33 (82.5)	44 (96.0)
Nor agree or disagree	5 (12.5)	0 (0.0)
Disagree of fully disagree	2 (5.0)	2 (4.0)
The text, the words on the tablet screen were readable enough in your opinion?		
Agree or fully agree	35 (87.5)	43 (94.0)
Nor agree or disagree	4 (10.0)	2 (4.0)
Disagree of fully disagree	1 (2.5)	1 (2.0)
The instructions given at each stage of the tablet questionnaire were satisfactory in your opinion?		
Agree or fully agree	35 (87.5)	40 (87.0)
Nor agree or disagree	5 (12.5)	4 (9.0)
Disagree of fully disagree	0	2 (4.0)
The questions were clear enough in the tablet version		
Agree or fully agree	38 (95.0)	45 (98.0)
Nor agree or disagree	1 (2.5)	0
Disagree of fully disagree	1 (2.5)	1 (2.0)
Did you feel like you were filling the same scale twice?		
Agree or fully agree	34 (85.0)	32 (69.0)
Nor agree or disagree	2 (5.0)	5 (11.0)
Disagree of fully disagree	4 (10.0)	9 (20.0)
Do you find it useful to replace the paper scales with a digital version?		
Agree or fully agree	22 (55.0)	38 (83.0)
Nor agree or disagree	13 (32.5)	5 (11.0)
Disagree of fully disagree	5 (12.5)	3 (6.0)
Which version of the scale did you find more comfortable?		
Paper questionnaire or telephone interview	27 (67.5)	12 (26.0)
Digital tablet	13 (32.5)	34 (74.0)
If you were asked to complete this scale again in the future, which version would you prefer?		
Paper questionnaire or telephone interview	20 (50.0)	7 (15.0)
Digital tablet	20 (50.0)	39 (85.0)
Can you check off the following terms that apply to this tablet questionnaire?		
Practical	22 (55.0)	28 (61.0)
Quick	7 (17.5)	12 (26.0)

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Questions	Patients (n=40), n (%)	Caregivers (n=46), n (%)
Ergonomic	11 (27.5)	15 (32.5)
Secure and ease data processing	11 (27.5)	10 (22.0)
Avoid waste	7 (17.5)	6 (13.0)
Impersonal tool	4 (10.0)	5 (11.0)
Not ergonomic	11 (27.5)	11 (24.0)
Not suitable for the older persons	15 (37.5)	10 (22.0)
Generates apprehension	9 (22.5)	0 (0.0)

Discussion

Principal Findings

This study shows that the digital version of the eEVA-13 is appropriate for identifying frailty among older adults and that the score it provides is similar to that obtained by the original paper or telephone version of the scale. The feasibility of the eEVA-13 scale was found to be excellent, although some older people who were unfamiliar with the use of digital objects required human assistance to use the digital tablet. According to the participants' experience questionnaires, the digital scale was found easy to use and was generally appreciated.

Our study was conducted on a special population of frail and very old patients and their relatives. One out of 2 patients was over 80 years old and 2 out of 3 had criteria for frailty. The use of digital tablets for medical assessment has not been studied before in such a population to our knowledge and we observed that it is feasible and well appreciated by the participants.

We observed some differences in usability between patients and family caregivers. Although the digital version was considered easy to use by all participants, the family caregivers stood out by preferring the digital version as being the most pleasant, as well as choosing it for possible future use. The patients were a little more reluctant to use the digital tool to answer the health questionnaire. Among the negative points mentioned by the participants, we can observe that the interest in using the electronic mode by an older population is perceived negatively by 37.5% of the patients and 22% of the caregivers. Indeed, very old patients are sometimes uncomfortable or untrained in the use of a digital tool and prefer to be able to give information in a more traditional way, using a pen and paper or interacting directly with a person. Ten family caregivers spontaneously explained that using the eEVA-13 would be too complex for an older person. These observations are consistent with the inclusion difficulties we encountered during the study. In fact, we collected significantly more refusals from eligible patients (31) than from eligible caregivers (6). Looking at the reasons for refusal among patients (Figure 3), the one that stood out was apprehension about the digital domain, fear of not knowing how to do it, and lack of knowledge in this field. Age and previous familiarity with digital devices seem to be key elements to be considered carefully when proposing the use of an assessment by an electronic instrument.

Comparison to Prior Work

We found equivalence between the digital version of the scale and the original version of the scale, and our findings are similar to those of other teams that have compared digital and paper versions of other medical tools in other settings [20-26]. Casamali et al [24] studied the use of the World Health Organization quality of life questionnaire on computer in a sample of older adults younger than those in our study (mean age 66 years) and found it to be feasible and to provide similar scores to the original paper instrument. The disadvantages of electronic patient-reported outcomes measures (PROms) have been described in the literature as potentially leading to risks of a "digital divide." Indeed, it has been observed in some studies that the advanced age of participants was a barrier to completing the electronic version of a questionnaire, compared to the paper version. In the case of older people with cancer or those who are not used to using digital devices, they needed time to get used to the devices or were more likely to encounter barriers when using them if they were not familiar with them beforehand [29].

Strengths and Limitations

This study was conducted using the recommendations of the International Society for Pharmacoeconomics and Outcomes Research, which emphasize the importance of validating electronic PROms against traditional PROms [30]. In addition, these recommendations provide methodological guidance for documenting equivalence between digital and traditional instruments [30]. As the transition from the original scale to eEVA-13 can be considered as a minor level of modification, our validation study was limited to exploring equivalence and usability, in agreement with the International Society for Pharmacoeconomics and Outcomes Research methodological guidance. We conducted a single-center study with a small sample size of 86 participants. These 2 characteristics represent the main limitations of this work.

Future Directions

The results obtained in this study show that it is possible to offer the eEVA-13 instrument as a self-questionnaire to family caregivers and older patients. We have started to use it in the waiting room of an outpatient department of a geriatric center, and it provides physicians with immediate information on the level of frailty of patients. In addition, digital technology might the advantage of saving time and processing and store the data instantly. Care should be taken with older patients who are unfamiliar with the use of digital devices, as they may require human assistance to fill the scale, or they may prefer to use the

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traditional paper scale. Despite these limitations, the eEVA-13 is an effective and innovative health support system for both family caregivers and patients. Certainly, the development of other PROms collected by digital devices is a promising avenue to facilitate geriatric assessment.

Data Availability

The data sets generated and analyzed during this study are available from the corresponding author on reasonable request.

Authors' Contributions

JB, CLL, and SP designed the study. VZK and NUD investigated the data. JB and J-HV designed the eEVA-13 survey. JB and CHT analyzed the data and JB, CHT, VZK, and NUD wrote the manuscript. VZK and NUD contributed equally to this work. All the authors approved the final version of the manuscript.

Conflicts of Interest

J-HV is the director of PRESAGE.

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Abbreviations

eEVA-13: Echelle électronique de vulnérabilité des ainés-13
EVA-13: Echelle de vulnérabilité des aînés-13
PROm: patient-related outcomes measure
VES-13: Vulnerable Elders Survey-13

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6. Article 4. A Digital Clock Drawing Test on Tablet for the Diagnosis of Neurocognitive Disorders in Older Adults.

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A Digital Clock Drawing Test on Tablet for the Diagnosis of Neurocognitive Disorders in Older Adults

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Abstract. The diagnosis of neurocognitive diseases is an important health issue for patients, families and healthcare professionals. The need to develop rapid, high-performance screening tools would improve access to care. The Clock Drawing Test (CDT) is widely used and validated with the older adults, and its digital version is becoming increasingly widespread. We propose to confirm its validity in a population of old patients hospitalized in a geriatric unit, and secondly to verify its performance in comparison with the reference diagnosis made by a specialized team in a memory consultation. CDTs were collected from older hospitalized patients, both in paper form and digitally on a touchscreen tablet. The results show good agreement between the paper and digital versions (kappa coefficient = 0.81). Sensitivity and specificity of the digital CDT were 0.84 and 0.59 respectively for the diagnosis of major cognitive disorders. The corresponding values were 0.72 and 0.59 for the diagnosis of mild neurocognitive disorders. User questionnaires indicate that older participants find the digital tablet easy to use. However, they prefer to use paper, even if they are open to learning how to use the tablet.

Keywords. digital clock drawing test, digital tablet, diagnosis, neurocognitive disorder, older adult

1. Introduction

The diagnosis of neurocognitive disorders is based on a battery of medical and neuropsychological tests. These require expertise and are carried out in specialized consultation centers. Access to these centers and specialists is still difficult, and waiting times are long. And yet, early detection of neurocognitive disorders enables measures to be put in place for both the person affected and those around them. Providing early cognitive stimulation can enable rapid management of the disease and maintain the person's cognitive abilities.

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The clock drawing test (CDT) is widely used to screen for cognitive disorders: it is quick, inexpensive and easy to administer [1]. It has been shown to detect cognitive disorders in the older adult [2]. However, there are several ways of administering it: with a pre-drawn circle, with a copying task, or simply on command on a blank sheet of paper. Current studies focus on the conversion of paper tests into numerical form, like the CDT, and on the use of digital tools such as tablets or smart pencils to record finer parameters that cannot be observed (number and duration of pauses, finger movements and pressure on the pencil, pressure on the tablet, direction and particularities of the drawing). These more precise data can be combined to detect disease. Machine learning methods applied to healthcare data can be used to develop prognostic tools. Machine learning approaches already exist and have produced interesting results on clock drawings [3]. Efforts to digitize the entire test are underway, and initial results are encouraging [4].

Our study aims to validate digital CDT versus conventional CDT in older adults at a geriatric hospital. We also studied the performance of the digital CDT in relation to cognitive diagnosis in older adults attending a memory clinic. A questionnaire was used to gather the user experience of the participants.

2. Methods

2.1. Participants

We recruited 257 participants; 100 of them were hospitalized in a geriatric hospital and participated in the study that compared conventional paper-and-pencil testing with digital clock testing. One hundred and fifty-seven older adults were recruited from a memory clinic and from the city's seniors' associations and participated in the study that assessed the sensitivity and specificity of the digital CDT for diagnosing neurocognitive disorders. These 157 people received the user experience questionnaire, but only 68 completed it.

2.2. Digital Clock Drawing Test

We used two tablets of the same size to collect the data and a free application available on Android and IOS where we download a circle on which it is possible to draw on.

- *Instructions:* Prior to the test, participants were asked to familiarize themselves with the use of a simple stylus, with no integrated technology, on the tablet by writing a few words. After that, we presented them a pre-defined circle on which they had to draw all the numbers on a clock face by using the stylus. Then they had to draw the hands to indicate 11:10.

- *Scoring system:* Several scoring systems exist for the CDT [5]. We choose two of them, the Greco and the Codex scoring systems [6]. The first is composed of a combination of different clock elements: hand placement, digit placement, gaps, errors, perseveration, unrecognized signs. The total is on 10. The test is considered normal with a score between 7 and 10; 6 is borderline and less than 5 is considered as abnormal. Codex scoring was chosen for its easy-to-use and

the facility to quote. The rating is binary (normal or not) and is based on 4 elements: all numbers are presents, numbers are correctly placed, presence of an hour hand and a minute hand, hands are correctly placed. If any of these criteria is missing, the CDT is considered abnormal.

- *Examiners:* Two qualified healthcare professionals independently assessed the CDT. In cases where their ratings differed, they reviewed them together to reach agreement.

- *Randomization:* In the validation sample, the order of execution of the CDT (paper then digital CDT, or reverse) was randomized.

- *Reference diagnosis of neurocognitive disorders*: For the performance sample, the result of the digital CDT was compared with the presence/absence of neurocognitive disorder and the type of neurocognitive disorder (major or mild) according to DSM-5 criteria.

2.3. User Questionnaire

After completing both conventional and digital CDTs, participants answered a user questionnaire. This self-questionnaire consisted of 9 Lickert questions and 2 open-ended questions on the use of the test on a tablet, its ergonomics, the clarity of instructions, ease of use, as well as the dimensions of the tablet and their preference between the two versions. The aim was to collect their feelings and preferences regarding the use of a tactile tablet for cognitive testing.

2.4. Analysis

We used STATA software to perform the analyses. We used the k-Test (kappa) to evaluate the concordance of conventional and digital CDT findings. We calculated the sensitivity and specificity of the digital CDT for the diagnosis of major cognitive disorder and mild neurocognitive disorders.

3. Results

3.1. Validation Sample

We recruited 100 patients, including 74 women (74%) and 26 men (26%). Their age was 83.7 ± 7 years (range 65 to 95). The contingency table for the Codex scoring version of the CDT is presented in Table 1. Agreement was obtained in 91% of cases. The kappa coefficient is 0.81, indicating almost perfect agreement (very good concordance).

Table 1. Contingency table for the Clock drawing test (CDT) using Codex scoring.

		Conventional CDT	
		Normal test	Abnormal test
Digital CDT	Normal test	33	6
	Abnormal test	3	58

The contingency table for the Greco scoring version is presented in Table 2. The kappa coefficient is 0.71, indicating average to good concordance.

Table 2. Contingency table for the Clock drawing test (CDT) using GRECO scoring

		Conventional version		
		Normal	Limit	Abnormal
Digital version	Normal	36	4	4
	Limit	1	1	3
	Abnormal	5	3	43

3.2. Performance Sample

We administered the digital CDT to 157 participants, including 80 women (76%) and 25 men (24%), Their age was 81 ± 7 years. They comprised 61 patients with major cognitive disorder, 49 patients with mild cognitive disorder, and 47 people with no cognitive disorder. The performance of the digital CDT for the reference diagnosis is shown in Table 3.

Table 3. Sensitivity (Se) and specificity (Spe) of the digital Clock Drawing Test (CDT) for the reference diagnosis (major or mild neurocognitive disorders).

	Se	**Spe**
Mild vs no neurocognitive disorder	0.72	0.59
Major vs no neurocognitive disorder	0.84	0.59

3.3. User Experience

After completing the CDT, participants were asked to fill in a questionnaire to obtain their feedback on the digital CDT on tablet comparatively to the paper and pencil version. We have collected 68 questionnaires as shown in Figure 1. These participants find the tablet easy to use for 49%. However, they still prefer to use paper version (69%), even if they are open to learning how to use the tablet (45%). The digitization of tests in the healthcare sector leaves them a little perplexed (47%), although they tend to agree (32% agree and 9% totally agree).

4. Discussion and Conclusions

We have found that the digital CDT is equivalent to the conventional CDT in hospitalized very old patients. Its sensitivity is good for diagnosing major or mild neurocognitive disorders, and its specificity is low, as has been shown in other studies. Its performance is interesting for the screening of neurocognitive disorders but does not make the digital CDT alone a diagnostic test for these conditions. We will include this test in a series of digital assessments that could help diagnose neurocognitive disorders in older adults.

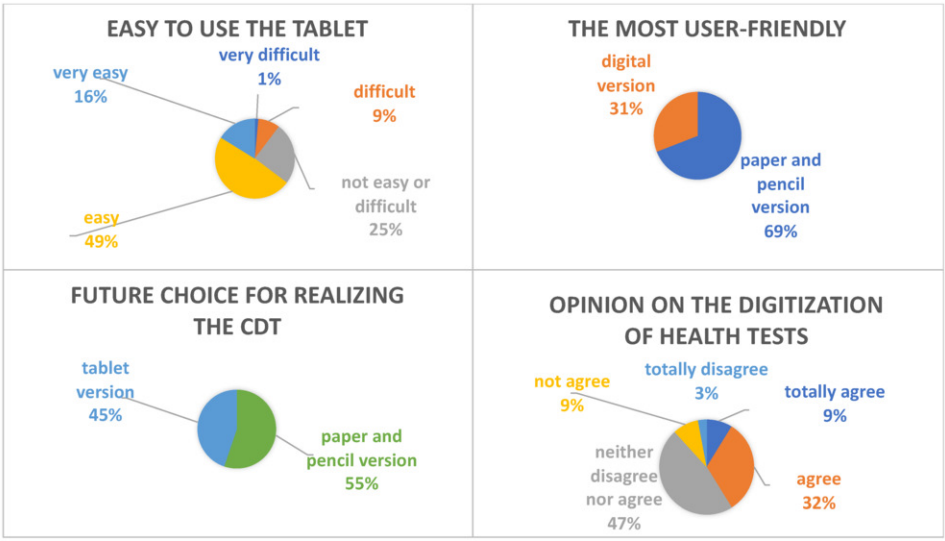

Figure 1. User experience questionnaire

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7. Article 5. Contribution of a Tablet-Based Tests to the Diagnosis of Neurocognitive Disorders in Older Adults: A Feasibility Study.

Digital Health and Informatics Innovations for Sustainable Health Care Systems
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Contribution of a Tablet-Based Tests to the Diagnosis of Neurocognitive Disorders in Older Adults: A Feasibility Study

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Abstract. Neurocognitive diseases are diagnosed in specialized centers such as memory clinics, where the waiting time can be long. The reference assessment involves a battery of tests carried out by a specialized team. Facilitating screening in primary care using new technologies could make it possible to appropriately direct care pathways towards specialist care. This work aimed to set up a battery of questionnaires, cognitive and manual dexterity tests on a digital tablet to screen people with cognitive impairment. Three groups of people are recruited from a memory consultation: people with major neurocognitive disorders, people with mild neurocognitive disorders and people with no cognitive impairment. Initial results in geriatric settings show that the digital tablet assessment test is feasible and well accepted, but that manual dexterity assessment needs to be adapted to the bodily particularities of the very old.

Keywords. tablet, older adult, neurocognitive disorder, manual dexterity, diagnosis.

1. Introduction

Neurocognitive disorders are diagnosed by a team of specialized professionals in memory consultation centers. Diagnosis requires a battery of tests including an extensive and time-consuming neurocognitive assessment. These centers are not accessible in all locations, where waiting times can take several months. This is an important period for early stimulation. Research is underway to develop neurocognitive testings on digital tools such as tablets [1] in order to facilitate screening in primary care setting. A previous study by members of our team has shown interesting results on the impairment of manual dexterity during the progression of Alzheimer's disease [2]. We aimed to produce a fast and easy-to-use testing on a touchscreen tablet, using a combination of simple

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questionnaires, cognitive and manual dexterity tests; a screening tool that could be offered to non-specialists in primary care.

2. Methods

Participants: We recruited consecutive participants from the memory clinics of two geriatric hospitals who completed a battery of neuropsychological tests, as well as participants without cognitive impairment from the city through seniors' associations.

Material: We used a Samsung Galaxy Tablet A8 with a simple stylus pen. We have chosen this equipment with a perspective of accessibility.

Procedure: All participants completed the same battery of testings on tablet, including self-questionnaires, cognitive tasks (including the clock drawing test). We also included manual dexterity exercises newly designed for the tablet and measure psychomotor symptoms such as minor neurological signs. It lasted around 1 hour and administered by a trained investigator. In addition, participants answered to a user experience questionnaire.

3. Preliminary Results, Discussion and Conclusion

We included 122 participants whose age was 83 ± 3.5 and who comprised 91 women (75%) and 31 men (25%). Test feasibility was excellent, as we had not refusals or overall failures. All participants answered the self-questionnaires without difficulty. Two participants refused the clock drawing test: one said it exhausted him, and the other for no clearly expressed reason. Three participants did not complete the manual dexterity test: 2 refused and 1 encountered technical problems that made it impossible to record the test. We experienced a number of technical issues during the manual dexterity exercise: detection of older people's fingers was a bit tricky, due to dry skin, deformation of the hand (thumb inwards) or the position of the hand to be held. Acceptability assessed by the user experience questionnaire was good. In accordance with the protocol, analysis of the performance of the test and of each subtest for the diagnosis of cognitive disorders will be carried out after inclusion of all participants (n=160).

Overall feasibility and acceptability were good, even if the feasibility of manual dexterity tests needs to be improved. Inclusion in the study is still ongoing, and analyses have yet to be completed. Our aim is to explore our data to define profiles for the 3 neurocognitive conditions based on statistical analysis and classification methods.

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IV. Étude clinique principale

Les résultats de ces études préliminaires étant encourageants, nous avons mis en place une étude clinique pour tester nos hypothèses et chercher la meilleure combinaison de variables qui permettrait un repérage bref et performant des TNC-L et TNC-M chez les personnes âgées. L'outil sur tablette consiste en plusieurs applications élaborées en collaboration avec l'équipe d'informatique du laboratoire IBISC (Informatique, Bioinformatique, Systèmes Complexes EA 4526) de l'Université d'Évry Paris-Saclay, et l'équipe de l'institut de psychiatrie et neurosciences de Paris (INSERM UMR_S 1266).

1. Préparation de l'étude clinique

Le protocole de l'étude a été rédigé et soumis auprès du comité de protection des personnes Est III avec l'obtention d'un avis favorable le 25/07/2022. Une déclaration auprès de la Commission Nationale de l'Informatique et des Libertés a été réalisée pour le traitement des données. Il a été enregistré dans le registre des études cliniques (*clinical trial NCT06032611*). La mise en place du protocole comprend les réunions d'informations auprès des différentes équipes des centres de recrutement, de la formation des investigateurs au protocole et de la procédure de recrutement des participants.

2. Collecte des données

Nous avons recruté des personnes âgées qui venaient en consultation au sein de deux centres mémoire d'Île-de-France. Elles présentaient une plainte cognitive et venaient pour en investiguer la cause. L'objectif de l'étude est d'identifier les variables d'intérêts parmi des questionnaires médicaux, des épreuves cognitives et des exercices de motricité fine, dans la classification des TNC. Un consentement écrit a été recueilli.

Le déroulement de l'étude consiste à remplir une série de questions médicales, puis à réaliser des tâches cognitives et de motricité fine sur une tablette tactile. Le temps de participation était d'environ 1 heure. Les données étaient pseudonymisées et enregistrées localement sur la tablette tactile. Elles étaient ensuite téléchargées directement de la tablette à l'ordinateur par un câble.

3. Traitement et analyses des données

Lors de la remontée des données, un premier travail de vérification a été réalisé pour s'assurer de leur bon enregistrement, en comparant les données numériques avec les cahiers d'observation associés.

Dans un deuxième temps, nous avons identifié, catégorisé et géré des données manquantes. Nous avons souhaité garder un maximum de données, c'est pourquoi nous avons choisi la méthode d'imputation simple des variables manquantes. Pour les variables numériques, nous avons fait le choix de les remplacer par la moyenne ou la médiane selon la distribution des valeurs. Pour les variables qualitatives, nous avons procédé au remplacement par l'occurrence majoritaire.

Les données aberrantes (*outliers*) ont été comptabilisées et identifiées pour chaque variable. Nous avons considéré comme données aberrantes les valeurs qui dépassaient la médiane de 1,5 multiplié par l'écart interquartile. Nous avons ainsi retrouvé un total de 503 données aberrantes. Chaque variable a été revue et nous avons décidé de ramener les données aberrantes aux valeurs les plus éloignées de l'intervalle de confiance le plus proche si la distribution ne suivait pas une loi normale. Si la distribution suivait une loi normale, nous avons ramené la valeur à la moyenne.

Un jeu de données nettoyé et complet a été obtenu au terme de ces différentes étapes. Il est la base des analyses statistiques et d'apprentissage automatique que nous avons

réalisé. Le but étant d'identifier les variables d'intérêts pour la classification des TNC (TNC-M, TNC-L et sans trouble).

3.1. Analyses statistiques

Le but des analyses est d'étudier chaque variable dans un premier temps, de déterminer lesquelles ont un apport pour la classification (diagnostic). Puis, dans un second temps de constituer une combinaison de variables avec le minimum nécessaire permettant de classer sans perte de performance.

Nous avons obtenu nos 3 groupes (TNC-M, TNC-L, sans trouble), puis nous avons choisi de réaliser des classifications en 2 groupes avec une signification clinique : la classification selon la présence de TNC-M (personnes ayant un TNC-M versus personnes TNC-L et sans TNC), la classification selon la présence de TNC (personnes ayant un TNC-M ou TNC-L versus personnes sans TNC) comme récapitulé dans la Figure 3 ci-dessous.

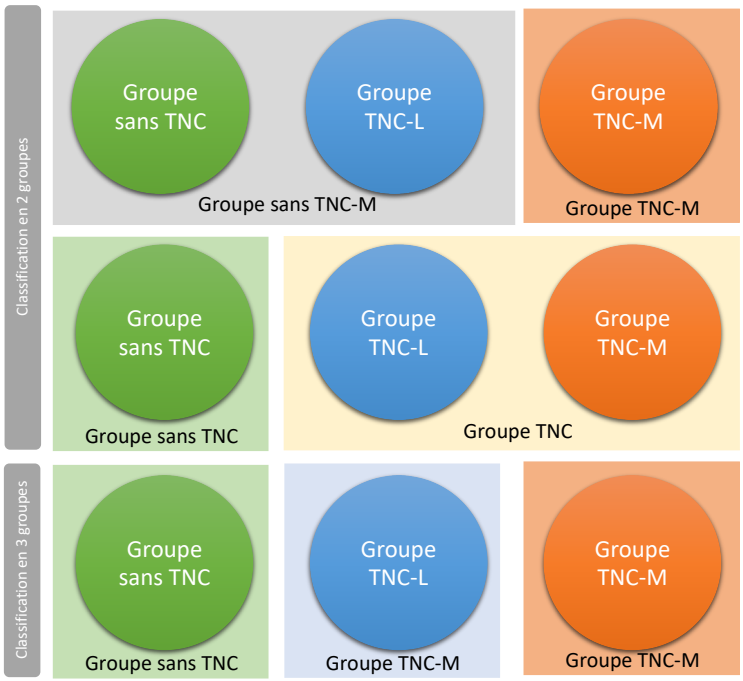

Figure 3. Groupes de classification

Test univariés

L'analyse de l'association de chaque variable avec le diagnostic a permis dans un premier temps de repérer celles potentiellement intéressantes pour la classification, et inversement d'en écarter d'autres. L'association entre les variables catégorielles et la classification diagnostique a été réalisée au moyen du test du chi-deux. L'association entre les variables quantitatives suivant une loi normale a été analysée par ANOVA pour la classification en trois groupes (Pas de TNC/TNC-L/TNC-M), ou par le test t de Student pour la classification en deux groupes (Pas de TNC/TNC ou Pas de TNC-M/TNC-M). Pour les variables dont la distribution ne suivait pas une loi normale, le test non paramétrique équivalent a été utilisé : test de Kruskal-Wallis et test U de Mann-Whitney respectivement.

Régressions logistiques multivariées

Suite aux analyses univariées, nous avons réalisé les analyses par régression logistique afin de ne garder que les variables indépendantes les plus pertinentes pour la classification. Nous avons pu identifier les variables corrélées et n'en sélectionner qu'une partie.

3.2. Premières approches d'apprentissage automatique

A partir des analyses univariées, nous avons utilisé plusieurs méthodes d'apprentissage automatique pour explorer les différents estimateurs et méthodes de sélection des variables sur notre jeu de données.

4. **Article 6. Digital tablet-based testings for the screening of neurocognitive disorders in older adults: a diagnosis study.** [in preparation]

Title: Digital tablet-based testings for the screening of neurocognitive disorders in older adults: a diagnosis study.

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Abstract

Background. The prevalence of neurocognitive disorders (NCD) is increasing as the population ages. The diagnosis includes a time-consuming medical and neuropsychological battery of tests in specialized centers. The development of effective screening tools could benefit primary care professionals by improving referral practices.

Objectives. To explore the feasibility of a digital tablet-based investigation comprising a wide set of questions combined with cognitive and manual dexterity tasks, study their relevance for the diagnosis of NCD, and select the best combination of variables likely to help in their screening.

Methods. Prospective diagnosis study conducted in two memory clinics. We recruited older adults who underwent a comprehensive cognitive assessment with a specialized team leading to a reference diagnostic. This consisted in three-category classification: no NCD, mild NCD (m-NCD) and major NCD (M-NCD). At the same time, they completed a variety of testings implemented on a touchscreen tablet which included a medical questionnaire, cognitive and manual dexterity tasks. We analyzed the dataset using several approaches to determine the most important variables for identifying M-NCD, or any NCD (either m-NCD or M-NCD). Several analyses using different estimators (random forest, xgboost, 3nn) and variable selection methods (logistic regression, k-best, seqdel) have been tested to determine the most relevant variables to discriminate them.

Results. We included 160 participants whose reference diagnosis were M-NCD for 58 of them, m-NCD for 52, and no NCD for 50. The feasibility of the index test battery was excellent; all participants answered the medical questionnaire, all completed the cognitive tasks, and there were 7 protocol stops during the manual dexterity tasks due to pain and poor hand detection. We achieved a final model with 9 variables for the detection of M-NCD and 5 for any NCD. The variables relevant for identifying M-NCD are those related to loss of independence, frailty,

information processing, sleep, and executive functions related to manual dexterity (inhibition and mental flexibility). Sensitivity was 81% and specificity 86%, with an AUC of 0.90 for the screening of M-NCD. The variables relevant to identifying NCDs are memory, categorization, processing speed, the presence of hypertension, and success in a motor task requiring mental flexibility. Sensitivity was 81% and specificity 82% with and AUC of 0.91 for the detection of any NCD.

Conclusion. We have identified two combinations of variables capable of distinguishing between any NCD and M-NCD with satisfactory performance for a screening.

Fundings: This study did not receive any fundings.

Keywords: older adults – manual dexterity – cognitive assessments – Alzheimer's disease – diagnosis – major neurocognitive disorder – mild neurocognitive disorder

INTRODUCTION

Neurocognitive disorders (NCD) are a group of diseases that involve a decline in performance in one or more cognitive areas such as memory, complex attention, executive functions, language, visuomotor functions, or social skills. Alzheimer's Disease International estimates that more than 55 million people are affected by major neurocognitive disorders (M-NCD) [1]. The annual cost of these diseases worldwide amounts to 733 billion euros. It includes diagnosis, care and hospitalization for complications: falls, malnutrition, depression, etc. In France, M-NCD affects around 1.2 million people, and it is a major cause of loss of autonomy, institutionalization, and hospitalization among older adults [2]. M-NCDs are irreversible, evolutive and no treatment is capable to reverse or stop the cognitive decline. The diagnosis of M-NCD is based on the DSM-5 criteria which rely on a detailed clinical assessment of the person, combined with neuropsychological tests. Its cause can be investigated using clinical profile, brain MRI imaging, biological markers in the cerebrospinal fluid or blood and sometimes with brain isotope imaging [3]. Early detection of M-NCD remains difficult, and this condition is widely under- and misdiagnosed [4,5]. In the recent decades, considerable attention had been paid to the diagnosis of m-NCD since this condition constitutes a prodromal condition of M-NCD for more than half of the patients [6]. In addition, life style intervention had been found to precent or postpone the progression to M-NCD [7,8]. Improving the early detection of NCD remains a major scientific and clinical challenge [9].

NCD screening tools are an important factor contributing to access to specialized care and diagnosis [10]. When healthcare professionals record cognitive complaints or symptoms, they are advised to use a screening tool to assess the likelihood of this diagnosis, as none of these symptoms are specific to the diagnosis [11]. Then they can appropriately refer patients with a high probability of NCD to specialist care and memory centers. The most famous and used cognitive tests for screening are the Mini-Mental State Examination (MMSE) [12] and the

Montreal Cognitive Assessment (MoCA) [13]. These tests have different performances in identifying NCD; MMSE is more performant to M-NCD, while the MoCA is more performant in detecting visuo-constructive difficulties [14]. Although their performances are very interesting, these tools are rarely used in primary care, particularly by general practitioners, due to the time required to administer them (approximately 10 min.) and the training they require.

Technologies are present in everyday life, enabling the digitization of assessment tools [15–17] that will provide more precise and detailed information on individual performance. Touchscreen tablets are mobile, intuitive, and do not require extensive training; users can interact directly with the screen without any intermediary which is interesting for older adults who are not used to dealing with computers [18]. The development of digital cognitive tests makes them easier to use by primary care teams. The digital tools allow the collection of more detailed data than a paper-based test and open up the possibility of diversifying the input data [19]. Recent studies analyze these data from several types using machine learning techniques [20,21]. Studies show promising results in helping to identify NCD, such as Qiu's study, which uses demographic data, medical history, functional assessments, medical imaging, and neuropsychological tests [22].

The aims of this study were to explore the feasibility of a digital tablet-based investigation comprising a wide set of questions, cognitive and manual dexterity tasks for patients of a memory clinic, study their relevance for the diagnosis of NCD, and select the best combination of variables likely to help in their screening. We hypothesized that the diversity of sources from medical questionnaire, cognitive and manual dexterity tasks, would improve the screening of NCDs.

METHODS

This study is a prospective diagnosis study that has been registered in clinical trial under the number NCT06032611. The protocol has been approved by the French national ethic committee (Comité de Protection des Personnes Est III) under the number IDRCB2022-A00609-34. Results are reported in accordance with the STARD 2015 guidelines [23] (supplementary material Table S1).

Participants

We recruited consecutive patients attending two memory clinics. Patients were eligible if they: (i) were attending the clinic for an initial cognitive assessment, (ii) did not have any hand conditions that would interfere with the use of a digital tablet, and (iii) were legally capable of giving consent. They were included if they: (i) agreed to participate in the study and signed the consent form, and (ii) for patients with NCD, if this condition was related to Alzheimer's disease according to the reference diagnosis determined by the memory clinic specialist. Finally, we also recruited additional participants from a senior citizens' association to complete the number of participants without NCDs using the same inclusion criteria except attending to the memory clinic. Absence of NCD was document by the absence of memory complaint and a MoCA test > 26.

Reference diagnosis

Participants recruited in the memory clinics underwent a complete assessment that included a neuropsychological evaluation comprising a battery of cognitive test and medical investigation. The diagnosis of the cognitive status (M-NCD, m-NCD, no NCD) was determined by the memory clinic specialist using DSM-5 criteria. For the patients with NCD, the same physician stated about its relationship with Alzheimer’s disease based on DSM-5 criteria, including

clinical profile, MRI imaging and in some cases additional investigations. Additional participants (n=24) were recruited from local citizen association and not underwent a full cognitive assessment in the memory clinic, but underwent a MoCA test done by the investigator.

Touchscreen tablet-based investigation

The battery of tests was performed on the same day that the patient came to the memory center for his consultation with the professional. In each center, an investigator received participants in a quiet room to realize the tablet-based investigation. For patient attending the memory clinic, this was done during the same day that the routine memory clinic assessment. The healthy volunteers underwent the tests under the same conditions as the other participants:

they came to the hospital and underwent the testings in consultation rooms or quiet environments. Participants were seated at a table and the touchscreen tablet was placed in the most comfortable position for them. We used the Samsung Galaxy Tab A8 which had a screen size of 10.5 inches, and a resolution of 1920 × 1200 pixels. Before passing the tablet to participants, the investigator had to enter the collected data into the medical record: MMSE, ADL, and IADL scores. Then, the participants had the tablet positioned at 40° on its stand for the cognitive tasks and medical questionnaire, then for the CDT some chose to place the tablet flat and others kept it inclined. For manual dexterity tasks, all participants placed the tablet flat on the table. A basic stylus was available for interacting with the touchscreen and was used according to the participants' preference. A familiarization phase with the tablet was carried out prior to the testings and the sound level has been adjusted so that the participant can hear the instructions clearly.

Index items

Medical questionnaire

The medical questionnaire was self-administered under the supervision of the investigator which intervene if the participant asked or faced some difficulties. The data collected were self-reported by the patient himself based on his own statements. The medical questionnaire comprised 16 closed-ended yes/no questions, that were driven from the literature on protective or risk factors for NCDs [7,24] and on validated pre-existing questionnaire [12,13,25–27]. They covered the following areas: lifestyle, sensory impairment, sleep, mood, physical activity, language, nutrition, independence, overall perception of health, and related illnesses. In addition, the medical questionnaire also included an assessment of frailty using the French version of the Vulnerable Elders Survey-13 (VES-13) [28] that comprises 12 additional questions.

Cognitive tasks

The cognitive tasks were based on the areas to be explored in the DSM-5 diagnostic criteria. We worked with a geriatric expert to select the most interesting tasks from among the validated tests, then chose those that were most practical to implement on a tablet. The cognitive task application is named AlzVR and was developed using Unity®. It has been the subject of a preliminary study involving students [29]. In the end, the cognitive tasks selected covered short-term memory, long-term memory, categorization, spatial and temporal orientation, flag recognition, and mental arithmetic.

The cognitive testing was launched by the participant. Then the test was self-administered by the participant with verbal instructions given by the device. A congratulatory message appeared at the end of each task to keep participants motivated until the end of the tests, regardless of

their answers. The testing consisted of 13 tasks in which the participant touched the screen to select or write the correct answer. In addition, a clock drawing test was carried out as follows: a large circle was displayed on the screen. The participant had to write the numbers of the clock inside the circle and then draw the hands to indicate a specific time. For each task, the number of correct answers and the time taken to complete the tasks were recorded.

Manual dexterity tasks

The manual dexterity application, Homecare, was developed by Dextrain company (Paris, France)[30], and measured performance in six tasks targeting specific cognitive-motor functions: finger recognition task, rhythm tapping task, multi-finger tapping task, sequence tapping task and line tracking task [31].

- Finger recognition task

The finger recognition task measured mental rotation, which is the ability to identify and select a specific finger from among five, based on spatial information on the screen. An avatar hand was displayed in different postures, and a dot appeared on a finger of this avatar, indicating the finger to move. Reaction time and number of errors were measured, and the different positions of the avatar hand were used to assess reaction time and “mental calculation” in this task.

- Rhythm tapping task

The rhythm tapping task measured temporal variability in a task in which the participant repeated taps with the index finger following a regular rhythm indicated by a sound signal (1, 2, or 3 Hz). After a moment, the sound signal stopped, the participant was asked to maintain the tapping frequency as regularly as possible. Measurements obtained included the average frequency performed (the ability to follow a frequency) and the variability of the taps (the ability to be regular). The latter variable was found to distinguish patients with NCD from age-matched participants without NCD in a previous study [32].

- Multi-finger tapping task

The multi-finger tapping task was designed to measure the independence of finger movements, reflecting motor selectivity and inhibition. The participant tapped (with 1 or 2 simultaneous fingers) on the tablet as quickly as possible following the given instruction (a blue ellipse indicates the finger or fingers to be moved). The most discriminating variables were: reaction time, success rate (percentage of correct trials) and activation rate of neighboring fingers not required in the task. The latter variable indicated the ability to perform selective finger movements and may detect cognitive decline [32].

- Sequence tapping task

The sequence tapping task investigated memory. The participant was asked to perform a sequence of finger taps and memorize it in the right order. The ability to memorize sequences was assessed by the success during a restitution phase, where the memory sequence must be performed.

- Max tapping task

The max tapping task consisted of tapping the index finger as many times as possible within a given time interval (15 seconds). The interval between each touch was recorded.

- Line-tracking task

The line-tracking task measured the precision and speed of visuomotor movements. The task involved using the index finger to follow a non-predictable trajectory, that moved across the screen, as quickly and precisely as possible. Path duration and spatial error were measured. In a second double-task condition, visual distractors (shapes) or numbers were displayed on the screen while the participant followed the trajectory. The participant had to subtract the numbers starting from 50 and give the answer at the end of the test. Time and error were compared between the single and double-task conditions to measure the effect of cognitive load on manual dexterity.

Prior the study, we proposed to hospitalized patients to realize the tablet-based battery of index tests in order to assess its practicability and use. We then proceed to minor modifications of the implementation of the questions and tasks in the tablet.

Variables issued from the tablet-based battery assessment

Finally, the 35 items included in the tablet-based assessment provided 135 variables, as several tasks were coded as success/failure, task completion times, and were subdivided into several items (the various components of the clock test, such as the position of the numbers and hands, the time display, etc.) and sub-scores (the sub-scores of the VES-13 scale on dependence, age, physical impairments etc.).

Statistics

The data were analyzed using STATA 16.1 (College Station, TX: StataCorp LLC). For variables analysis, we used a 3-group classification (no NCD, m-NCD, M-NCD) and 2-groups classifications: absence of NCD versus any NCDs (either m-NCD and M-NCD), and absence of M-NCD (either no NCD and m-NCD) versus M-NCD. Participants were assigned to groups after the reference diagnosis has been established by the memory clinic specialist, sometimes several days after completing the battery of index tests.

For univariate analyses, each variable was examined in relation to the 3-group classification. Values of quantitative variables were compared using ANOVA or Kruskal-Wallis test depending of normality of their distribution. Values of category variables were compared using the chi-square test. A p value of 0.10 or less in the univariate analysis was chosen to select the variables that were entered into the multivariate and machine learning models. Then, we performed a multivariate analysis using logistic regression to identify the variables that contributed independently to the classification. We pooled groups in order to compare 2 -group

classifications: firstly, for presence/absence of any NCD, and secondly for the presence/absence of M-NCD. From these initial multivariate analyses, we selected the significant variables from each source (medical questionnaire, cognitive tasks, manual dexterity tasks) in order to create a new set of limited number of variables. This model enabled us to create a final model with an even smaller number of variables by removing correlated variables. The performance of the final model was assessed using ROC curves, the area under the curve, sensitivity and specificity calculation.

We also used a Python environment (Python 3.11.9, with the libraries of scikit-learn 1.5.1 and py-xgboost 3.0.2.) to run classification models based on the significant variables from the univariate analysis: logistic regression, extreme gradient boosting (xgboost), support-vector machine (svm), decision tree, random forest, 3 nearest neighbors (3nn), 5 nearest neighbors (5nn) and 7 nearest neighbors (7nn). These models were first run with variables selected from the univariate analysis and then with only a subset of variables obtained by applying a feature selection method in order to compare them and choose the one that would fit best with the dataset. Three features selection methods were tested: (i) an univariate feature selection method that select the k highest scores (k-best), (ii) a sequential feature selection method, that iteratively removes the variable that contributes the least to the F1 score in a three-way cross-validation setting (seqdel), (iii) logistic regression from the previous statistical analysis.

RESULTS

Participant's characteristics

We included 160 participants consecutively from the 17/04/2023 to the 29/11/2024 and comprised: 58 participants diagnosed with a M-NCD, 52 diagnosed with a m-NCD and 50 controls without a documented NCD. The mean age was 79.8 ± 6.6 years and comprised 116 women (72.5%). Baseline characteristics of the participants were shown in the Table 1. All

participants were included in the analysis. Significant differences between the groups were observed in terms of MMSE score, with participants in the M-NCD group having a lower MMSE score. In this group, participants reported significantly higher use of antidepressants and less frequent regular physical activity and social activities, as well as a decrease in the frequency of visual disturbances or hearing aid use.

Table 1. Characteristics of the participants

Variable	no NCD (n=50)	m-NCD (n=52)	M-NCD (n=58)	p
Data from medical records				
Age (years), m ± SD	78.6 ± 7.1	79.3 ± 6.0	81.4 ± 6.8	0.069
Women, n (%)	46 (85.2)	37 (71.1)	37 (63.8)	0.062
MMSE score (0-30), m ± SD	28.1 ± 1.6	24.6 ± 4.1	21.5 ± 3.6	<0.001
Self-reported data from the questionnaire				
Hypertension, n (%)	27 (54.0)	18 (34.6)	25 (43.1)	0.142
Depression, n (%)	11 (22.0)	20 (38.5)	12 (20.7)	0.071
Antidepressant intake, n (%)	11 (22.0)	18 (34.6)	30 (51.7)	0.006
Sleep medicine intake, n (%)	12 (24.0)	14 (26.9)	13 (22.4)	0.857
Visual impairment, n (%)	49 (98.0)	49 (94.2)	39 (67.2)	<0.001
Physical activity, n (%)	36 (72.0)	36 (69.2)	28 (48.3)	0.019
Social activity, n (%)	38 (76.0)	25 (48.1)	19 (32.8)	<0.001
Smoker, n (%)	2 (4.0)	3 (5.8)	3 (5.2)	0.917
Hearing impairment, n (%)	24 (48.0)	18 (34.6)	17 (29.3)	0.123
Hearing aid device, n (%)	23 (46.0)	13 (25.0)	13 (22.4)	0.017
Overweight, n (%)	19 (38.0)	21 (40.4)	15 (25.9)	0.225

NCD: neurocognitive disorder, m-NCD: mild neurocognitive disorder, M-NCD: major neurocognitive disorder, MMSE: mini mental state examination, MoCA: Montreal cognitive assessment

Feasibility of tablet-based assessments

All the items of the medical questionnaire and cognitive tasks were fully realized by the participants corresponding to an excellent feasibility. All the participants completed this part in 10 to 15 minutes. All the items of manual dexterity tasks were fully realized by 153 (96%) participants. The manual dexterity assessment was interrupted on participant's demand in 7 cases: 2 cases of refusal to perform all tasks due to tiredness, 2 cases of stopping during the last line-following exercise due to visual problems and pain related to osteoarthritis, and 3 cases of stopping after the first exercise due to pain in the hand. The manual dexterity tasks took between 25 minutes and over an hour to complete. Those who took more than an hour were all part of the group of people with M-NCD.

Univariate comparison of variables between diagnosis groups

Variables from the medical questionnaire

Of the medical questionnaire variables, 18 showed significant differences for the comparison of the three groups (supplementary material Table S2). Some of these were related to lifestyle (frequent physical activity, frequent social activities), frailty, health status (depression, antidepressant use, visual impairment, hearing aid use), while others were related to dependency (need for help with shopping, meal preparation, housework, laundry, using public transport, taking medication and managing finances).

Variables from cognitive tasks

Among the variables related to cognitive tasks, 26 showed significant differences when comparing the three groups (supplementary material Table S3). These concerned success to certain tasks (immediate and delay memory, temporal orientation, mental calculation), categorization abilities, the elements of the clock drawing test (presence of all numbers, right position of hours, hands length, correct time set), calculating change, calculating dates, response times (for memory, temporal orientation, calculation, categorization).

Variables from manual dexterity tasks

Among the manual dexterity tasks, 18 variables were significant for the comparison of the three groups (supplementary material Table S4). These concerned: success in tasks (that require mental rotation, memorization of a sequence), variability (between taps and following a rhythmic pattern), coactivation, understanding and following instructions.

Variables independently related to major neurocognitive disorders

In a first attempt, we realized a multivariate logistic regression that identified 9 variables that discriminate M-NCD participants from those without M-NCD (Table 2). They comprise 4 variables from the medical questionnaire, 3 from cognitive tasks and 2 from the manual dexterity tasks. These variables and their odds-ratio are listed in the Table 2. The results of the logistic regression analysis realized to select the variables in the final model are shown in the supplementary material (Table S5, Table S6, Table S7). The final model includes 9 variables: clock recognition task response time, flag recognition task response time, response time for the global cognitive tasks, help with taking medication, falling asleep while reading, frailty score (VES-13), VES-13 subscore according to dependency, finger recognition - success rate at first trial, finger recognition – global success rate for the condition of mental rotation (Table 2).

Table 2. Adjusted odds ratios for the final model for identifying any neurocognitive disorder and major neurocognitive disorders.

Variable	Association with the presence of any NCDs	Major NCD	
	OR (95% CI)	OR (95% CI)	p
Medical questionnaire			
Self-declaration of hypertension (ref. absence)	0.30 (0.11-0.78)		0.013
Help with taking medication (ref. no help)		5.73 (1.72-19.06)	0.004
Falling asleep while reading (ref. awake)		0.32 (0.11-0.94)	0.038
Frailty score – VES 13 (per 1 point increase)		0.71 (0.50-1.01)	0.055
Frailty subscore according to autonomy (per 1 point increase)		2.25 (1.25-4.08)	0.007
Cognitive tasks			
Failure to delayed memory task (ref. success)	0.09 (0.01-0.76)		0.027
Failure to categorize tools (ref. success)	0.12 (0.03-0.51)		0.004
Time recognition task response time (per 1 second increase)		0.90 (0.81-0.99)	0.037
Flag recognition task response time (per 1 second increase)		0.70 (0.49-1.01)	0.055
Response time for calculating the date 2 months ago (per 1 second increase)	1.07 (1.03-1.12)		0.001
Response time for the global cognitive tasks (per 1 second increase)		1.06 (1.02-1.11)	0.003
Manual dexterity tasks			
Finger recognition - success rate 2 (per 1 point increase)	0.02 (0-0.32)		0.006
Finger recognition - success rate 2 (per 1 point increase)		0.02 (0-0.24)	0.002
Finger recognition - success rate at first trial (per 1 point increase)		0 (0-0.13)	0.007

The Receiver Operating Characteristic (ROC) curves showed the final model's ability to discriminate cases of M-NCD are shown in Figure 1. Sensitivity was 81.0 % and specificity

86.3%, with an area under the curve (AUC) of 0.90. This combination allowed a correct classification of 84.38% of the participants.

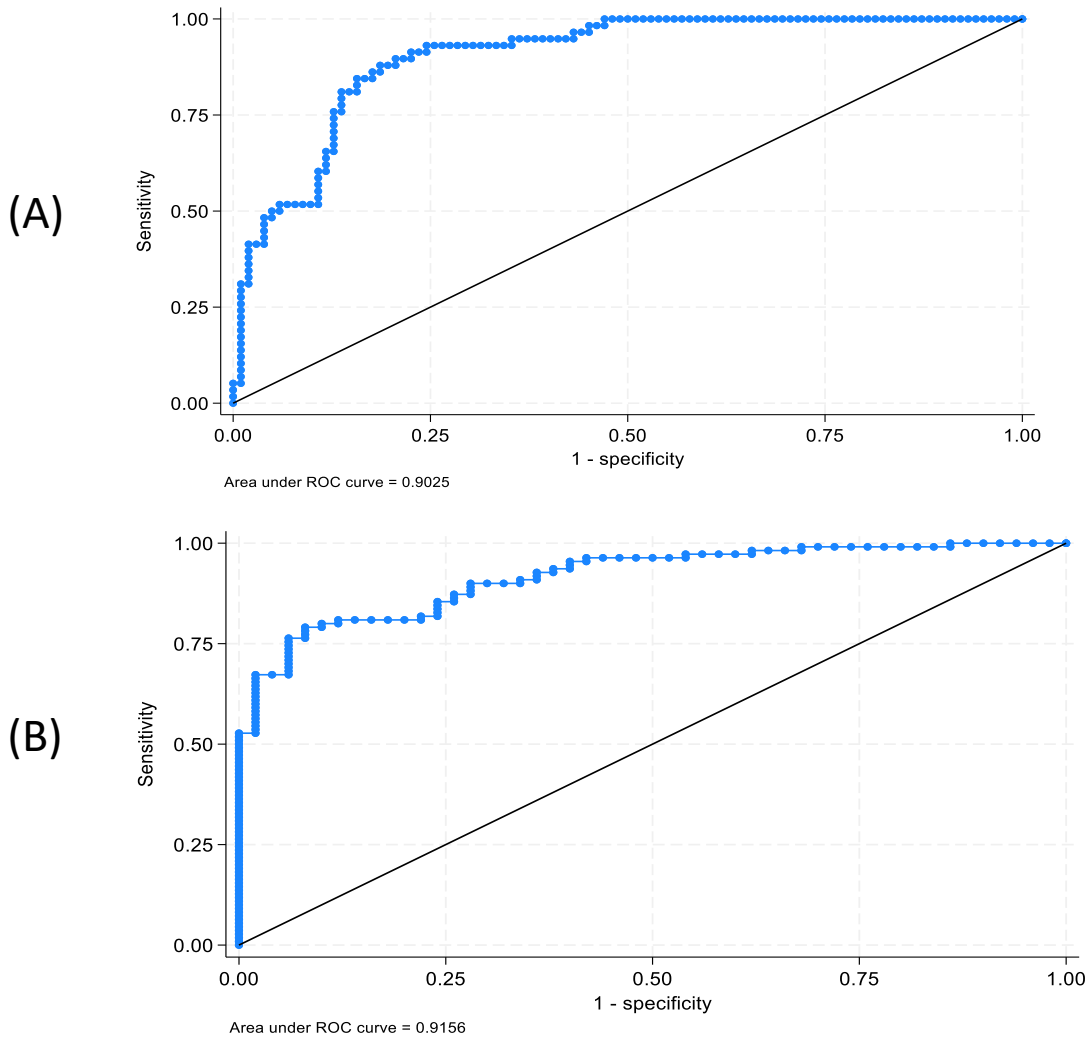

Figure 4. ROC curves for the screening of major neurocognitive disorder (A) and for the screening of neurocognitive disorders (B)

In a second attempt, we realized machine learning analysis to explore the same classification. We used logistic regression, extreme gradient boosting (xgboost), support-vector machine (svm), decision tree, random forest, 3 nearest neighbors (3nn), 5 nearest neighbors (5nn) and 7 nearest neighbors (7nn). The best performance for M-NCD classification, based on the F1-score, was obtained by all variables from all tests, using an SVM estimator and seqdel feature selection with a F1-score of 0.803 (Table 3). Then, the cognitive tasks had a F1-score of 0.711 with xgboost estimator and logistic regression as feature selection. The medical questionnaire

combined with cognitive tasks had a F1-score of 0.676 with random forest estimator and logistic regression for feature selection. The medical questionnaire combined with manual dexterity tasks had a F1-score of 0.667 with svm estimator and kbest as feature selection. The cognitive tasks combined with manual dexterity tasks had a F1-score of 0.662 with random forest estimator and kbest as feature selection. Medical questionnaire performed a F1-score of 0.639 with random forest estimator and kbest as feature selection. The manual dexterity tasks had a F1-score of 0.524 with random forest estimator and regression logistic as feature selection.

Table 3. Performances of different machine learning models for the diagnosis of major neurocognitive disorder

Type of tests	Estimator	Feature selection	F1-Score	Precision/ PPV	Recall/ Sensitivity	Accuracy	Specificity	NPV
All	Svm_rbf	seqdel	**0.803**	0.796	0.811	0.860	0.887	0.895
Medical questionnaire	Random forest	kbest	0.639	0.641	0.638	0.744	0.802	0.802
Cognitive tasks	xgboost	Logistic regression	**0.711**	0.705	0.830	0.793	0.830	0.846
Manual dexterity tasks	Random forest	Logistic regression	0.524	0.661	0.450	0.720	0.867	0.742
Medical questionnaire + cognitive tasks	Random forest	Logistic regression	0.676	0.708	0.672	0.775	0.829	0.822
Medical questionnaire + Manual dexterity tasks	Svm_rbf	kbest	0.667	0.668	0.675	0.768	0.821	0.821
Cognitive tasks + Manual dexterity tasks	Random forest	kbest	0.662	0.654	0.673	0.756	0.801	0.817

PPV: Positive Predictive Value; NPV: Negative Predictive Value

Variables independently related to any neurocognitive disorders

In a first attempt, we realized a multivariate logistic regression that identified 5 variables that discriminate participants with any NCD from those without NCD (Table 2). They comprised one variable from the medical questionnaire, three from cognitive tasks and one from the manual dexterity tasks. These variables and their odds-ratio are listed in the Table 2. The results of the logistic regression analysis realized to select the variables in the final model are shown in the supplementary material (Table S8, Table S9, Table S10). The final model includes 5 variables: self-declaration of hypertension, success at tasks (delayed memory, categorization, finger recognition task) and the calculation of the date 2 month ago. The ROC curve was shown

in Figure 1. Sensitivity was 80.9% and specificity was 82.0% with and AUC of 0.91. This combination allowed 81.25% of participants to be classified correctly.

The best performance for NCDs classification, based on the F1-score, was obtained by all variables from all tests, using 5nn estimator and seqdel feature selection (Table 4). Medical questionnaire combined with manual dexterity tasks had a F1-score of 0.864 with svm estimator and logistic regression as feature selection. Medical questionnaire combined with cognitive tasks had a F1-score of 0.862 with svm estimator and logistic regression as feature selection. Cognitive tasks combined with manual dexterity tasks had a F1-score of 0.853 with svm estimator and logistic regression as feature selection. Manual dexterity tasks had a F1-score of 0.844 with svm estimator and kbest as feature selection. Medical questionnaire had a F1-score of 0.838 with random forest estimator and kbest as feature selection. Cognitive tasks had a F1-score of 0.838 with random forest estimator and logistic regression as feature selection.

Table 4. Performances of different machine learning models for the diagnosis of any neurocognitive disorders

Type of tests	Estimator	Feature selection	F1-Score	Precision/PPV	Recall/Sensitivity	Accuracy	Specificity	NPV
All	5nn	seqdel	**0.933**	0.940	0.927	0.908	0.852	0.855
Medical questionnaire	Random forest	kbest	0.838	0.806	0.875	0.775	0.571	0.689
Cognitive tasks	Random forest	Logistic regression	0.838	0.807	0.876	0.774	0.578	0.689
Manual dexterity tasks	Svm_rbf	kbest	0.844	0.827	0.869	0.786	0.635	0.694
Medical questionnaire + cognitive tasks	Svm_rbf	Logistic regression	0.862	0.839	0.894	0.811	0.654	0.745
Medical questionnaire + Manual dexterity tasks	Svm_rbf	Logistic regression	**0.864**	0.863	0.868	0.817	0.715	0.722
Cognitive tasks + Manual dexterity tasks	Svm_rbf	Logistic regression	0.853	0.826	0.884	0.798	0.626	0.723

PPV: Positive Predictive Value; NPV: Negative Predictive Value

DISCUSSION

In this study, we found that feasibility of touchscreen tablet-based assessment for cognitive disorders was excellent in older adults attending a memory clinic. From a large panel of questions and tasks from various sources (medical questionnaire, cognitive tasks, and manual dexterity tasks) and implemented in the touchscreen tablet, we identified a set of variables that enable satisfactory detection of M-NCD and NCDs by combining data from medical questionnaire, cognitive tasks, and manual dexterity tasks. We achieved final models with 9 relevant variables for the detection of M-NCD and 5 variables for NCDs. Specificity and sensitivity of these final combinations were respectively 86.3% and 81.0% for the M-NCD and 82.0% and 80.9% for the NCDs. For the screening of M-NCD, all type of information provided good identification, and cognitive tasks were useful for detecting cognitive disorders, which is logically consistent. To identify NCDs, all type information enabled accurate identification, and cognitive tasks are the most useful for detecting cognitive disorders.

Our study confirms that touchscreen tablet can be used by older patients in a context of medical diagnosis. The development of screening tools is expanding in several contexts. Li's team [33] studied kinetic movements during a drawing and dragging task on a touchscreen tablet to identify m-NCD in people who came to the hospital and nursing homes. Chan developed a tool (Electronic cognitive screen) [15] for detecting m-NCDs and M-NCDs in individuals from research clinics and the community. These tests are brief, self-administered, and perform effectively in detecting cognitive disorders. In our preliminary work, we highlighted the value of these tools in detecting m-NCD [34] and M-NCD [35], and that efforts in methodology and harmonization should be encouraged.

Our study is original as we investigated large number of items, which came from several types of sources: medical questionnaire, cognitive tasks, and manual dexterity tasks. We explored their relevance for the diagnosis of M-NCD and for that of any NCD among patients attending

a memory clinic. By this way we consider the three diagnostic categories relevant for clinicians and not only M-NCD or m-NCD considered separately as it was done in many studies [34,35]. Our first analyses of the dataset had highlighted certain variables, but it also opened up the possibility for many more in-depth analyses. Our first analyses of the dataset had highlighted certain variables, but it also opened up the possibility for many more in-depth analyses.

Compared to similar tools found in the literature, the models driven from our study show better performances to those of MemScreen's, a smartphone application developed by Dumurgier et al [36], a tool designed to diagnose m-NCD in primary care. The MemScreen tool had a sensitivity of 78.6 % and a specificity of 78.7 % for the detection of m-NCD. Another tool, the BrainCheck battery, was developed by Ye et al. [37] and performed well, with 88% of sensitivity and specificity for M-NCD and 77% sensitivity and specificity in separating the m-NCD from the control and M-NCD groups. But these comparisons are a bit premature because the objective of our work was to find this combination of relevant variables, but it is not yet a tool in itself.

Our study has some limitations. We faced difficulties by recruiting a sufficient number of participants without NCD among persons attending to memory centers. We recruited additional participants from a sports association in the city and this might introduce a selection bias. Another limitation consisted in the quite small number of participants and in the large number of variables ended in our investigation, representing a significant challenge to use machine learning techniques.

Based on the findings of our study, we will design an application in a touchscreen tablet that can be used by older adults with cognitive symptoms and that can be implemented in primary care settings that could help healthcare professionals distinguish between M-NCD and m-NCD. In addition, it would be interesting to revisit the tool, retaining only the variables we selected

in final models, and conduct a real-life study to confirm these results with a larger sample size as part of a multicenter study.

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Authors' Contributions: Conceptualization: JB; Data curation: NUD, FB & JB; Formal analysis: NUD, QLB, FB, JB & PHW; Investigation: NUD & FM; Methodology: FM, JB; Project administration: JB, FM, SP & NUD; Resources: SP & PGL; Software: MT, FD, GL, SO; Supervision: JB; Validation: PGL & JB; Writing – original draft: NUD, FB, JB; Writing – review & editing: JB FB & NUD.

Abbreviations

AUC: Area Under the Curve

MCI: Mild Cognitive Impairment

MMSE: Mini-Mental State Examination

MoCA: Montreal Cognitive Assessment

m-NCD: Mild Neurocognitive Disorder

M-NCD: Major Neurocognitive Disorder

NCD: Neuro Cognitive Disorder

ROC: Receiver Operating Characteristic

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Supplementary materials

Table S1. STARD grid

Section & Topic	No	Item	Reported on page #
TITLE OR ABSTRACT			
	1	Identification as a study of diagnostic accuracy using at least one measure of accuracy (such as sensitivity, specificity, predictive values, or AUC)	1
ABSTRACT			
	2	Structured summary of study design, methods, results, and conclusions (for specific guidance, see STARD for Abstracts)	2
INTRODUCTION			
	3	Scientific and clinical background, including the intended use and clinical role of the index test	4
	4	Study objectives and hypotheses	5
METHODS			
Study design	5	Whether data collection was planned before the index test and reference standard were performed (prospective study) or after (retrospective study)	6
Participants	6	Eligibility criteria	6
	7	On what basis potentially eligible participants were identified (such as symptoms, results from previous tests, inclusion in registry)	6
	8	Where and when potentially eligible participants were identified (setting, location and dates)	6
	9	Whether participants formed a consecutive, random or convenience series	6
Test methods	10a	Index test, in sufficient detail to allow replication	7-10
	10b	Reference standard, in sufficient detail to allow replication	6
	11	Rationale for choosing the reference standard (if alternatives exist)	6
	12a	Definition of and rationale for test positivity cut-offs or result categories of the index test, distinguishing pre-specified from exploratory	-
	12b	Definition of and rationale for test positivity cut-offs or result categories of the reference standard, distinguishing pre-specified from exploratory	6
	13a	Whether clinical information and reference standard results were available to the performers/readers of the index test	6
	13b	Whether clinical information and index test results were available to the assessors of the reference standard	6
Analysis	14	Methods for estimating or comparing measures of diagnostic accuracy	11-12
	15	How indeterminate index test or reference standard results were handled	11-12
	16	How missing data on the index test and reference standard were handled	11
	17	Any analyses of variability in diagnostic accuracy, distinguishing pre-specified from exploratory	-
	18	Intended sample size and how it was determined	6
RESULTS			
Participants	19	Flow of participants, using a diagram	-
	20	Baseline demographic and clinical characteristics of participants	13
	21a	Distribution of severity of disease in those with the target condition	13
	21b	Distribution of alternative diagnoses in those without the target condition	12
	22	Time interval and any clinical interventions between index test and reference standard	7
Test results	23	Cross tabulation of the index test results (or their distribution) by the results of the reference standard	
	24	Estimates of diagnostic accuracy and their precision (such as 95% confidence intervals)	15-17
	25	Any adverse events from performing the index test or the reference standard	-
DISCUSSION			
	26	Study limitations, including sources of potential bias, statistical uncertainty, and generalisability	19-20
	27	Implications for practice, including the intended use and clinical role of the index test	20
OTHER INFORMATION			
	28	Registration number and name of registry	6
	29	Where the full study protocol can be accessed	-
	30	Sources of funding and other support; role of funders	3, 20

Table S2. Univariate analysis of the characteristics of the participants and the self-reported medical questionnaire for the three groups

variable	no NCD (n = 50)	m-NCD (n = 52)	M-NCD (n = 58)	p
From medical report				
Age (years), m (sd)	78.6 (7.1)	79.3 (81.4)	81.4 (6.8)	0.069
Sex, n (%)	8.0 (16.0)	15.0 (28.9)	21.0 (21.0)	0.062
MMSE score (0-30), m (sd)	28.1 (1.6)	24.6 (21.5)	21.5 (3.6)	<0.001
Independence for ADLs (0-6), median (IQR)	6 (6-6)	6 (5-6)	6 (5-6)	0.345
Independence for IADLs (0-8), median (IQR)	8 (7-8)	8 (7-8)	5 (3-7)	0.001
From self-reported medical questionnaire				
Antidepressant intake, n (%)	11 (22.0)	18 (35.0)	30 (51.7)	0.006
Benzodiazepine intake, n (%)	1 (2.0)	1 (2.0)	5 (8.6)	0.141
Sleeping pills intake, n (%)	12 (24.0)	14 (27.0)	13 (22.4)	0.857
Praxis disorder, n (%)	1 (2.0)	2 (4.0)	5 (8.6)	0.260
Visual impairment, n (%)	49 (98.0)	49 (94.0)	39 (67.2)	<0.001
Hearing impairment, n (%)	24 (48.0)	18 (35.0)	17 (29.3)	0.123
Hearing aid, n (%)	23 (46.0)	13 (25.0)	13 (22.4)	0.017
Hearing aid proposal, n (%)	25 (50.0)	22 (42.0)	22 (37.9)	0.446
Repeat request, n (%)	20 (40)	13 (25)	18 (31)	0.263
Physical activity, n (%)	36 (72.0)	36 (69.0)	28 (48.3)	0.019
Social activity, n (%)	38 (76.0)	25 (48.0)	19 (32.8)	<0.001
Smoker, n (%)	2 (4.0)	3 (6.0)	3 (5.2)	0.917
Hypertension, n (%)	27 (54.0)	18 (35.0)	25 (43.1)	0.142
Overweight, n (%)	19 (38.0)	21 (40.0)	15 (25.9)	0.225
Diabetes, n (%)	7 (14.0)	10 (19.0)	9 (15.5)	0.760
Depression, n (%)	11 (22.0)	20 (38.0)	12 (20.7)	0.071
Parkinson's disease, n (%)	0 (0)	0 (0)	0 (0)	
Stroke, n (%)	3 (6)	6 (12)	4 (7)	0.540
Epilepsy, n (%)	0 (0)	0 (0)	1 (2)	0.413
Other brain diseases, n (%)	0 (0)	0 (0)	2 (3)	0.168
Help to use the phone, n (%)	0 (0)	5 (10)	5 (9)	0.087
Help for shopping, n (%)	3 (6)	14 (27)	22 (38)	0.001
Help with meals, n (%)	1 (2)	8 (15)	18 (31)	<0.001
Help with housework, n (%)	10 (20)	16 (31)	27 (47)	0.013
Help with laundry, n (%)	1 (2)	8 (15)	8 (14)	0.056
Help with public transport, n (%)	4 (8)	10 (19)	25 (43)	<0.001
Help with taking medication, n (%)	2 (4)	6 (12)	26 (45)	<0.001
Help with budget management, n (%)	3 (6)	9 (17)	29 (50)	<0.001
Search for words, n (%)	22 (44)	32 (62)	26 (45)	0.128
Nervousness in the last 14 days, n (%)	24 (48)	25 (48)	28 (48)	1.000
Worried for the last 14 days, n (%)	14 (28)	15 (29)	18 (31)	0.937
Upset in last 14 days, n (%)	14 (28)	14 (27)	20 (34)	0.643
Falling asleep while reading, n (%)	22 (44)	16 (31)	11 (19)	0.019
Falling asleep while sitting inactive, n (%)	2 (4)	4 (8)	6 (10)	0.458
Falling asleep while sitting and talking, n (%)	1 (2)	0 (0)	1 (2)	0.609
Presence of frailty (VES-13), n (%)	20 (40)	21 (40)	36 (62)	0.029
VES-13 total score, 0-10 (sd)	2.2 (2.0)	3.0 (4.4)	4.4 (3.4)	0.003
VES-13 subscore – age (0-3), median (IQR)	1 (0-1)	1 (1-1)	1 (1-3)	<0.001
VES-13 subscore - physical limitations (0-2), median (IQR)	0 (0-1)	0 (0-2)	0 (0-2)	0.240
VES-13 subscore – dependency (0-4), median (IQR)	0 (0-0)	0 (0-0)	0 (0-4)	<0.001

Table S3. Univariate analysis of the cognitive tasks for the three groups

variable	no NCD (n = 50)	m-NCD (n = 52)	M-NCD (n = 58)	p
Success in the task				
Immediate memory, n (%)	48 (96)	48 (92)	46 (46)	0.014
Delayed memory, n (%)	49 (98)	42 (81)	27 (27)	<0.001
Recognition of the year, n (%)	50 (100)	48 (92)	47 (47)	0.003
Season recognition, n (%)	48 (96)	44 (85)	47 (47)	0.060
City recognition, n (%)	47 (94)	50 (96)	55 (55)	0.880
Flag recognition, n (%)	50 (100)	48 (92)	57 (57)	0.062
Date calculation 2 months ago - month, n (%)	49 (98)	45 (87)	39 (39)	<0.001
Date calculation 2 months ago (year), n (%)	50 (100)	50 (96)	47 (47)	0.001
Money change, n (%)	41 (82)	42 (81)	38 (38)	0.080
Categorization, n (%)	41 (82)	33 (63)	35 (35)	0.037
Categorization - transport, n (%)	48 (96)	46 (88)	52 (52)	0.349
Categorization - fruit, n (%)	49 (98)	52 (100)	57 (57)	0.609
Categorization - tool, n (%)	47 (94)	34 (65)	35 (35)	<0.001
Time recognition, n (%)	40 (80)	33 (63)	40 (40)	0.175
Normal clock drawing test - codex, n (%)	30 (60)	25 (48)	13 (13)	<0.001
Hours well-placed, n (%)	40 (80)	34 (65)	28 (28)	0.003
Presence of all numbers, n (%)	45 (90)	39 (75)	37 (37)	0.007
Small and large hands, n (%)	40 (80)	35 (67)	23 (23)	<0.001
Duration				
Immediate memory response time (sec) (sd)	33.2 (2.8)	36.2 (5.6)	36.9 (6.9)	<0.001
Delayed memory response time (sec), m (sd)	16.7 (3.8)	20.3 (23.9)	23.9 (4.9)	<0.001
Response time for date calculation 2 months ago (sec), median (IQR)	22.3 (14.6-26.1)	28.9 (21.5-49.0)	40.9 (30.5-61.1)	<0.001
Total response time for cognitive tasks (sec), median (IQR)	233 (212-256)	272 (238-330)	302 (264-331)	<0.001
Time recognition response time (sec), m (sd)	32.6 (5.8)	38.0 (38.4)	38.4 (7.0)	<0.001
Flag recognition response time (sec), m (sd)	11.9 (2.1)	13.0 (13.4)	13.4 (2.0)	<0.001
City recognition response time (sec), m (sd)	11.6 (6.0)	13.2 (15.1)	15.1 (4.8)	<0.001
Response time to recognition of the year (sec), m (sd)	11.0 (3.3)	12.8 (14.1)	14.1 (4.1)	<0.001
Season recognition response time (sec), m (sd)	10.9 (3.1)	13.9 (14.0)	14.0 (4.0)	<0.001
Categorization response time (sec), m (sd)	13.0 (5.1)	16.8 (18.5)	18.5 (6.7)	<0.001
Response time for first part of cognitive tasks (sec), m (sd)	140.8 (21.9)	163.8 (174.9)	174.9 (24.3)	<0.001
Categorization response time – transport (sec), median (IQR)	8.3 (5.3-16.0)	11.8 (6.1-17.3)	13.5 (8.7-20 .0)	0.011
Categorization response time – tools (sec), median (IQR)	9.9 (6.7-14.6)	12.0 (7.2-21.3)	11.6 (7.6-22.2)	0.184
Categorization response time – fruit (sec), median (IQR)	6.9 (5.9-11.3)	10.1 (7.4-15.1)	13.1 (9.1-17.1)	<0.001
Money change response time (sec), median (IQR)	33.5 (27.1-50.1)	31.8 (26.5-49.7)	33.5 (25.3-48.8)	0.845

Table S4. Univariate analysis of the manual dexterity tasks for the three groups

variable	no NCD (n = 50)	m-NCD (n = 52)	M-NCD (n = 58)	p
Success in the task				
Finger recognition - success at first trial in mirror tasks, % (sd)	100 (0)	100 (10)	100 (10)	0.349
Finger recognition - success at first trial in mirror tasks, % (sd)	100 (10)	100 (9)	90 (10)	0.016
Finger recognition - success at first trial in mental rotation tasks, % (sd)	90 (10)	90 (90)	90 (10)	0.094
Finger recognition - success in mental rotation tasks, median (IQR)	0.9 (0.9-1)	0.9 (0.5-1)	0.5 (0.5-0.9)	<0.001
Finger recognition - coactivation in mirror tasks, % (sd)	0 (10)	10 (10)	10 (10)	<0.001
Finger recognition - coactivation in mental rotation tasks, % (sd)	10 (10)	10 (10)	10 (10)	0.224
Multi finger tapping - success, % (sd)	100 (0)	100 (100)	100 (0)	0.215
Multi finger tapping - coactivation, % (sd)	10 (10)	20 (20)	20 (20)	0.004
Multi finger tapping - success at first trial, % (sd)	90 (10)	90 (80)	80 (20)	0.015
Sequence finger tapping - memorization, n (%)	46 (92)	33 (63)	28 (28)	<0.001
Understanding of instructions				
Finger recognition - instructions understood, n (%)	50 (100)	48 (92)	55 (55)	0.154
Finger recognition - instructions achieved, n (%)	50 (100)	52 (100)	58 (58)	
Rhythm tapping - instructions understood, n (%)	50 (100)	44 (85)	51 (51)	0.019
Rhythm tapping - instructions achieved, n (%)	49 (98)	52 (100)	57 (57)	0.609
Line tracking - instructions understood, n (%)	49 (98)	47 (90)	54 (54)	0.274
Line tracking - instructions achieved, n (%)	50 (100)	52 (100)	54 (54)	0.027
Sequence finger tapping - instructions understood, n (%)	50 (100)	50 (96)	54 (54)	0.170
Sequence finger tapping - instructions achieved, n (%)	50 (100)	52 (100)	56 (56)	0.168
Multi finger tapping - instructions understood, n (%)	50 (100)	49 (94)	54 (54)	0.182
Multi finger tapping - instructions achieved, n (%)	50 (100)	52 (100)	57 (57)	0.413
Max tapping - instructions understood, n (%)	50 (100)	49 (94)	56 (56)	0.242
Max tapping - instructions achieved, n (%)	50 (100)	52 (100)	58 (58)	
Duration				
Max taping - variability between fingertips, ms (sd)	93.7 (86.9)	96.2 (153.9)	153.9 (117)	0.003
Max taping - average time between fingertips, ms (sd)	245.1 (61.2)	263.8 (309.5)	309.5 (90.2)	<0.001
Rhythm tapping - average taps with beep-1Hz, ms (sd)	945 (165)	1011 (1102)	1102 (238)	<0.001
Rhythm tapping - variability between taps with beep-2Hz, ms (sd)	315.5 (429.2)	553.9 (808.7)	808.7 (674.8)	<0.001
Rhythm tapping - variability between taps with beep at 1Hz, ms (sd)	297.8 (343.7)	433.5 (620.5)	620.5 (513.4)	0.002
Rhythm tapping - average taps with beep at 2Hz, ms (sd)	1034 (231)	1107 (1240)	1239 (353)	0.004
Rhythm tapping - variability between taps no beep-2Hz, ms (sd)	206.8 (284.0)	393.0 (523.1)	523.1 (519.3)	0.004
Rhythm tapping - variability between taps with beep at 3Hz, ms (sd)	149.6 (244.5)	299.7 (352.5)	352.5 (382.8)	0.004
Rhythm tapping - variability between taps no beep at 1Hz, ms (sd)	266.3 (316.1)	316.7 (428.3)	428.3 (384.8)	0.016
Rhythm tapping - average taps without beep at 2Hz, ms (sd)	981 (204)	1076 (1128)	1128 (359)	0.078
Rhythm tapping - variability between taps no beep at 3Hz, ms (sd)	585 (972)	859 (871)	871 (1080)	0.160
Multi finger tapping simple finger lift - reaction time, ms (sd)	777 (105)	805 (839)	839 (125)	0.015
Finger recognition - reaction time in mental rotation tasks, ms (sd)	1263 (272)	1329 (1325)	1325. (252)	0.198
Rhythm tapping - average taps without beep at 1Hz, ms (sd)	1030 (240)	1069 (1137)	1137 (331)	0.230
Finger recognition - reaction time in mirror tasks, ms (sd)	909.3 (373.6)	754.3 (689.0)	689 (512.3)	0.257
Rhythm tapping - average taps with beep at 3Hz, ms (sd)	930.0 (160.1)	989.1 (987.4)	987 (298)	0.504
Rhythm tapping - average taps without beep at 3Hz, ms (sd)	1013 (443)	1051 (1033)	1033 (537)	0.730
Line tracking - duration (2), ms (sd)	62.9 (18.4)	59.9 (63.5)	63.5 (15.2)	0.746
Line tracking - duration (1), ms (sd)	57.9 (14.7)	58.0 (59.6)	59.6 (12.7)	0.937
Characteristics of manual dexterity tasks				
Hand used, right (%), m (sd)	48.0 (96)	52.0 (100)	56.0 (56)	0.366
Max tapping – slope, m (sd)	-4 (4.2)	-3.3 (-4.5)	-4.5 (6.2)	0.635
Line tracking - SpeedPeaks (1), (n per second), m (sd)	0.9 (0.4)	0.8 (0.8)	0.8 (0.3)	0.498
Line tracking - SpeedPeaks (2), (n per second), m (sd)	0.8 (0.4)	0.7 (0.8)	0.8 (0.5)	0.728
Line tracking - micro-movements (1), (n per second), m (sd)	61.8 (6.7)	61.5 (60.7)	60.7 (6.4)	0.563
Line tracking - micro-movements (2), (n per second), m (sd)	61.2 (6.8)	61.6 (60.2)	60.2 (6.9)	0.549

Table S5. Adjusted odds ratios for major neurocognitive disorder of variables from medical questionnaire (versus absence of major neurocognitive disorders).

Variable	OR (95% CI)	p
Age (per a year increase)	1.06 (0.91-1.24)	0.437
Sex – male (ref. female)	2.28 (0.71-7.31)	0.164
Help for shopping (ref. no help)	0.65 (0.14-3.02)	0.581
Help with meals (ref. no help)	1.22 (0.23-6.55)	0.820
Help with housework (ref. no help)	1.58 (0.47-5.31)	0.458
Help with public transport (ref. no help)	1.20 (0.31-4.68)	0.797
Help with taking medication (ref. no help)	7.60 (1.90-30.34)	**0.004**
Falling asleep while reading (ref. awake)	0.29 (0.10-0.87)	**0.027**
Failure to categorize tools (ref. success)	1.35 (0.49-3.73)	0.564
Failure to give the correct change (ref. success)	2.79 (0.89-8.74)	0.078
Failure to calculate the date 2 months ago – month (ref. success)	2.66 (0.75-9.52)	0.132
Failure to calculate the date 2 months ago – year (ref. success)	4.23 (0.5-35.84)	0.186
Abnormal clock (ref. normal)	0.63 (0.12-3.17)	0.574
Missing hours (ref. presence)	0.76 (0.2-2.85)	0.686
Incorrect position of hours (ref. correct position)	1.22 (0.34-4.42)	0.763
Incorrect size of the hands (ref. correct length)	4.85 (1.23-19.11)	**0.024**
Incorrect time (ref. correct time)	0.93 (0.25-3.44)	0.916
Frailty score – VES 13 (per 1 point increase)	0.43 (0.22-0.83)	**0.012**
Frailty (ref. absence of frailty)	1.10 (0.21-5.74)	0.910
Frailty subscore by age (per 1 point increase)	1.73 (0.55-5.39)	0.346
Frailty subscore according to dependency (per 1 point increase)	4.23 (1.7-10.57)	**0.002**

Table S6. Adjusted odds ratios for major neurocognitive disorder of variables from cognitive tasks (versus absence of major neurocognitive disorders).

Variable	OR (95% CI)	p
Failure to immediate memory task (ref. success)	1.17 (0.21-6.65)	0.858
Failure to delayed memory task (ref. success)	2.87 (0.77-10.73)	0.118
Failure to the task of recognition of the year (ref. success)	0.39 (0.08-2.02)	0.262
Failure to the task of recognition of the season (ref. success)	1.02 (0.28-3.72)	0.982
Failure in the categorization task - completing a series of images (ref. success)	0.62 (0.23-1.69)	0.353
Categorization task response time for fruits (per 1 second increase)	1.07 (0.99-1.16)	0.074
Categorization task response time for transport (per 1 second increase)	1.03 (0.97-1.1)	0.273
Categorization task response time for tools (per 1 second increase)	1.00 (0.94-1.05)	0.859
Response time for calculating the date 2 months ago (per 1 second increase)	1.04 (1.00-1.07)	**0.036**
Total response time (per 1 second increase)	0.99 (0.97-1.01)	0.425
Immediate memory task response time (per 1 second increase)	0.88 (0.75-1.03)	0.113
Time recognition task response time (per 1 second increase)	0.82 (0.70-0.97)	**0.019**
Delayed memory task response time (per 1 second increase)	0.99 (0.82-1.20)	0.915
Flag recognition task response time (per 1 second increase)	0.69 (0.48-0.98)	**0.039**
City recognition task response time (per 1 second increase)	0.92 (0.79-1.07)	0.277
Response time to the year recognition task (per 1 second increase)	0.90 (0.74-1.09)	0.279
Response time to the season recognition task (per 1 second increase)	0.91 (0.77-1.07)	0.241
Response time to the categorization task (per 1 second increase)	0.91 (0.77-1.07)	0.265
Response time for the global cognitive tasks (per 1 second increase)	1.17 (1.01-1.35)	**0.037**

Table S7. Adjusted odds ratios for major neurocognitive disorder of variables from manual dexterity tasks (versus absence of major neurocognitive disorders).

Variable	OR (95% CI)	p
Age (per a year increase)	1.00 (0.92-1.08)	0.967
Sex – male (ref. female)	1.65 (0.58-4.70)	0.346
Sequence finger tapping - misunderstanding of instructions (ref. understanding of instructions)	3.67 (0.17-79.19)	0.406
Sequence finger tapping – no memorization (ref. memorized)	1.53 (0.53-4.43)	0.432
Multi finger tapping - misunderstanding of instructions (ref. understanding of instructions)	2.79 (0.31-24.93)	0.358
Rhythm tapping - misunderstanding of instructions (ref. understanding of instructions)	0.31 (0.05-1.85)	0.200
Finger recognition – success rate (per 1 point increase)	0.04 (0-2660.14)	0.569
Finger recognition - success rate at first trial (per 1 point increase)	0 (0-0.27)	**0.029**
Finger recognition – coactivation rate (per 1 point increase)	0.03 (0-259.21)	0.455
Finger recognition - success rate 2 (per 1 point increase)	0 (0-0.10)	**0.001**
Finger recognition - success rate at first trial 2 (per 1 point increase)	0.01 (0-13.18)	0.223
Finger recognition - coactivation 2 (per 1 point increase)	0 (0-20.43)	0.186
Max tapping - average time between fingertips (per 1 second increase)	1.00 (0.99-1.01)	0.789
Max tapping - standard deviation between fingertips	1.01 (1.00-1.01)	0.071
Multi finger tapping – success rate (per 1 point increase)	6.13 (0-87800000)	0.829
Multi finger tapping - success rate at first trial (per 1 point increase)	0.01 (0-2.18)	0.089
Multi finger tapping – coactivation rate (per 1 point increase)	0 (0-0.44)	**0.029**
Multi finger tapping - reaction time (per 1 second increase)	1.00 (1.00-1.01)	0.406
Rhythm tapping - average taps with beep at 1Hz (per 1 point increase)	1.00 (1.00-1.01)	0.208
Rhythm tapping - average taps with beep at 2Hz (per 1 point increase)	1.00 (1.00-1.00)	0.896
Rhythm tapping - average taps without beep at 2Hz (per 1 point increase)	1.00 (1.00-1.00)	0.781
Rhythm tapping - standard deviation between taps with beep at 1Hz (per 1 point increase)	1.00 (1.00-1.00)	0.532
Rhythm tapping - standard deviation between taps without beep at 1Hz (per 1 point increase)	1.00 (1.00-1.00)	0.774
Rhythm tapping - standard deviation between taps with beep at 2Hz (per 1 point increase)	1.00 (1.00-1.00)	0.821
Rhythm tapping - standard deviation between taps without beep at 2Hz (per 1 point increase)	1.00 (1.00-1.00)	0.954

Table S8. Adjusted odds ratios for any neurocognitive disorders of variables from medical questionnaire (versus absence of neurocognitive disorders).

Variable	OR (95% CI)	p
Age (per a year increase)	1.03 (0.87-1.22)	0.736
Sex – male (ref. female)	5.18 (1.41-19.05)	**0.013**
Presence of hypertension (ref. absence)	0.21 (0.06-0.69)	**0.010**
Help for shopping (ref. no help)	2.58 (0.35-18.99)	0.351
Help with meals (ref. no help)	0.93 (0.03-31.62)	0.968
Help with housework (ref. no help)	1.98 (0.43-9.02)	0.379
Help with laundry (ref. no help)	3.65 (0.11-123.67)	0.472
Help with public transport (ref. no help)	0.84 (0.07-9.67)	0.891
Help with taking medication (ref. no help)	2.08 (0.17-25.74)	0.569
Falling asleep while reading (ref. awake)	0.48 (0.15-1.47)	0.198
Failure to categorize tools (ref. success)	11.14 (2.12-58.47)	**0.004**
Failure to calculate the date 2 months ago – month (ref. success)	34.54 (1.02-1164.98)	**0.048**
Abnormal clock (ref. normal)	0.23 (0.03-1.62)	0.140
Missing hours (ref. presence)	0.80 (0.10-6.32)	0.829
Incorrect position of hours (ref. correct position)	2.09 (0.32-13.66)	0.442
Incorrect size of the hands (ref. correct length)	1.68 (0.28-10.03)	0.567
Incorrect time (ref. correct time)	12.34 (1.88-80.99)	**0.009**
Frailty score – VES 13 (per 1 point increase)	0.84 (0.22-3.23)	0.805
Frailty (ref. absence of frailty)	0.15 (0.02-1.27)	0.081
Frailty subscore by age (per 1 point increase)	1.29 (0.27-6.20)	0.747
Frailty subscore according to physical limitations (per 1 point increase)	2.22 (0.39-12.51)	0.365
Frailty subscore according to autonomy (per 1 point increase)	2.07 (0.50-8.56)	0.317

Table S9. Adjusted odds ratios for any neurocognitive disorders of variables from cognitive tasks (versus mild and major neurocognitive disorders).

Variable	OR (95% CI)	p
Age (per a year increase)	0.97 (0.89-1.06)	0.476
Sex– male (ref. female)	4.25 (1.22-14.84)	**0.023**
Failure to immediate memory task (ref. success)	0.09 (0-2.38)	0.151
Failure to delayed memory task (ref. success)	26.41 (1.01-687.69)	**0.049**
Failure to the task of recognition of the season (ref. success)	2.99 (0.42-21.35)	0.274
Failure in the categorization task - completing a series of images (ref. success)	1.22 (0.32-4.57)	0.772
Categorization task response time for fruits (per 1 second increase)	1.02 (0.92-1.13)	0.710
Categorization task response time for transport (per 1 second increase)	1.04 (0.96-1.12)	0.373
Categorization task response time for tools (per 1 second increase)	1.04 (0.96-1.11)	0.337
Response time for calculating the date 2 months ago (per 1 second increase)	1.08 (1.02-1.14)	**0.005**
Total response time (per 1 second increase)	0.99 (0.97-1.01)	0.381
Immediate memory task response time (per 1 second increase)	0.48 (0.18-1.24)	0.127
Clock recognition task response time (per 1 second increase)	0.43 (0.17-1.12)	0.084
Delayed memory task response time (per 1 second increase)	0.44 (0.17-1.18)	0.105
Flag recognition task response time (per 1 second increase)	0.23 (0.07-0.73)	**0.012**
City recognition task response time (per 1 second increase)	0.43 (0.17-1.12)	0.085
Response time to the year recognition task (per 1 second increase)	0.38 (0.14-1.04)	0.060
Response time to the season recognition task (per 1 second increase)	0.57 (0.23-1.41)	0.223
Response time to the categorization task (per 1 second increase)	0.45 (0.18-1.18)	0.104
Response time for the global cognitive tasks (per 1 second increase)	2.45 (0.94-6.38)	0.066

Table S10. Adjusted odds ratios for any neurocognitive disorders of variables from manual dexterity tasks (versus mild and major neurocognitive disorders).

Variable	OR (95% CI)	p
Age (per a year increase)	0.97 (0.90-1.06)	0.545
Sex – male (ref. female)	6.99 (1.92-25.42)	0.003
Sequence finger tapping – no memorization (ref. memorized)	6.04 (1.20-30.51)	0.029
Finger recognition – success rate (per 1 point increase)	0.50 (0-99900000)	0.943
Finger recognition - success rate at first trial (per 1 point increase)	0 (0-20.35)	0.138
Finger recognition – coactivation rate (per 1 point increase)	18.32 (0-433861.1)	0.571
Finger recognition - reaction time (per 1 second increase)	1.00 (1.00-1.00)	0.743
Finger recognition - success rate 2 (per 1 point increase)	0.01 (0-1.01)	0.050
Finger recognition - coactivation 2 (per 1 point increase)	0.01 (0-39.63)	0.289
Finger recognition - reaction time (per 1 second increase)	1.00 (1.00-1.00)	0.714
Max tapping - average time between fingertips (per 1 second increase)	1.00 (0.99-1.01)	0.914
Max tapping - standard deviation between fingertips (per 1 point increase)	1.00 (0.99-1.01)	0.550
Multi finger tapping - success rate (per 1 point increase)	0 (0-251304.50)	0.408
Multi finger tapping - success rate at first trial (per 1 point increase)	0.33 (0-1053.45)	0.787
Multi finger tapping - coactivation rate (per 1 point increase)	1.23 (0-3678.87)	0.959
Multi finger tapping - reaction time (per 1 second increase)	1.00 (1.00-1.01)	0.701
Rhythm tapping - average taps with beep at 1Hz (per 1 point increase)	1.00 (1.00-1.01)	0.245
Rhythm tapping - average taps without beep at 1Hz (per 1 point increase)	1.00 (0.99-1.00)	0.506
Rhythm tapping - average taps with beep at 2Hz (per 1 point increase)	1.00 (0.99-1.00)	0.576
Rhythm tapping - average taps without beep at 2Hz (per 1 point increase)	1.00 (1.00-1.00)	0.967
Rhythm tapping - standard deviation between taps with beep at 1Hz (per 1 point increase)	1.00 (1.00-1.00)	0.683
Rhythm tapping - standard deviation between taps without beep at 1Hz (per 1 point increase)	1.00 (1.00-1.00)	0.553
Rhythm tapping - standard deviation between taps with beep at 2Hz (per 1 point increase)	1.00 (1.00-1.00)	0.873
Rhythm tapping - standard deviation between taps without beep at 2Hz (per 1 point increase)	1.00 (1.00-1.00)	0.628
Rhythm tapping - standard deviation between taps with beep at 3Hz (per 1 point increase)	1.00 (1.00-1.01)	0.005

Discussion générale

Analyse globale des travaux

Notre travail pose les bases pour la validation et l'élaboration d'un outil de repérage des TNC sur tablette tactile. Nous avons confirmé la faisabilité de l'utilisation de tablettes tactiles pour l'évaluation de la cognition chez les personnes âgées. Nous avons aussi vu l'intérêt du numérique pour détecter les TNC chez les personnes âgées par deux méta-analyses qui ont mis en lumière une bonne performance des outils numériques mais également un manque d'homogénéité des études liée à la grande diversité des outils utilisés. Nous avons observé que les tests brefs et auto-administrés avaient des performances similaires aux tests longs et administrés par des évaluateurs : ces tests brefs et auto-administrés devraient être davantage développés dans les soins primaires pour aider les professionnels à orienter les personnes malades vers les centres spécialisés. De plus, les outils numériques ne déforment pas les résultats des tests classiques car ils sont aussi performants que ces mêmes outils en version papier. Les avantages du numérique sont nombreux comme la praticité de passation, l'enregistrement des données et la possibilité d'automatisation de la cotation, ainsi qu'une intégration dans les dossiers médicaux, ce qui apporterait un gain de temps pour l'évaluateur. Des dispositifs numériques de repérage des TNC existent et sont nombreux (82). L'étude de Tsoy et al. en décrit 10 qui sont brefs et auto-administrés (29) : le *Computer Assessment of Memory and Cognitive Impairment* (83), le *Computer-Administered Neuropsychological Screen for Mild Cognitive Impairment* (84), le *Computerized Cognitive Screening* (85), le *CNS Vital Signs* (86), le *Computerized Self-Test* (87), le *CogState* (88), le *CogState Brief Battery* (89), le *Cognitive Testing on Computer* (90), le *digitally translated Self-Administered*

Gerocognitive Examination (91), et un dernier sans nom (92). Ces tests présentent de bonnes performances dans les conditions des études mais manquent de validation en situation de diagnostic réel. Malgré tout l'intérêt que présentent ces outils, nous souhaitions étudier la faisabilité de ce type de test numérique et reproduire des résultats similaires dans le contexte de soins gériatriques français. En effet, sur les deux méta-analyses que nous avons menées, ce qui représente 58 articles, nous n'avons retrouvé que deux outils numériques en langue française : le DigiTrack de l'équipe de Ben-Sadoun (93) qui était basé sur le suivi oculaire, et un test sur tablette adapté d'une version papier (*cancellation test*) de l'équipe de Wu (94).

L'atout majeur de notre étude clinique repose dans sa méthode : c'est une étude prospective, conduite en conditions de vie réelle, c'est-à-dire que les participants sont inclus sans connaître le diagnostic de référence. En effet, dans un travail de classification, il est fréquent de constituer des groupes de personnes ayant déjà bénéficié d'un diagnostic et d'étudier leurs résultats à un nouveau test à évaluer. Cette approche permet souvent des résultats clairs et bien définis avec de bonnes performances au prix d'un fort biais de sélection. Mais la faiblesse de cette méthode est de ne pas prendre en compte les personnes au diagnostic incertain comme cela peut être le cas dans la réalité clinique de la pratique médicale. Dans notre approche prospective avec l'utilisation de batteries de tests index, les résultats de performance sont souvent plus mitigés, mais reflètent une meilleure réalité de terrain.

L'étude clinique que nous avons menée auprès des personnes âgées a permis la constitution d'un jeu de données riche en informations, regroupant des données issues d'un questionnaire médical, de tâches cognitives et de motricité fine. Nos analyses ont mis en évidence une combinaison restreinte de 9 variables pour la détection des TNC-

M et une combinaison de 6 variables pour la détection des TNC globaux (tableau 6). Les performances de ces premiers modèles sont satisfaisantes pour un repérage de première ligne et regroupent des variables des différentes tâches et questionnaires.

Tableau 6. Variables d'intérêts des modèles finaux pour le repérage des troubles neurocognitifs majeurs et des troubles neurocognitifs

		Utilité pour identifier la présence de :	
Variables	Type de variable	TNC majeur ou léger	TNC majeur
Présence d'une hypertension*	Questionnaire	oui	
Aide pour prendre ses médicaments	Questionnaire		oui
Endormissement assis pendant une lecture	Questionnaire		oui
Score de fragilité – VES 13	Questionnaire		oui
Sous-score d'autonomie dans l'échelle de fragilité	Questionnaire		oui
Échec à la tâche de mémoire différée	Tâche cognitive	oui	
Échec à la tâche de catégorisation des outils	Tâche cognitive	oui	
Temps de réponse pour la reconnaissance de l'heure	Tâche cognitive		oui
Temps de réponse pour le calcul de la date 2 mois avant	Tâche cognitive	oui	
Temps de réponse pour la reconnaissance du drapeau	Tâche cognitive		oui
Temps de réponse pour l'ensemble des tâches cognitives	Tâche cognitive		oui
Finger recognition - réussite à la rotation mentale	Dextérité manuelle	oui	oui
Finger recognition - réussite au premier lever	Dextérité manuelle		oui

*donnée déclarative recueillie auprès du participant

Nous avons donc réussi à obtenir des combinaisons réduites de variables issues des différents tests pour détecter les TNC mais cette mixité des données ne semble pas améliorer les performances des modèles.

Les variables pertinentes pour le repérage des TNC-M sont celles en lien avec la perte d'autonomie (besoin d'aide pour la gestion et la prise des médicaments), la fragilité intrinsèque liée à l'âge et à la diminution des capacités physiques, la fragilité liée à la perte d'autonomie, le traitement d'information pour réaliser l'ensemble des tâches cognitives, le traitement de l'information pour la résolution de problème (reconnaissance de la bonne heure sur un cadran d'horloge, reconnaissance du drapeau), le sommeil (endormissement lors de la lecture) et les fonctions exécutives de la motricité fine pour l'inhibition (lever le bon doigt au premier lever) et la flexibilité

mentale (rotation mentale). Les variables d'intérêts pour le repérage des TNC sont celles sollicitant la mémoire différée, la résolution de problème (tâche de catégorisation) et sa vitesse de traitement (calcul de la date il y a 2 mois), le taux de réussite dans l'exercice de flexibilité mentale en motricité fine (tâche du *finger recognition)* et la présence de maladies concomitantes (hypertension). Les combinaisons de variables que nous avons retrouvées comprennent bien nos 3 modalités d'évaluation : des questions médicales, des tâches cognitives et des tâches de motricité fine. Cependant, sur les 6 tâches de motricité fine et le nombre de variables important qui en découle (taux de succès aux différentes tâches, vitesse de traitement, coactivation des doigts, intervalle inter-tapes, etc.) seulement 2 variables issues de la même tâche sont restées dans les modèles finaux et n'ont pas amélioré la détection des TNC comme attendu. Au final, les variables retenues concernent l'évaluation de la mémoire, les fonctions exécutives, et la vitesse de traitement des informations.

Limites et difficultés rencontrées

Ce travail présente plusieurs limites, dont principalement le faible nombre de participants de notre échantillon pour les analyses en apprentissage automatisé, avec un grand nombre de variables. De plus, le recrutement des participants a été biaisé par le fait que la population du groupe « sans trouble neurocognitif » devait idéalement venir des centres mémoire et avoir la même évaluation que les deux autres groupes, mais il n'a pas été possible de recruter suffisamment de personnes dans cette situation au sein des établissements concernés. Nous avons dû recruter via le réseau territorial, c'est-à-dire que nous avons envoyé un mail à une association de sport des aînés de la ville connue des équipes de l'hôpital pour des actions de prévention. Ce groupe s'est

avéré un peu plus jeunes que ceux des patients avec TNC et il comportait une proportion plus grande de femmes. Ce biais de sélection a pu influencer la recherche des variables discriminantes du diagnostic, même si nous avons pris soin d'ajuster les analyses en fonction de l'âge et du sexe. La sélection des items du questionnaire médical a été réalisée auprès d'un seul expert médical, il aurait été plus rigoureux de récolter l'avis d'un panel d'experts, voire d'utiliser une méthodologie de type DELPHI. Nous pouvons aussi nous questionner sur la validité du test de l'horloge qui est une source d'informations cognitives intéressante mais pourrait évoluer dans le futur, avec l'utilisation importante des montres et horloges analogiques (95,96). Dans les analyses de notre travail, nous avons seulement eu recours à des techniques supervisées mais il aurait également été intéressant d'utiliser des techniques non supervisées pour comparer les classifications obtenues avec celles du diagnostic réel, comme dans l'étude de Qiu et al. (45), où des modèles d'apprentissage profonds ont été développés à partir de données mixtes de plusieurs cohortes américaines. Leurs résultats sont très encourageants pour le repérage des TNC-M, et permettent une classification similaire au diagnostic de référence, notamment par l'utilisation de nombreuses données dont celles d'imageries cérébrales qui ne sont pas toujours disponibles dans les soins courants. L'utilisation de technique d'apprentissage profond (*deep learning*) commencent à être utilisés en médecine, mais l'effet « boîte noire » ne permet pas de comprendre toute la logique d'analyse sous-jacente, ce qui peut mener à des erreurs non explicables et des réticences chez certains cliniciens (30).

Perspectives et travaux à venir

Nos méta-analyses permettent aux cliniciens de choisir des outils déjà existants en fonction de leurs besoins de terrain, tout en prenant en compte les caractéristiques qui

ressortent de nos travaux. Les résultats de cette thèse donnent une base pour l'élaboration d'un outil numérique sur tablette. Une étude en condition de vie réelle serait intéressante à réaliser : il faudrait créer un outil contenant les combinaisons restreintes de variables établies par nos travaux, et réaliser des évaluations à un nouvel échantillon de personnes venant consulter un centre spécialisé sans connaître leur diagnostic, puis de comparer les résultats. A côté de cela, les variables ressorties pourraient être intégrées dans un jeu sérieux, dans l'objectif d'un entraînement cérébral. Pour compléter notre travail, nous pourrions incorporer une évolution des questions en fonction des réponses fournies, de type arbre de décision, qui pourrait affiner le repérage des TNC entre TNC-L et TNC-M. Une autre piste serait un modèle d'évaluation à domicile qui pourrait être utile pour les personnes en difficulté pour se déplacer. Pour permettre une appropriation de l'outil par des professionnels de terrain, il semble important de les former, de proposer un outil simple avec une interprétation claire des résultats, qui soit idéalement gratuit, traduit et validé dans plusieurs langues. L'attrait des analyses d'apprentissage automatique ouvre la voie à des analyses plus complexes, tenant en compte de la grande variété des données et qui considère la diversité des profils de malades. Les techniques d'apprentissage automatique sont très intéressantes pour la médecine, notamment du fait que des données incomplètes permettent des prédictions robustes (97). Il aurait aussi été intéressant d'utiliser les méthodes d'apprentissage automatique pour les extractions des caractéristiques (*feature extraction*), pour comparer les variables retenues avec celles des méthodes des régressions logistiques. Dans une réflexion plus générale, il serait intéressant d'étudier l'intérêt d'outils numériques pour prédire le risque de conversions des TNC-L vers les TNC-M (98), ; de même il serait intéressant d'étudier leur apport pour prédire le profil évolutif de la maladie chez les patients, notamment pour identifier précocement

les personnes dont la maladie évolue rapidement (appelés *fast decliners dans la littérature*) et ceux qui sont résilients (*slow decliners)*.

Conclusion

La réflexion autour de l'utilisation des outils numériques dans l'évaluation cognitive des personnes âgées doit être poursuivie. Ces outils ont un réel potentiel et sont prometteurs pour la prise en soin des personnes âgées. Les concepteurs de futurs outils de repérage doivent favoriser des outils brefs et auto-administrés, et créer des interfaces utiles et utilisées par et pour les personnes âgées. Les futurs travaux doivent favoriser les validations en situation de vie réelle. Les méthodes et caractéristiques des outils numériques doivent être bien décrits afin de permettre des comparaisons adéquates. Par ailleurs, l'inclusion des personnes fragiles doit être encouragée pour obtenir une meilleure représentativité de la population âgée. La collaboration pluridisciplinaire de ces travaux entre gériatrie, informatique médicale, et neurosciences a enrichi les réflexions sur les différentes approches de chaque domaine sur le sujet, et a apporté une pertinence et un sens à ce projet.

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Annexes

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Annexe 1 : Mini-Mental State Examination (MMSE)

MINI MENTAL STATE EXAMINATION (M.M.S.E) Date :……. Evalué(e) par : ……. Niveau socio-culturel ……..	Etiquette du patient

ORIENTATION

Je vais vous poser quelques questions pour apprécier comment fonctionne votre mémoire. Les unes sont très simples, les autres un peu moins. Vous devez répondre du mieux que vous pouvez.
Quelle est la date complète d'aujourd'hui ? ……

☞ *Si la réponse est incorrecte ou incomplète, posez les questions restées sans réponse, dans l'ordre suivant* :

	!0ou1!		!0ou1!
1. en quelle année sommes-nous ?	!____!	4. Quel jour du mois ?	!____!
2. en quelle saison ?	!____!	5. Quel jour de la semaine ?	!____!
3. en quel mois ?	!____!		

☞ *Je vais vous poser maintenant quelques questions sur l'endroit où nous nous trouvons*.

6. Quel est le nom de l'Hôpital où nous sommes ?	!____!
7. Dans quelle ville se trouve-t-il ?	!____!
8. Quel est le nom du département dans lequel est située cette ville ?	!____!
9. Dans quelle province ou région est situé ce département ?	!____!
10. A quel étage sommes-nous ici ?	!____!

APPRENTISSAGE

☞ *Je vais vous dire 3 mots ; je voudrais que vous me les répétiez et que vous essayiez de les retenir car je vous les demanderai tout à l'heure*.

11. Cigare		[citron		[fauteuil	!____!
12. fleur	ou	[clé	ou	[tulipe	!____!
13. porte		[ballon		[canard	!____!

Répéter les 3 mots.

ATTENTION ET CALCUL

☞ *Voulez-vous compter à partir de 100 en retirant 7 à chaque fois ?*

14.	93	!____!
15.	86	!____!
16.	79	!____!
17.	72	!____!
18.	65	!____!

☞ *Pour tous les sujets, même pour ceux qui ont obtenu le maximum de points, demander :* « voulez-vous épeler le mot MONDE à l'envers » : E D N O M.

RAPPEL

☞ *Pouvez-vous me dire quels étaient les 3 mots que je vous ai demandé de répéter et de retenir tout à l'heure ?*

19. Cigare		[citron		[fauteuil	!____!
20. fleur	ou	[clé	ou	[tulipe	!____!
21. porte		[ballon		[canard	!____!

LANGAGE

22. quel est le nom de cet objet?	Montrer un crayon.	!____!
23. Quel est le nom de cet objet	Montrer une montre	!____!
24. Ecoutez bien et répétez après moi : « PAS DE MAIS, DE SI, NI DE ET »		!____!

☞ *Poser une feuille de papier sur le bureau, la montrer au sujet en lui disant :* « écoutez bien et faites ce que je vais vous dire » (consignes à formuler en une seule fois) :

25. prenez cette feuille de papier avec la main droite.	!____!
26. Pliez-la en deux.	!____!
27. et jetez-la par terre ».	!____!

☞ *Tendre au sujet une feuille de papier sur laquelle est écrit en gros caractères : « FERMEZ LES YEUX » et dire au sujet* :

28. «faites ce qui est écrit ».	!____!

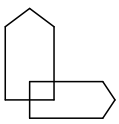
☞ *Tendre au sujet une feuille de papier et un stylo en disant :*

29. voulez-vous m'écrire une phrase, ce que vous voulez, mais une phrase entière. »	!____!

PRAXIES CONSTRUCTIVES.

☞ *Tendre au sujet une feuille de papier et lui demander :*

30. « Voulez-vous recopier ce dessin ».	!____!



SCORE TOTAL (0 à 30) **!____!**

FERMEZ LES YEUX

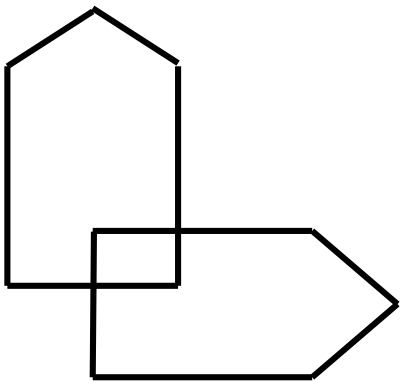
Phrase :

……

……

……..

Recopier le dessin :

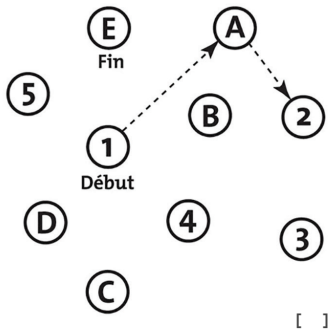


Annexe 2 : Montreal Cognitive Assessment (MoCA)

MONTREAL COGNITIVE ASSESSMENT (MoCA®)
Version 8.1 Français

Nom :
Scolarité :
Sexe :
Date de naissance :
DATE :

VISUOSPATIAL / EXÉCUTIF — POINTS



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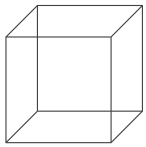
Copier le cube



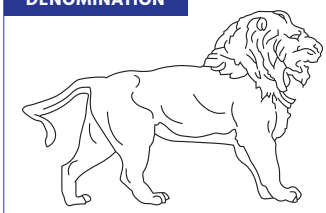
[ ]

Dessiner une HORLOGE (Onze heures et dix minutes) (3 points)

[ ] Contour [ ] Chiffres [ ] Aiguilles

__/5

DÉNOMINATION



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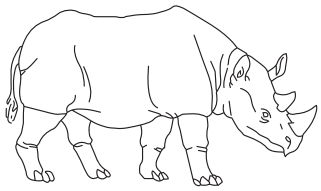

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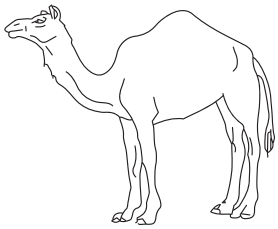


[ ]

__/3

MÉMOIRE — Lire la liste de mots, le sujet doit la répéter. Faire 2 essais même si le 1er essai est réussi. Faire un rappel après 5 minutes.

	VISAGE	VELOURS	ÉGLISE	MARGUERITE	ROUGE
1ER ESSAI					
2E ESSAI					

PAS DE POINT

ATTENTION — Lire la série de chiffres (1 chiffre / sec.). Le sujet doit la répéter dans le même ordre. [ ] 2 1 8 5 4
Le sujet doit la répéter à l'envers. [ ] 7 4 2

__/2

Lire la série de lettres. Le sujet doit taper de la main à chaque lettre A. Pas de points si ≥ 2 erreurs.
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Soustraire série de 7 à partir de 100. [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 ou 5 soustractions correctes : **3 pts**, 2 ou 3 correctes : **2 pts**, 1 correcte : **1 pt**, 0 correcte : **0 pt**

__/3

LANGAGE — Répéter : Le colibri a déposé ses œufs sur le sable. [ ]
L'argument de l'avocat les a convaincus. [ ]

__/2

Fluidité du langage. Nommer un maximum de mots commençant par la lettre « F » en 1 min. [ ] _____ (N ≥ 11 mots)

__/1

ABSTRACTION — Similitude entre ex : banane - orange = fruit [ ] train - bicyclette [ ] montre - règle

__/2

RAPPEL — Memory Index Score (MIS)

(MIS)	Doit se souvenir des mots SANS INDICE	VISAGE	VELOURS	ÉGLISE	MARGUERITE	ROUGE	Points pour rappel SANS INDICE seulement
X3		[ ]	[ ]	[ ]	[ ]	[ ]	
X2	Indice de catégorie						MIS = ____ /15
X1	Indice choix multiples						

__/5

ORIENTATION — [ ] Date [ ] Mois [ ] Année [ ] Jour [ ] Endroit [ ] Ville

__/6

© Test MoCA Inc. Created by Z. Nasreddine MD www.mocacognition.com

Administré par : _____

Entraînement et certification requis pour assurer la précision.

MIS : /15
(Normal ≥ 26/30)
Ajouter 1 point si scolarité ≤ 12 ans

TOTAL __/30

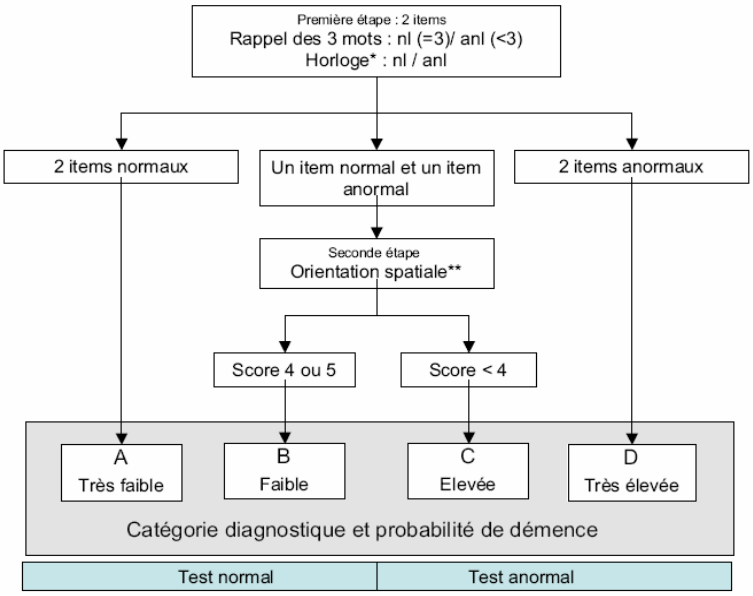
ADMINISTRÉ PAR Um Din, Nathavy EXAMINATEUR CERTIFIÉ MOCA ID FRUMDNA710696097-01

Annexe 3 : Test CODEX - *Cognitive disorders examination*

Evaluation cognitive ultra-rapide par le test CODEX

Page à imprimer pour les dossiers médicaux

Nom : ..... Date : …/……./…….
Prénom : ..... Evaluateur : .....



Cotation du test CODEX

1. Cotation du test de l'horloge :

Les nombres sont-ils tous présents ?	Oui-Non	
Sont-ils correctement placés ?	Oui-Non	***4 OUI =***
Y a t-il une petite et une grande aiguille ?	Oui-Non	***horloge normale***
Leurs directions sont elles convenables ?	Oui-Non	***sinon anormale***

2. Cotation du rappel des 3 mots

Les 3 mots sont bien rappelés = ***Rappel des 3 mots normal***

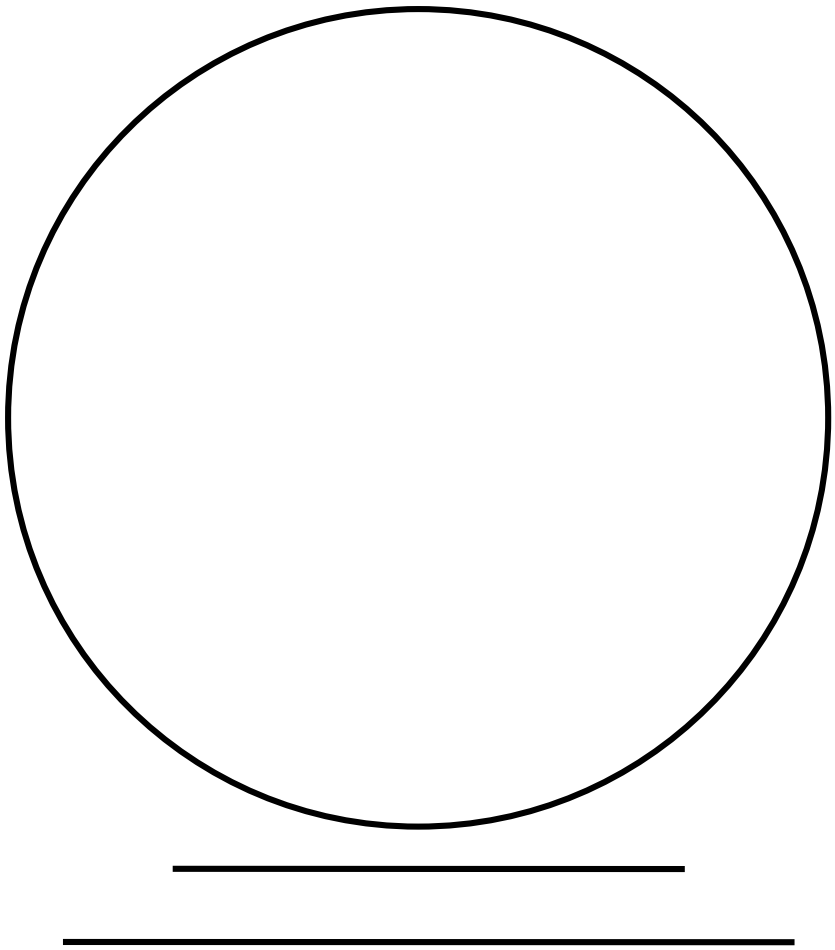
3. Utilisez l'arbre de décision pour savoir si la seconde étape est nécessaire

Horloge et 3 mots normaux = CODEX normal (Catégorie diagnostique A)
Horloge et 3 mots anormaux = CODEX anormal (Catégorie diagnostique D)
Autres cas = faire la seconde étape

4. Cotation de la seconde étape :

Comptez 1 point par bonne réponse
Somme = 4 ou 5 : = CODEX normal (Catégorie diagnostique B)
Somme = 0, 1, 2 ou 3 = CODEX anormal (Catégorie diagnostique C)

Le test CODEX a été mis au point par le Pr Belmin et son équipe à l'hôpital Charles Foix, Ivry-sur-Seine
Information sur le test sur le site www.testcodex.org
Références : Presse Med 2007; 36:1183-90; Revue de Gériatrie 2007; 32:627-31.



NOM : ……...
PRENOM : …….
Heure demandée : …….

Date : ……..
Evaluateur ……

Le test CODEX a été mis au point par le Pr Belmin et son équipe à l'hôpital Charles Foix, Ivry-sur-Seine
Information sur le test sur le site www.testcodex.org
Références : Presse Med 2007; 36:1183-90 ; Revue de Gériatrie 2007; 32:627-31.

Annexe 4 : Échelle de Vulnérabilité des Ainés-13 (EVA-13)

Echelle de Vulnérabilité des Ainés-13

1. Age_____

SCORE : 1 POINT SI AGE DE 75 à 84 ANS
3 POINTS SI AGE ≥ 85 ANS

2. D'une façon générale, par comparaison aux personnes de votre âge, diriez-vous que votre santé est :
   - ☐ Mauvaise*
   - ☐ Correcte*
   - ☐ Bonne
   - ☐ Très bonne
   - ☐ Excellente

SCORE : 1 POINT SI REPONSE MARQUEE * (CORRECTE ou MAUVAISE)

3. En moyenne, à quel point avez-vous des difficultés pour faire les activités physiques suivantes ?

	Aucune difficulté	Légères difficultés	Quelques difficultés	Beaucoup de difficultés	Incapable de le faire
a. Se pencher, s'accroupir ou se mettre à genoux ?.....	☐	☐	☐	☐*	☐*
b. Soulever ou porter des objets d'au moins 4 kg ?.....	☐	☐	☐	☐*	☐*
c. Lever ou étendre les bras au-dessus du niveau des épaules ?.....	☐	☐	☐	☐*	☐*
d. Écrire, manipuler ou saisir de petits objets ?.....	☐	☐	☐	☐*	☐*
e. Marcher 400 mètres ?.....	☐	☐	☐	☐*	☐*
f. Faire des tâches ménagères difficiles comme frotter les planchers ou laver des vitres ?.....	☐	☐	☐	☐*	☐*

SCORE : 1 POINT POUR CHAQUE REPONSE DE LA QUESTION 3 (a à f) MARQUEE *;
SCORE MAXIMUM = 2 POINTS

4. Avez-vous quelques difficultés, en raison de votre santé ou de votre condition physique, pour :

a. Faire vos courses pour des achats personnels (comme des affaires de toilettes ou des médicaments) ?

☐ OUI → Avez-vous besoin d'aide pour faire les courses ☐ OUI* ☐ NON
☐ NON
☐ JE NE LE FAIS PAS → Est-ce en raison de votre santé ? ☐ OUI* ☐ NON

b. Gérer l'argent (comme suivre ses dépenses ou payer des factures) ?

☐ OUI → Avez-vous besoin d'aide pour gérer l'argent ☐ OUI* ☐ NON
☐ NON
☐ JE NE LE FAIS PAS → Est-ce en raison de votre santé ? ☐ OUI* ☐ NON

c. Marcher à travers une pièce (l'utilisation d'une canne ou d'un déambulateur est possible) ?

☐ OUI → Avez-vous besoin d'aide pour marcher ☐ OUI* ☐ NON
☐ NON
☐ JE NE LE FAIS PAS → Est-ce en raison de votre santé ? ☐ OUI* ☐ NON

d. Faire de petites tâches ménagères (comme faire la vaisselle, du rangement, ou du nettoyage) ?

☐ OUI → Avez-vous besoin d'aide pour les petites tâches ménagères ? ☐ OUI* ☐ NON
☐ NON
☐ JE NE LE FAIS PAS → Est-ce en raison de votre santé ? ☐ OUI* ☐ NON

e. Prendre une douche ou un bain ?

☐ OUI → Avez-vous besoin d'aide pour prendre une douche ou un bain ? ☐ OUI* ☐ NON
☐ NON
☐ JE NE LE FAIS PAS → Est-ce en raison de votre santé ? ☐ OUI* ☐ NON

SCORE : <u>4 POINTS</u> SI UNE OU PLUSIEURS REPONSES DE LA QUESTION 4 (a à e) MARQUEES *

Annexe 5 : Photos du dispositif d'évaluation



Figure S1. Déroulement de la tâche du dessin de l'horloge

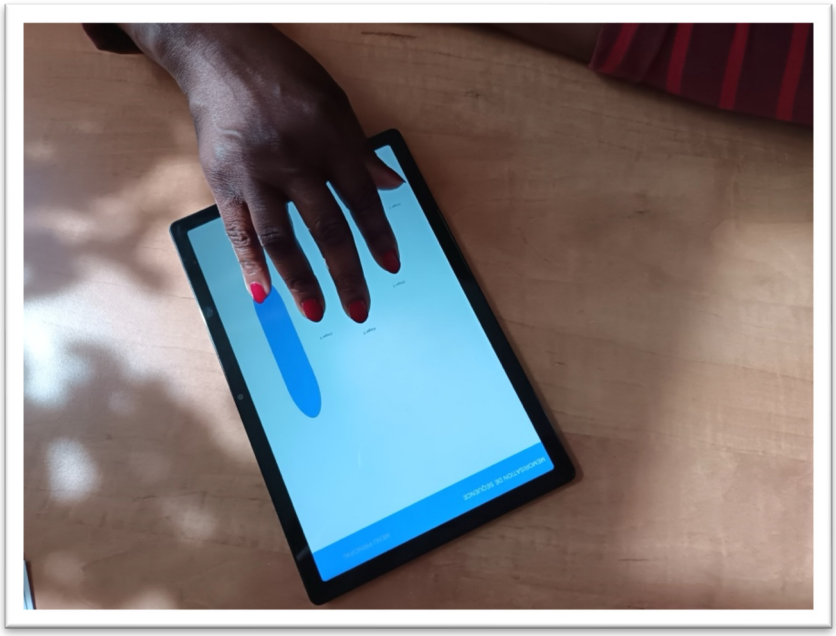


Figure S2. Déroulement d'une tâche de motricité fine (finger recognition)

Annexe 6 : Exemples d'écrans de la batterie de tests Cognum

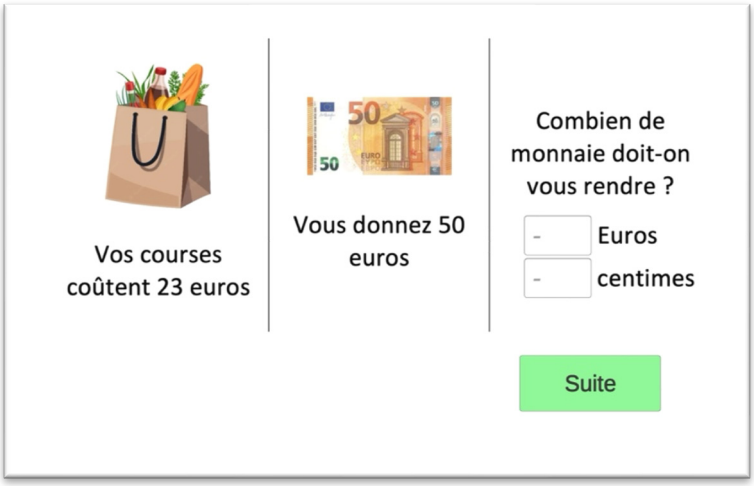


Figure S3. Écran de la tâche cognitive du rendu de monnaie



Figure S4. Écran de la tâche cognitive de catégorisation

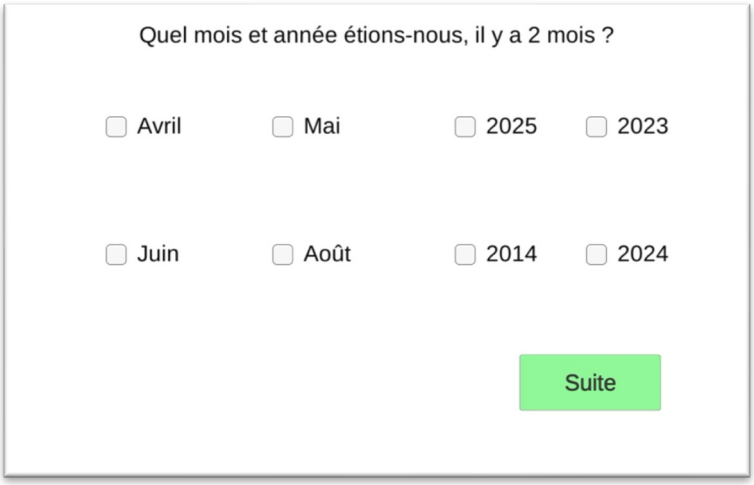


Figure S5. Écran de la tâche cognitive du calcul de la date antérieure de 2 mois

Annexe 7 : Lettre d'information et consentement des participants de l'étude clinique

Lettre d'information aux patients pour l'étude intitulée « Intérêt de deux dispositifs numériques pour le diagnostic des troubles neurocognitifs chez les personnes âgées ayant des symptômes cognitifs »

Madame, Monsieur,

Nous vous proposons de participer à une étude menée par le Pr Belmin et dont le promoteur est l'Association Rivages. Cette lettre d'information vous détaille en quoi elle consiste.
Prenez le temps de lire attentivement ces informations afin de réfléchir à votre participation. Le médecin s'assurera à plusieurs reprises, si nécessaire, de la bonne compréhension du patient pendant et après lecture de la lettre d'information et, au besoin, il reformulera certains points.

BUT DE L'ETUDE

L'objectif de cette étude est d'élaborer un algorithme mathématique pour classer les personnes en 3 groupes : personnes avec un trouble neurocognitif majeur, personnes avec un trouble neurocognitif léger et des personnes sans trouble neurocognitif. Nous réaliserons cet algorithme en comparant les données de votre dossier médical et les données récoltées par une tablette tactile et une montre connectée.

BENEFICES ATTENDUS

Nous espérons pouvoir mettre en place un système d'aide au diagnostic pour les professionnels de santé à partir des données de ces dispositifs numériques, et améliorer l'accès au parcours de soins pour les personnes malades.

DEROULEMENT DE L'ETUDE

Si vous acceptez de participer, nous vous proposerons des questionnaires et exercices à réaliser sur une tablette tactile avec l'aide d'un de nos investigateurs. Ces exercices sont issus ou inspirés de tests et échelles validés cliniquement, qui sont adaptés au support de la tablette. Les questionnaires porteront sur votre mémoire, votre humeur, votre sommeil, votre autonomie. Des épreuves cognitives et de motricité fine seront réalisés. Il y aura également un questionnaire d'utilisation de la tablette à la fin.
Après ces exercices, nous vous prêterons une montre connectée, que vous porterez pendant 7 jours consécutifs. Cette montre enregistrera : votre température, votre fréquence cardiaque, votre conductance cutanée (c'est l'activité électrique biologique enregistrée à la surface de votre peau) et votre actimétrie (la quantité de mouvement que vous réalisez). Cette montre sera à restituer au bout de 7 jours.

Toutes ces données seront enregistrées et nous les analyserons pour élaborer un algorithme mathématique avec une équipe spécialisée en informatique biomédicale et universitaire, pour établir 3 groupes : les personnes avec un trouble neurocognitif majeur, les personnes avec un trouble neurocognitif léger et les personnes sans trouble neurocognitif.

RISQUES POTENTIELS

Les tests et échelles numériques proposés sur la tablette tactile ne présentent pas de risques particuliers. La montre connectée fonctionne avec des ondes Bluetooth, similaires à celles des objets connectés du quotidien. Les dispositifs numériques (tablette et montre) sont utilisés dans leur fonctionnement habituel.

FRAIS DE L'ETUDE

Aucune compensation financière n'est fournie pour la participation à cette étude.

LEGISLATION - CONFIDENTIALITE

Conformément aux articles L. 1121-1 et suivants du Code de la Santé Publique, le Comité de Protection des Personnes « Comité de Protection des Personnes Est III » a étudié cette étude et a émis un avis favorable à sa réalisation le 25/07/2022.
Toute information vous concernant recueillie pendant cet essai sera traitée de façon confidentielle, et sera conservée pendant une durée de 15 ans après la fin de la recherche. Seuls les responsables de l'étude, leur partenaire et éventuellement les autorités de Santé pourront avoir accès à ces données :

- Le promoteur de l'étude l'association Rivages et l'investigateur de l'étude le Pr Joël Belmin, 7 av de la République, 94200 IVRY SUR SEINE, tél : 01 49 59 45 54

Ainsi, les données recueillies resteront sur le territoire français.

A l'exception des personnes qui traiteront les informations dans le plus strict respect du secret médical, votre anonymat sera préservé. La procédure de pseudonymisation des données se fait par l'application d'un numéro attribué à la personne, combiné au type de données et le lieu d'inclusion. La publication des résultats de l'étude ne comportera aucun résultat individuel.

Le promoteur de la recherche et les investigateurs s'engagent à respecter la protection des données personnelles à chaque instant de la loi n°78-17 du 6 janvier 1978 relative à l'informatique, aux fichiers et aux libertés et du Règlement européen sur la protection des données personnelles (RGPD - règlement européen appliqué depuis le 25 mai 2018):

- Les données recueillies à l'occasion de cette étude seront récoltées en partie dans un cahier d'observation papier et une autre partie dans un fichier informatisé conservés par le promoteur,
- Toute information vous concernant sera traitée de façon confidentielle,
- Seuls les responsables de l'étude, leurs partenaires et éventuellement les autorités de Santé pourront avoir accès à ces données. A l'exception des personnes qui

traiteront les informations dans le plus strict respect du secret médical, votre anonymat sera préservé,

- S'agissant de données nominatives, vous bénéficierez à tout moment du droit d'accès et de rectification, à la portabilité, d'opposition, de réclamation, de suppression, de limitation et d'oubli des données vous concernant auprès des responsables de l'étude,
- La publication des résultats de l'étude ne comportera aucun résultat individuel,
- Les données récoltées resteront en France, dans l'Union Européenne.

Ces droits sont à exercer auprès de l'intermédiaire du Dr Joël Belmin ou du Délégué à la Protection des Données de l'étude, le Dr Witold Jarzebowski, membre de l'Association Rivages, witold.jarzebowski@ch-bastia.fr.
La loi prévoit que la déclaration du fichier informatisé des données personnelles collectées pour la recherche doit être faite avant le début effectif de la recherche.
Vous avez la possibilité de faire un recours directement à la CNIL si vous êtes en désaccord avec le promoteur et le responsable des données au 01 53 73 22 22 ou par un questionnaire en ligne disponible par ce lien : https://www.cnil.fr/fr/webform/adresser-une-plainte.
De plus, conformément à la loi, les résultats globaux de l'étude pourront vous être communiqués si vous le souhaitez.
Si vous avez des questions pendant votre participation à cette étude, vous pourrez contacter le médecin responsable de l'étude, le Pr Joël Belmin.

Vous êtes libre d'accepter ou de refuser de participer à cette étude. Cela n'influencera pas la qualité des soins qui vous seront prodigués.

Nous vous remercions d'avoir pris le temps de lire cette lettre d'information.

FORMULAIRE DE CONSENTEMENT

Je soussigné(e), Mme, M. [rayer la mention inutile] (nom, prénom) :

……

Participation à l'étude :

- J'accepte librement de participer à l'étude intitulée : « Intérêt de deux dispositifs numériques pour le diagnostic des troubles neurocognitifs chez les personnes âgées ayant des symptômes cognitifs », organisée par l'Association Rivages, promoteur de l'étude, et qui m'est proposée par le Professeur Belmin investigateur de cette étude.
- J'ai pris connaissance de la note d'information version 01 du 14/06/2022 (3 pages) m'expliquant l'objectif de cette étude, la façon dont elle va être réalisée et ce que ma participation va impliquer,
- Je conserverai un exemplaire de la note d'information et du formulaire de consentement,
- J'ai reçu des réponses adaptées à toutes mes questions,
- J'ai disposé d'un temps suffisant pour prendre ma décision,
- J'ai compris que ma participation est libre et que je pourrai interrompre ma participation à tout moment, sans encourir la moindre responsabilité et préjudice pour la qualité des soins qui me seront prodigués. J'indiquerai alors au médecin investigateur si je souhaite ou non que les données recueillies, jusqu'au moment de ma décision, soient utilisées,
- Je suis conscient(e) que ma participation pourra aussi être interrompue par le médecin investigateur si besoin.

Date et Signature de la personne participant à l'étude

Nom Prénom :

Date : Signature :

Annexe 8 : Communication orale à l'International Society for Gerontechnology

N. Um Din, F. Maronnat, G. Loup, F. Badra, S. Otmane, J. Belmin (2024). Cognitive testings on a touch-screen tablet for older adults: A feasibility study. Gerontechnology, 23(2), 1-1 https://doi.org/10.4017/gt.2024.23.s.987.opp

OPP: DEMENTIA & TECHNOLOGY

Cognitive testings on a touch-screen tablet for older adults: A feasibility study

N. Um Din, F. Maronnat, G. Loup, F. Badra, S. Otmane, J. Belmin

Purpose Digital tools are currently being developed to help with the diagnosis of neurocognitive disorder (NCD). Their use in primary care as screening tools could optimize referral to specialized teams. We aimed to develop a simple, easy-to-use neurocognitive screening tool on a touchscreen tablet to distinguish between people with major NCD, those with mild NCD and those with no NCD. We hypothesize that, depending on cognitive impairment, differences in correct responses and response times differ significantly. **Method** We implemented self-questionnaires and tasks for touch-screen tablets self-questionnaires inspired from conventional cognitive tools relevant to screen cognitive impairment. They comprised simple cognitive tasks like immediate and delayed recall of 3 words, temporal orientation questions, categorizations. Response times for tasks were also recorded. The screens have been designed to be used by the participant alone or with the help of a supervisor. Finally, we composed a battery of self-questionnaires and cognitive tasks that can be completed in 10-15 minutes. This battery was offered to 77 consecutive patients from a memory clinic and 28 volunteers without cognitive complaints recruited from a citizens' association. Cognitive diagnoses were based on DSM-5 criteria. Variables were compared using the Kruskal-Wallis test and Pearson's chi2 test and the level of significance was 0.05. **Results and Discussion** Among the 105 participants, there were 79 women (75%) and 26 men (25%) and aged 79.9 +/- 7.5 years; 40 were free from NCD, 40 had a major NCD and 25 a mild NCD. All the participants realized the full battery of tests on tablets. Success for each task and response times are shown in Table 1. Four variables were found to discriminate cognitive patient and will be combined to the battery. The feasibility of our digital tablet battery for older adults is excellent, and initial results show promising aspects for cognitive screening.

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Wilson, S.A., Byrne, P., Rodgers, S. E., Maden M. (2022). A Systematic Review of Smartphone and Tablet Use by Older Adults With and Without Cognitive Impairment, Innovation in Aging, 6, 2, igac002, https://doi.org/10.1093/geroni/igac002

Keywords: tablet-based, neurocognitive disorder, diagnosis, older adults

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Table 1. Preliminary results of cognitive tests on tablet according to cognitive status (reference diagnosis)

Success for task or response time	Neurocognitive Disorder			P
	none (n=40)	mild (n=25)	major (n=40)	
Success for task, n (%)				
Immediate recall	38 (95)	24 (96)	30 (75)	0.900
Delay recall	39 (98)	20 (80)	18 (45)	<0.001***
Clock recognition	29 (73)	18 (72)	25 (63)	0.575
Recognition of the flag of the country	40 (100)	22 (88)	39 (98)	0.420
Recognition of the city	37 (93)	23 (92)	37 (93)	0.997
Identify the year	40 (100)	22 (88)	32 (80)	0.130
Identify the season	38 (95)	21 (84)	31 (78)	0.790
Guess a logical sequence	32 (80)	12 (48)	23 (58)	0.190
Calculation of the months 2 months ago	38 (95)	19 (76)	26 (65)	0.004**
Categorization orange/banana	39 (98)	25 (100)	39 (98)	0.727
Categorization train/bike	39 (98)	20 (80)	36 (90)	0.064
Categorization ruler/watch	39 (98)	14 (56)	20 (50)	<0.001***
Response time, median (IQR)				
to categorize orange/banana	7 (6, 13)	11 (8, 14)	13 (9, 17)	0.042*
to categorize train/bike	7 (4, 13)	10 (5, 14)	13 (8, 19)	0.003**
to categorize ruler/watch	9 (6, 14)	12 (7, 19)	12 (7, 25)	0.110
for calculating change	34 (29, 48)	29 (24, 34)	34 (22, 49)	0.197
for calculating the date 2 months ago	22 (14, 27)	41 (27, 55)	41 (33, 61)	<0.001***

RT: response time, IQR: interquartile range ;
,,*** indicate the level of significance : <0.05, <0.01 and <0.001, respectively.*