

Development of a Computerized Multi-Factor Neurocognitive Screening System

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Abstract: Neurocognitive disorders (NCDs) present a significant challenge in aging populations, impacting cognitive function and quality of life. This project represents development of a computerized multi-factor neurocognitive screening system (MFNS) as a comprehensive approach to assess susceptibility to NCDs. NCDs, including Alzheimer's disease and Parkinson's disease, are multifactorial conditions affecting memory, attention, language, and executive functions. Current diagnostic methods involve clinical evaluations, cognitive testing, and neuroimaging, but often fail to detect subtle early signs. The MFNS integrates cognitive assessments, including screening for neurocognitive functional domains, symptom domains, and behavioral changes, alongside evaluation of known risk factors. A novel component includes speech biomarker-based screening using digital technologies to analyze speech patterns for early detection markers. This approach aims to improve diagnostic accuracy and enable earlier interventions, potentially enhancing patient outcomes. Future directions involve refining algorithms, expanding datasets, and addressing ethical considerations to optimize the MFNS for widespread clinical use, marking a pivotal advancement in neurocognitive healthcare.

Keywords: Alzheimer's Disease; Dementia; Cognitive Assessment; Mild Cognitive Impairment ; Aging

1. BACKGROUND

Neurocognitive disorders (NCDs) encompass a range of conditions characterized by a decline in cognitive function due to damage or disease affecting the brain. These disorders can result from various causes, including Alzheimer's disease, Parkinson's disease, stroke, traumatic brain injury, and other conditions impacting the brain's structure or function. Symptoms of NCDs often include impairments in memory, attention, language, and executive functions, significantly affecting daily living and quality of life. The severity of symptoms can vary, with some individuals experiencing mild cognitive impairments, while others may face severe dementia. Diagnosis typically involves a combination of medical history, cognitive testing, and neuroimaging, and treatment may include medications, cognitive therapies, and lifestyle changes aimed at managing symptoms and slowing disease progression [1].

Neurocognitive disorders occur due to various underlying causes that damage brain cells or disrupt their function [2]. The primary factors include neurodegenerative diseases like Alzheimer's and Parkinson's, which lead to the gradual loss of neurons and synapses; cerebrovascular events like strokes, which impede blood flow to the brain and cause tissue death; traumatic brain injuries that physically damage brain tissue; infections such as HIV or encephalitis that inflame and impair brain function; and systemic illnesses like liver or kidney disease that cause metabolic imbalances affecting the brain. Additionally, genetic predispositions, lifestyle factors such as chronic alcohol use or poor diet, and environmental toxins can contribute to the onset and progression of neurocognitive disorders. The complex interplay of these factors results in the deterioration of cognitive functions and, ultimately, the symptoms observed in these disorders.

The prevalence of neurocognitive disorders varies based on factors such as age, type of disorder, and geographic region [3]. Alzheimer's disease, the most common form of neurocognitive disorder, affects approximately 5–10% of individuals aged 65 and older, with prevalence increasing to nearly 30–50% in those over 85. Vascular dementia, another common type,

accounts for around 10–20% of dementia cases. Parkinson's disease affects about 1–2% of people over 60. Mild cognitive impairment (MCI), a precursor to more severe neurocognitive disorders, affects about 15–20% of people aged 65 and older. Overall, the global prevalence of dementia is estimated to be around 50 million people, a number expected to triple by 2050 due to an aging population. Variations in prevalence are influenced by factors like genetics, lifestyle, healthcare quality, and diagnostic criteria used in different studies and regions.

Current diagnostic solutions for neurocognitive disorders involve a multifaceted approach combining clinical evaluations, cognitive testing, and advanced imaging techniques [4,5]. Initial assessment includes a thorough medical history and physical examination, focusing on cognitive symptoms, functional abilities, and any changes over time. Standardized cognitive tests, such as the Mini-Mental State Examination (MMSE) [6] or Montreal Cognitive Assessment (MoCA) [7], are used to evaluate memory, attention, language, and executive functions. Neuroimaging techniques, like MRI and CT scans, help visualize brain structure, identifying atrophy, lesions, or other abnormalities indicative of specific disorders [8]. PET scans can detect amyloid plaques or tau tangles associated with Alzheimer's disease [9]. Laboratory tests may be conducted to rule out other causes, such as vitamin deficiencies or thyroid dysfunction. Genetic testing is sometimes employed for early-onset cases or familial patterns. Advances in biomarkers, including cerebrospinal fluid analysis and blood tests for specific proteins, are increasingly used to enhance diagnostic accuracy and monitor disease progression. This comprehensive approach allows for a more accurate and early diagnosis, essential for effective management and treatment planning.

Cognitive assessment is crucial for the early diagnosis of neurocognitive disorders because it can detect subtle cognitive changes before anatomical and biological biomarkers become apparent. Early cognitive testing, through tools like the Mini-Mental State Examination (MMSE) or Montreal Cognitive Assessment (MoCA), can identify declines in memory, attention, executive function, and other cognitive domains,

which are often the first signs of neurocognitive disorders [10,11]. These assessments are non-invasive, cost-effective, and can be administered in various settings, making them accessible for widespread screening. Identifying cognitive deficits at an early stage allows for timely interventions, such as lifestyle modifications, cognitive therapies, and, when available, pharmacological treatments, potentially slowing disease progression and improving quality of life. Additionally, early diagnosis through cognitive assessment enables better planning and support for patients and families, enhancing their ability to manage the disorder. Given that anatomical changes, such as brain atrophy visible on MRI, and biological markers, like amyloid plaques detectable via PET scans, typically emerge at later stages, cognitive assessments remain a vital tool for early detection and proactive management of neurocognitive disorders.

The risks of misclassification and misdiagnosis with brief cognitive assessments stem from several factors, including the limitations of the tests, the variability in test administration, and individual differences among patients [12,13]. Brief cognitive assessments, such as the MMSE and MoCA, may not capture the full spectrum of cognitive abilities and can be influenced by factors like education, cultural background, language proficiency, and test anxiety, potentially leading to false positives or negatives. For instance, highly educated individuals might score within normal ranges despite having early cognitive impairment, while those with lower education levels might score poorly despite having no neurocognitive disorder. Variability in how tests are administered and interpreted by different practitioners can also contribute to inconsistent results. Additionally, some cognitive impairments might be subtle or fluctuate, making them difficult to detect in a single assessment. Misclassification can lead to unnecessary anxiety, inappropriate treatments, and failure to address the true underlying condition, while misdiagnosis can delay appropriate care and interventions, ultimately impacting patient outcomes. Therefore, brief cognitive assessments should be part of a comprehensive diagnostic approach, including detailed medical history, thorough clinical evaluation, and, when necessary, advanced diagnostic tools to ensure accuracy and reliability.

For early diagnosis of neurocognitive disorders, a comprehensive approach is essential, encompassing neurocognitive functional domains, neurocognitive symptom domains, behavioral domains, and widely recognized risk factors. This multifaceted strategy involves detailed cognitive assessments that evaluate various functional domains such as memory, attention, executive function, language, and visuospatial abilities. It also includes thorough evaluations of neurocognitive symptom domains, identifying early signs such as forgetfulness, difficulty concentrating, and problem-solving challenges. Behavioral assessments are crucial to detect changes in mood, personality, and social interactions that often accompany neurocognitive decline. Recognizing and evaluating widely recognized risk factors, such as age, family history, cardiovascular health, diabetes, hypertension, and lifestyle factors like diet and physical activity, are integral to this approach. Combining these elements allows for a more accurate and early identification of neurocognitive disorders, facilitating timely intervention, personalized treatment plans, and proactive management strategies that can significantly improve patient outcomes and quality of life.

2. NEUROCOGNITIVE FUNCTIONAL, SYMPTOM, BEHAVIOURAL DOMAINS, RISK FACTORS AND SPEECH BIOMARKERS

The DSM-5 outlines six key neurocognitive functional domains essential for diagnosing neurocognitive disorders: complex attention, executive function, learning and memory, language, perceptual-motor, and social cognition. Complex attention involves the ability to sustain and divide attention and process information efficiently, while executive function includes higher-order processes like planning, decision-making, and mental flexibility. Learning and memory pertain to encoding, storing, and retrieving information, with deficits leading to issues like forgetting recent events. The language domain encompasses expressive and receptive abilities, including word finding and comprehension. Perceptual-motor functions involve the integration of sensory and motor skills, affecting tasks like hand-eye coordination and spatial reasoning. Social cognition includes interpreting social cues, recognizing emotions, and understanding social norms. Evaluating these domains provides a comprehensive understanding of cognitive strengths and weaknesses, aiding in accurate diagnosis and differentiation of neurocognitive disorders [14].

Neurocognitive symptom domains encompass a range of deficits that manifest in various cognitive functions crucial for daily life. The 5 A's—agnosia, amnesia, apraxia, anomia, and aphasia—highlight distinct challenges: Agnosia involves difficulty recognizing familiar objects or people despite intact sensory abilities. Amnesia refers to impaired memory, affecting the ability to recall past events or learn new information. Apraxia is the inability to perform purposeful movements or tasks, despite intact motor function, often seen in activities like dressing or using tools. Anomia is characterized by difficulty finding words or names, resulting in frequent pauses or circumlocutions during speech. Aphasia refers to language impairments affecting comprehension, expression, or both, commonly following stroke or brain injury. These symptoms can occur in isolation or combination, depending on the underlying neurocognitive disorder, significantly impacting communication, daily activities, and overall quality of life. Identifying and assessing these symptoms are crucial for early diagnosis and appropriate intervention strategies tailored to each individual's needs [15,16,17].

Behavioral symptom domains in neurocognitive disorders encompass a range of changes in an individual's behavior, personality, and social interactions that often accompany cognitive decline. Affective symptoms include mood disturbances such as depression, anxiety, irritability, and emotional lability, which can significantly impact emotional well-being. Psychotic symptoms may manifest as hallucinations (perceiving things that are not present) or delusions (false beliefs), often related to the individual's cognitive impairment. Agitation and aggression can occur, characterized by restlessness, pacing, verbal outbursts, or even physical aggression, which may be triggered by confusion or frustration. Apathy, seen as a lack of interest, motivation, or initiative, leads to reduced engagement in activities and social interactions. Sleep disturbances, including insomnia or excessive daytime sleepiness, are common and can exacerbate cognitive and behavioral symptoms. Wandering and disinhibition may result in wandering behaviors or socially inappropriate actions due to impaired judgment. These

behavioral changes can vary in severity and impact, requiring tailored management approaches that may include environmental adjustments, caregiver support, behavioral interventions, and in some cases, pharmacological treatments to alleviate symptoms and improve overall quality of life for individuals with neurocognitive disorders [19].

The risk factors for neurocognitive disorders encompass a broad spectrum of influences [18]. Aging is the primary risk factor, with the prevalence of disorders such as Alzheimer's disease increasing significantly after age 65. Genetic factors play a role, with specific gene variants increasing susceptibility, especially in early-onset cases. Cardiovascular health is critical, as conditions like hypertension, diabetes, and high cholesterol increase the risk of vascular dementia and Alzheimer's disease. Traumatic brain injury, particularly repeated concussions or severe head injuries, elevates the risk, as do lifestyle factors such as physical inactivity, smoking, excessive alcohol consumption, and poor diet. Educational attainment and cognitive reserve are protective factors, while social isolation and lack of mental stimulation may contribute to increased risk. Addressing these multifactorial risk factors through lifestyle modifications, cardiovascular risk management, cognitive engagement, and early intervention strategies is crucial for reducing the incidence and severity of neurocognitive disorders across populations.

Speech biomarkers in neurocognitive disorders refer to measurable changes in speech patterns, characteristics, or performance that can indicate the presence, progression, or specific characteristics of these disorders. These biomarkers can be detected through various aspects of speech, including language fluency, syntax, semantics, prosody (rhythm and intonation), and articulation [20]. In Alzheimer's disease, for example, individuals may exhibit reduced vocabulary, increased pauses or hesitations, and difficulty with word-finding or maintaining coherent conversation. Changes in speech rate, pitch variation, and grammatical errors may also be observed. In Parkinson's disease, speech biomarkers may include reduced loudness, monotone speech (hypophonia), and impaired articulation or rapid speech due to dysarthria. Advanced technologies like natural language processing (NLP) and machine learning are increasingly used to analyze these biomarkers objectively from recorded speech samples, offering potential tools for early detection, monitoring disease progression, and assessing treatment effectiveness in neurocognitive disorders.

3. THE COMPUTERIZED MULTI-FACTOR NEUROCOGNITIVE SCREENING SYSTEM (MFNS)

3.1 Specifications

The system is administered digitally through electronic devices such as smartphones, tablets, and computers. The whole administration process is supervised by at least one adult (aged 18 and over). Before starting the screening process, electronic devices' audiovisual parameters are checked and adjusted according to the needs of the users by the supervisors. A quiet space is required to administer the screening process without any potential source of distractions. The supervisor is required to have basic knowledge about the whole process and the purpose. It is recommended but not mandatory that the screening process be administered by a licensed healthcare provider. Even though the screening process can be carried out remotely, the presence of at least one supervisor is required.

3.2 System Overview

The MFNS is a 6-step procedure. This is a digitalized system backed by the MFNS proprietary algorithm that encompasses neurocognitive functional domains, neurocognitive symptom domains, behavioral symptom domains as well as risk factors. This comprehensive approach has the potential to increase diagnostic accuracy, as misdiagnosis is not uncommon with widely used brief neurocognitive assessment batteries. The algorithm and the contents are collected from MedTheme Corporation's private digital repositories [23].

3.3 Data Collection

The very first step involves taking the users' data regarding name, age, and educational background through a digitalized system. It also involves data regarding time and date the users participate in the screening process as well as the location that includes the name of the city, province or state or district (if applicable) and the country to evaluate users' orientation to time and place.

3.4 Neurocognitive Functional Domains Screening (NFDS)

The second step is Screening for Neurocognitive Functional Domains (NFDS). This neurocognitive screening model evaluates the users' neurocognitive functional domains such as perception, attention, memory, language, decision-making ability, learning ability, and visuospatial executive functioning through introducing the users to different cognitive tasks such as trail test, clock reading, numerical reasoning, number-alphabet substitution, and delayed recall [Table 1]. A score is assigned and saved to the individual users upon their participation in the aforementioned tasks according to their respective performance level. The whole process will be carried out digitally by an automated system.

3.5 Neurocognitive Symptom Domains Screening (NSDS)

The third step is Screening for Neurocognitive Symptom Domains (NSDS). It evaluates neurocognitive symptom domains such as aphasia, agnosia, anomia, apraxia, and amnesia [Table-1]. During this screening process, the users are introduced to a specific number of audiovisual clips and later they are introduced to certain tasks based on those audiovisual clips. A score is assigned and saved to the users upon their participation in the aforementioned tasks according to their respective performance levels as part of the digitalized automated system, similar to the score-assigning process used in the second step.

Table 1. Comprehensive Screening Approach

Domain	Model	Task Items	Biomarkers Detected
Functional	NFDS, NSDS	24	8
Symptom	NSDS,SO SB	29	5
Speech	SOSB	7	5
Behavioral	Questionnaire	26	15
Risk Factors	Questionnaire	34	18

3.6 Screening for Objective Speech Biomarkers (SOSB)

The fourth step is the Speech Biomarker-based Neurocognitive Screening (SOSB). During this process, the users are introduced to different cognitive tasks such as concept and image description, abstraction, and delayed recall. The users' individual verbal responses to the tasks are recorded digitally to detect a highly specific speech biomarker and, as a functional component of the automated system, scores are assigned and saved to the individual users respectively according to their level of performance.

3.7 Questionnaires and Checklists

The fifth step is completed by the users' caregiver(s) or family member(s) or, in some exceptional cases, the users themselves. They are required to fill out a questionnaire or checklist in multiple-choice format and select the single best option. The checklist or questionnaire includes data regarding behavioral symptom domains specific to neurocognitive disorders.

Similar to the fifth step, the sixth step is also completed by the users' caregiver(s) or family member(s) or, in some exceptional cases, the users themselves. They are required to fill out a questionnaire or checklist that includes data regarding the widely recognized risk factors for neurocognitive disorders.

4. QUANTIFICATION AND SCHEDULING

The final score for individual users is expressed in percentage based on their respective assigned score in steps 2–4. A highly specific categorization system is implemented, and the users are assigned susceptibility scores respectively. The susceptibility scores determine the users' individual status in a vulnerability scale. The scale encompasses susceptibility status ranging from Insignificant Susceptibility to Alarmingly High Susceptibility. Different susceptibility statuses are coded with different shades of different colors for visualization, ranging from dark green to dark red [Figure. 1].

The users go through all the steps 2–4 in three consecutive sessions 48 hours apart to mitigate risks of cognitive fatigue [21] that can potentially interfere with assessment outcomes. The duration of the sessions is 20, 30, and 40 minutes respectively for steps 2–4. Therefore, the whole screening process takes about a week to provide the users and (or) their family member(s) and (or) caregiver(s) with a preliminary preclinical report regarding the users' individual neurocognitive status and susceptibility to neurocognitive disorders.

5. DISCUSSION

Encompassing the neurocognitive functional, symptom, behavioral domains, risk factors, and speech biomarkers in a single system holds significant promise for future directions in research and clinical practice. This approach offers non-invasive, objective measures that can enhance early detection and monitoring of disease progression, potentially leading to earlier intervention and improved outcomes for patients. Advancements in technology, particularly artificial intelligence and machine learning, enable the analysis of subtle changes in speech patterns that may precede clinical symptoms, providing a window into the underlying neurodegenerative processes [22,23].

Integrating speech biomarkers into diagnostic protocols could enhance accuracy and complement existing methods such as neuroimaging and cognitive testing. Moreover, such screening

and monitoring systems may serve as sensitive indicators of treatment efficacy, allowing for personalized therapeutic approaches and longitudinal assessments. Collaborative efforts across disciplines, including neuroscience, linguistics, and computational science, are crucial for developing robust algorithms and standardized protocols for speech biomarker analysis. Ethical considerations regarding data privacy and consent will also be paramount in harnessing these technologies for clinical use. Ultimately, leveraging speech biomarkers represents a transformative avenue towards earlier detection, more precise monitoring, and targeted interventions in neurocognitive disorders, shaping the future of neurocognitive healthcare.



Figure. 1 Vulnerability Scale

6. CONCLUSION

The present work describes the design and preliminary implementation of a Computerized Multi-Factor Neurocognitive Screening System (MFNS) that integrates standardized cognitive domain testing, symptom and behavioral checklists, risk-factor assessment, and objective speech-biomarker analysis into a unified, digitally administered screening protocol. By combining structured neurocognitive functional and symptom domain tasks with caregiver-reported behavioral and risk-factor data and with automated speech analysis, the MFNS advances a multidimensional model of early susceptibility detection that addresses many limitations of brief, single-domain screens. The architecture and stepwise administration (including three-session scheduling to reduce fatigue) reflect a pragmatic balance between comprehensiveness and feasibility for deployment on consumer devices under supervised conditions.

Conceptually, the MFNS capitalizes on complementary sources of information—performance-based cognitive metrics, structured symptom probes, informant reports, and digital speech signatures—to increase sensitivity for subtle preclinical change while seeking to reduce misclassification associated with education, language, and single-epoch assessment. The inclusion of speech biomarker extraction (SOSB) is particularly noteworthy: automated acoustic-linguistic measures have the potential to detect prodromal changes that precede overt deficits on traditional tests, and when fused with domain-specific scores they can enrich phenotypic resolution and support individualized risk stratification. Importantly, the system's quantitative vulnerability scale and visualization strategy provide clinically meaningful outputs that can facilitate triage and longitudinal monitoring.

Notwithstanding these strengths, the MFNS remains at a preclinical and developmental stage and must be interpreted in light of several limitations. The current specification and preliminary reporting do not substitute for empirical validation: rigorous psychometric evaluation is required to establish reliability, criterion validity (against gold-standard clinical diagnoses and biomarker modalities), sensitivity/specificity across disease stages, and test–retest stability. Potential sources of bias—educational, cultural, linguistic, and device heterogeneity—must be explicitly quantified and mitigated through stratified sampling and culturally adapted stimulus

sets. Additionally, algorithmic transparency and external generalizability must be demonstrated by reporting model parameters, feature importance, and performance in independent, demographically diverse cohorts.

Translationally, realizing the MFNS's promise will require a staged program of work: (1) data accrual from sufficiently powered, well-characterized cohorts (including longitudinal follow-up), (2) iterative model development with cross-validation and external testing, (3) prospective clinical utility studies examining impact on diagnostic pathways and patient outcomes, and (4) regulatory and implementation planning that addresses device certification, data governance, and integration into existing clinical workflows. Ethical and practical safeguards—robust informed consent procedures, secure handling of audiovisual and health data, supervision requirements for administration, and strategies to minimize harm from false positives or negatives—must be embedded from the outset. Collaboration across neurology, geriatrics, computational linguistics, and bioethics will be essential to refine algorithms and to ensure responsible deployment.

The MFNS represents a theoretically grounded and technically feasible framework for multidimensional neurocognitive screening that leverages objective speech biomarkers alongside classical cognitive and behavioral assessments. If validated in diverse, longitudinal cohorts and implemented with rigorous attention to equity, privacy, and clinical integration, the MFNS has the potential to meaningfully improve early detection, monitoring, and personalized management of neurocognitive disorders. Future work should prioritize empirical validation, transparency of analytic methods, and pathways for safe translation into routine clinical and community settings.

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8. REFERENCES

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