



AI-Enhanced Mobile APP to Aid in Early Detection of Cognitive Impairment

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Abstract

Importance: The diagnosis of Alzheimer's disease (AD) often relies on a "rule out" approach, yielding only a 60% accuracy rate [1]. Recent studies have shown that AI-based assessments can outperform traditional clinical testing in predicting disease progression [2]. With advancements in diagnostic tools for early cognitive impairment, there is a critical need for an accessible screening method to detect pre-clinical changes and improve patient outcomes. Digital technologies combined with artificial intelligence (AI) offer a novel strategy for early detection [3,4].

Objective: To determine the utility of a novel, currently available remote quantified neurologic assessment of cognitive and neurologic function on a mobile phone app in detecting cognitive impairment.

Design, Setting, and Participants: This cohort study of screening tests examined BeCare Neuro App data collected from user-reported symptoms and quantitative measures of neurologic function via quantified activities and questionnaires. The app assesses cognition across four domains using tasks similar to comprehensive in-clinic neuropsychological exams, reporting performance against normative scores of time and accuracy metrics [5,6]. tasks include: the "Cognitive Test" (decoding messages by pairing symbols with letters), the "Stroop Test" (naming the color of displayed words), the "Memory Test" (recalling a disappearing animal), and the "Tap Test" (tapping randomly appearing coins). The participants included users with subjective complaints of memory loss and/or cognitive impairment and users with neurologic complaints other than cognitive impairment.

Results: Data from sixty-five users who reported "cognitive" or "memory loss" and 212 users who did not report "cognitive" or "memory loss" and who completed all tests was analyzed. Users reporting cognitive impairment consistently scored in the bottom third of the population. Specifically, 90.8% (59/65) had at least one activity in the bottom third, 66.2% (43/65) had two or more, and 30.8% had three or more activities in that range. In contrast, users not complaining of memory loss or cognitive impairment, 21.7% (46/212) had at least one test in the bottom third, 9.0% (19/212) had two or more. and 2.4% (5/212) had three or more.

Conclusions and Relevance: The BeCare Neuro App demonstrates potential as a screening tool for early cognitive impairment, identifying patients who require further evaluation. Given the recent advances in new treatments for early-stage AD, early detection will greatly affect patient outcomes [7]. The expense of standard of care diagnostic tools and the rapidly increasing prevalence of AD makes an inexpensive, effective, and accessible screening tool such as BeCare Neuro App invaluable.

Keywords: Alzheimer's Disease (AD); Artificial Intelligence (AI)

Key Points

- **Question:** How sensitive is the BeCareLink Neuro App's Quantitative Neurologic assessments in detecting cognitive impairment?
- **Findings:** This cohort study of screening tests found statistically significant potential for remote gamified quantitative assessments to detect early cognitive changes in patients with various neurologic disorders. Patients with self-reported memory loss and/or cognitive impairment were more likely to fall in the bottom 30th percentile of the general population than patients with neurologic complaints other than cognitive impairment.
- **Meaning:** The BeCare Neuro App shows promise as an early screening tool for cognitive impairment, helping clinicians identify patients who may benefit from earlier intervention.

Introduction

More than 6.5 million Americans over age of 65 are living with AD. This number is predicted to increase to 50 million by 2050. There are over 55 million people worldwide living with dementia (as of 2020). That number is expected to double every 20 years, reaching 139 million in 2050. Thirty percent of seniors die from AD or other dementias [1].

Recent trials of potential therapeutics highlight the need for pre-clinical detection to make the greatest impact on disease development/progression [8]. Part of the issue of detection in the early phase is the lack of recognition of Mild Cognitive Impairment (MCI) outside of normal aging. Each year, 10-15 percent of patients with MCI will go on to develop dementia [9]. Approximately 12-18% of people 60 years or older are living with MCI, and the population of Americans over 65 years of age has increased by more than 30% over the past decade [10,11].

To differentiate MCI arising from other causes such as systemic disorders, psychiatric disorders, and Traumatic Brain Injury, signs of early cognitive impairment must be recognized. One impediment to detection of MCI is that less than 20% of Americans know what it is, and as a result, early signs are not reported to clinicians [12]. Physi-

cians diagnose MCI by performing clinical exams including simple assessments of cognitive function, such as recall, new learning, naming and comprehension.

One of the greatest barriers to early diagnosis and detection of progression in neurologic disorders is the difficulty in obtaining and interpreting the neurologic examination. The neurologic exam is detailed, requires great expertise, is time-consuming, and is time-sensitive to when new symptoms are detected. Moreover, even when performed by a seasoned neurologist, the results are subjective. Two neurologists examining the same patient will have divergent findings.

Compounding the difficulty of making the diagnosis of MCI or even early dementia is the shortage of neurologists. The neurologist shortage is projected to worsen by approximately 20 percent by 2025 [1]. Currently, over 70 percent of patients with neurologic disorders are not seen by neurologists [13]. While PCP's frequently make the diagnosis of dementia, only 50 percent of primary care doctors who see neurologic patients even perform a neurologic exam [14]. This results in delayed diagnosis and delayed detection of disease progression. Estimates show that in high-income countries, only 20-50% of dementia cases are recognized in the primary care doctors' offices [15]. Moreover, in one survey, greater than 25% of primary care physicians reported being "only sometimes" or "never" comfortable answering patient questions about AD and other dementias [16].

Pre-clinical detection of AD has been advanced by bio-markers such as CSF measurement for beta-amyloid (AB42), positron emission tomography (PET) with Amyvid (which can detect abnormal amyloid deposits 17 years before clinically-evident disease, serum levels of tau, and genetic testing for certain genotypes (APO E genotypes, APP, PSEN 1, PSEN2) which are associated with a greater chance of developing AD [17-19]. These tests are expensive and hindered by a lack of accessibility [20]. Recent AI models have shown that brain wave patterns recorded during sleep can predict decline years before symptoms emerge [19]. Deep learning models using hippocampal MRI and follow-up cognitive data have demon-

strated strong predictive capabilities, but require specialized imaging infrastructure [20].

BeCare AD Link is a revolutionary platform to capture pre-clinical and clinical manifestations with a more holistic and quantitative overview of quantitative neurologic assessment that can be performed remotely and inexpensively, bridging the accessibility hurdles.

Methods

This is a retrospective study. Patient consent had been obtained on the initial download of the app for clinical studies upon deidentification of the data. Inclusion criteria was patients ages 18-90. Exclusion criteria was not completing sufficient BeCare activities. A search was conducted on the app for patients with complaints of cognitive impairment and memory loss to include in the symptomatic cohorts. App users were divided into three cohorts. One cohort included patients who self-reported complaints of memory loss, one cohort included patients who self-reported complaints of cognitive impairment, and the third cohort included patients who had other complaints (including pain, fatigue, headache, incoordination, change in vision, depression, motor dysfunction, change in sensation) but no reported cognitive or memory complaints.

A total of 277 users were included in the analysis, with a mean age of 41 (SD 11.3) years. Of these, 97% (268/277) identified as female and 3% (8/277) as male. The high proportion of female participants may reflect a greater likelihood of women to engage with app-based health monitoring platforms, consistent with trends observed in digital health adoption, a reported greater health literacy and concern amongst women, and a higher lifetime risk for females of developing Alzheimer's disease. However, this demographic skew warrants consideration when interpreting the generalizability of findings. The final analysis included 65 users with cognitive and memory complaints and 212 users with other complaints who had completed all the cognitive tests in the app.

Cognitive test

Users decode messages by pairing symbols with letters. This task assesses memory and information processing speed and is based on the standard code test [21].

Memory test

Two animals are displayed simultaneously before one disappears. Users are then shown the one that did not disappear and a new animal image. They then must choose the one that had not disappeared from a group of images of animals, including the one that had disappeared. This task assesses memory and problem-solving.

It is similar to the PASAT test (The Paced Auditory Serial Addition Test) which is a neuropsychological test used to assess cognitive functions like attention, processing speed, and working memory, by requiring participants to mentally add a sequence of numbers presented audibly or visually.

Stroop test

Users are asked to tap on the ribbon that matches the color of the ribbon, not the meaning of the word describing a color. This task measures executive function and inhibition and mimics the in-person Stroop test [22].

Tap test

Users are asked to tap randomly appearing coins. This task measures fine motor function and is similar to 9 Hole Peg Test. Tests using similar AI-based motor assessments have shown utility in early identification of MCI [4,23]. Multimodal AI-based motor assessments have also been shown to differentiate MCI from normal aging [4].

Statistical analysis

To refine data quality and detect anomalies, two unsupervised machine learning techniques were applied: K-means clustering and hierarchical clustering. These methods grouped users based on performance patterns across the cognitive tasks. Outliers—such as users whose task scores deviated significantly from all clusters—were flagged for further review. K-means, which partitions users into k distinct clusters based on feature similarity, helped identify consistent response behavior. Hierarchical clustering, which builds nested clusters in a tree-like structure, was used to confirm the robustness of these groupings and to isolate users whose task completion data suggested misunderstanding or erratic interaction. This dual approach enhanced the integrity of the dataset by filtering non-representative entries without discarding data based solely on deviation from the mean.

The Mann-Whitney test was used to compare the distribution of test scores to demonstrate that the observed differences are unlikely due to chance. We used AI-enhanced techniques to filter data that did not reflect full understanding or effort. While statistical analysis, such as z scoring, is useful for identifying data points that deviate significantly from the mean, we used 2 AI techniques (K-means and hierarchical clustering) to group similar data points and identify outliers, which should not be discarded.

The ANOVA test and a heatmap test were employed to determine the significance in showing the variance in results between the four tests was greater than the variance of results within each group.

Results

BeCareLink has over 20,000 users. The tap test has been completed over 34,000 times, the cognitive test over 18,000 times, the memory test over 18,000 times, and the stroop test over 12,000 times. The BeCareLink platform computes a population percentile for users as they complete an activity using various metrics. This analysis aligns with other predictive models such as the Florey Dementia Index [7]. A standard metric for these activities combines the time and accuracy for completing each step of the activity. For example, each identification of a symbol in the Cognitive, Memory, and Stroop test corresponds to a single step. For the Tap, each tap on a coin corresponds to a step. Therefore, an activity is considered a collection of steps; an average value is produced from the collection each time a user completes the activity. This value scores ac-

tivity instance. A population of scores is produced for each activity and a population percentile can be computed for each score.

A total of 277 participants (mean [SD] age, 41 [11.3]; 268 females [97%], 8 males [3%]) were included in the screening for the composite of the cognitive, memory, stroop and tap tests. There were 65 users who completed all four tests and reported their limiting symptom as “cognitive” or “memory loss”. There were 212 users who completed all four tests and reported neurologic symptoms other than cognitive impairment or memory loss.

Population percentiles were computed for each of these users in each activity. The analysis found users who reported these symptoms reliably placed in the bottom 3rd of the population. Those reporting cognitive limitations had a 90.8% (59/65) chance of completing one or more activities in the bottom third of the general population, a 66.2% (43/65) chance of completing two or more activities in the bottom third of the general population, and a 30.8% chance of completing 3 or more activities in the bottom third of the general population.

Those not reporting cognitive limitations had a 21.7% (46/212) chance of completing one or more activities in the bottom third of the general population, a 9.0% (19/212) chance of completing two or more activities in the bottom third of the general population, and a 2.4% (5/212) chance of completing 3 or more activities in the bottom third of the general population.

The Mann-Whitney test compares the distribution of test scores. The analysis resulted in a p-value of <0.05, indicating that the observed differences are unlikely to be due to chance.

Table 1: Performance on App-Based Cognitive Tasks by Symptom Reporting Status.

No of Activities in Bottom 30 th Percentile	Users With Cognitive/Memory Complaints (n = 65), No. (%)	Users Without Cognitive/Memory Complaints (n = 212), No. (%)
≥1 activity	59 (90.8)	46 (21.7)
≥2 activities	43 (66.2)	19 (9.0)
≥3 activities	20 (30.8)	5 (2.4)
Abbreviation: App, application.		

Table 2: ANOVA Results by Symptom Group.

Symptom Group	F Statistic	P Value	Interpretation
Cognitive Loss	7.66	0.000067	Statistically significant difference in score distributions across test types within this group.
Memory Loss	8.75	0.000020	Statistically significant variation in outcomes based on test type within this group.

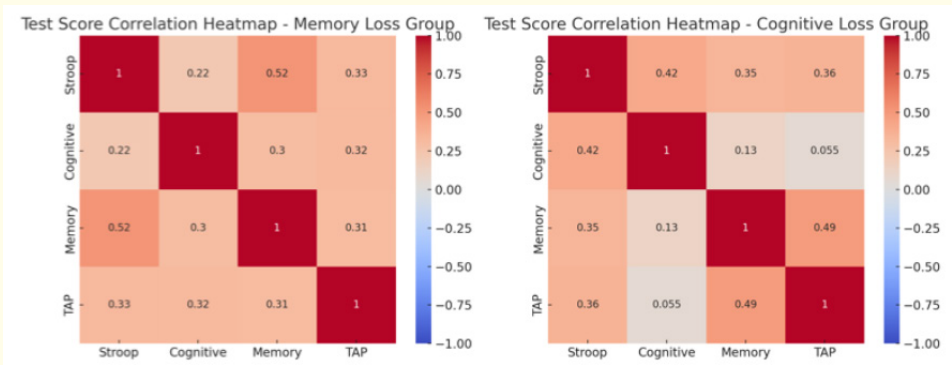


Figure 1: Test Score Correlation Heatmap Memory Loss Group vs Cognitive Loss Group.

These heatmaps display correlation coefficients among the four test scores (Stroop, Cognitive, Memory, TAP) separately for each group (cognitive loss, memory loss). The fact that none of the squares are dark red (other than the diagonals) suggests that the tests do measure different functions, mirroring the ANOVA results.

Figure 3 presents the percentile distribution curves for performance on the Cognitive, Memory, Stroop, and Tap tests from users of the BeCare Neuro App. Each curve reflects the relative frequency of users falling into different percentiles.

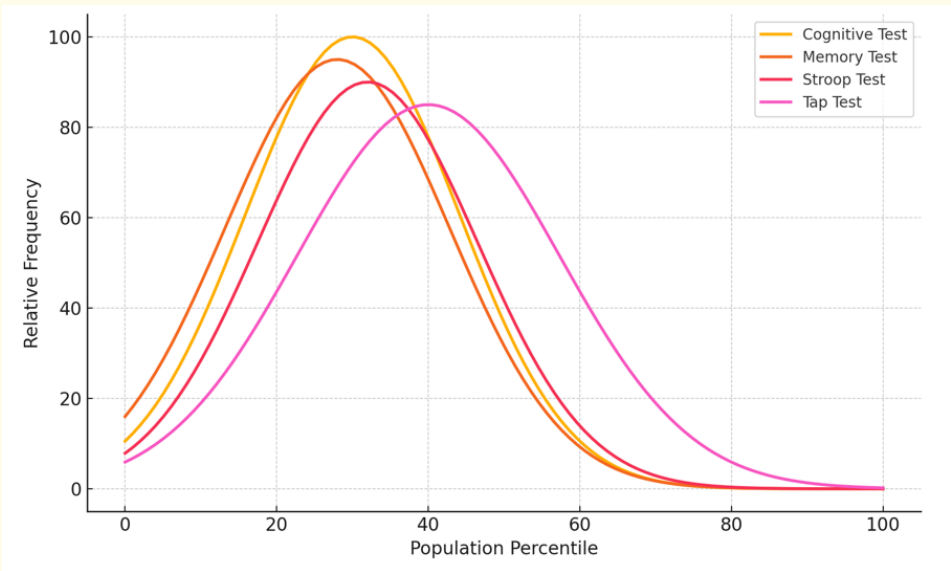


Figure 2: Combined Percentile Score Curves for Cognitive, Memory, Stroop, and Table Tests.

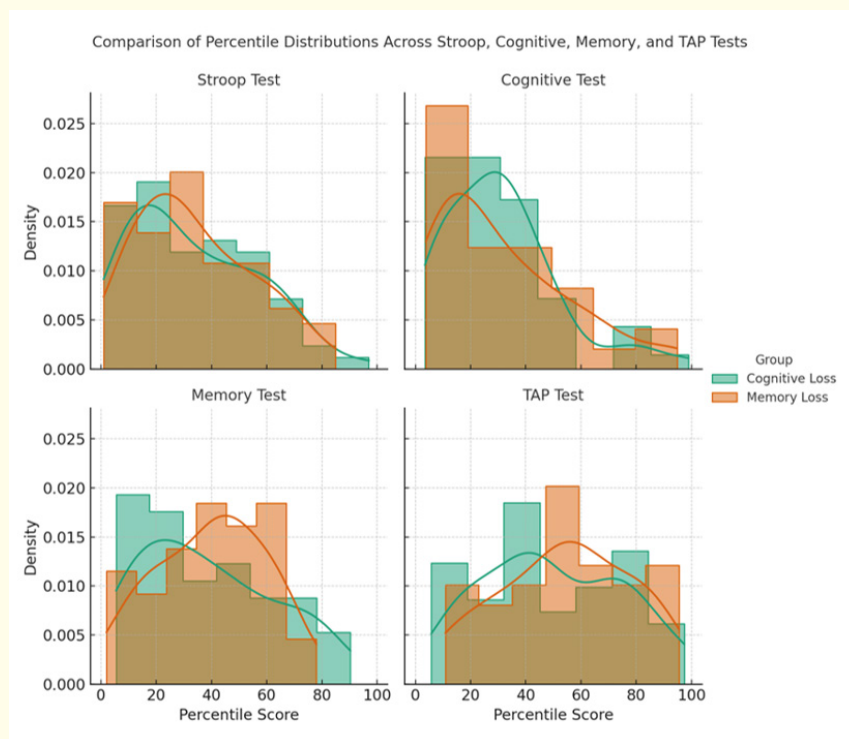


Figure 3: Comparison of Percentile Distribution Across Stroop, Cognitive, Memory, and TAP Tests.

The key observation from Figure 3 is that the cognitive, memory and stroop tests all demonstrate a leftward shift, with peaks around the 30th percentile. The tap test curve which at a relative 3 percent higher percentile range.

Discussion

BeCare Link's mission was to create comprehensive quantitative neurologic assessments that mimic what is performed by clinicians in person, while improving the assessment with quantitative data analyzed by Artificial Intelligence. The result will be improved patient outcomes and more expedient, efficient, and inexpensive clinical trials with stronger outcome measures as they are based on objective data. Similar approaches using AI to predict dementia risk and detect Alzheimer's via smartphone speech patterns have shown promise in recent research [4,5,19,24]. Other digital screening tools include explainable sensor-based AI, and portable

AI assessment systems [24,25], as well as drawing-based tests [23]. Emerging non-invasive tools, such as AI interpretation of eye scans, sleep EEG patterns and retinal imaging also under investigation [19,26-29].

The Cognitive, Memory and Stroop tests used in the BeCare Neuro app and included in this study are based on standard tests administered in neuropsychological evaluations for cognitive impairment. The Tap test was included based on studies that have shown finger-tapping to be slowed pre-clinically or at early detection. Coordination was also shown in these studies to be affected similarly [30-32]. The BeCareLink tap test quantitatively measures both fine motor function and coordination.

The results show a statistically significant worsened performance on the cognitive tests and the tap tests in patients with com-

plaints of memory and cognitive impairment as compared to the cohort with non-cognitive neurologic complaints. The ANOVA and heatmap results both show that the four tests measure different cognitive domains and emphasize the need to test multiple cognitive domains in screening for dementia and AD [30].

All of the percentile curves demonstrate a leftward shift of the peak mean, around the 30th percentile cut off that was identified as the marker of concern. While the peak for the tap was significantly higher than the rest of the tests, it still showed a greater area under the curve toward the lower percentiles.

The leftward shift of the cognitive, memory and stroop tests indicates that a substantial proportion of users with self-reported cognitive or memory complaints perform worse than the general population. The clustering around lower percentiles aligns with the expected deficits in early cognitive impairment. While the Tap Test curve peaks at a slightly higher percentile range compared to the other tests, it still shows a modest skew toward the lower percentiles, suggesting early fine motor or coordination changes in some users. The relatively higher tap performance may reflect that motor coordination deficits are less sensitive indicators of early cognitive impairment compared to measurements of established cognitive domains [29].

The statistically significant worsened performance on the cognitive and the tap tests in patients with complaints of memory and cognitive impairment as compared to the cohort with non-cognitive neurologic complaints supports the hypothesis that the BeCare Neuro App, a remote, accessible, affordable tool, can effectively screen for dementia. Systematic reviews have confirmed the promise of AI in identifying MCI across various modalities, aligning with the present findings [6] and with recent work such as the Florey Dementia Index, which uses AI to predict Alzheimer's onset age in asymptomatic individuals [33].

BeCare Link was created to promote earlier detection and enhanced monitoring for progression in different chronic neurologic

disorders, narrowing the care-gap created by socioeconomic disparity and lack of access to quality healthcare leveraging digital phenotyping to transform behavioral data into actionable clinical insight [34]. Through our remote assessment available to patients when they detect change, we have empowered patients and caregivers to play an active role in their treatment and have forged a clinical partnership between clinicians and patients.

Strengths and limitations

This study is not without limitations. First, the patient population was small. Next, the criteria for cohort creation were based on patient-reported symptoms. A stronger statistical significance might be achieved with a larger population including individuals already diagnosed with MCI, AD or Dementia through evaluations such as Amyvid-PET scan and lumbar punctures. Further, our results cannot be generalized to all individuals without examination in cohorts with a larger representation of diverse ethnic populations [35]. This demographic profile may limit the generalizability of the findings to older populations or a more balanced gender distribution. Finally, age-matched the cohorts and controls for other medical conditions affecting cognition, such as hypertension, and diabetes would strengthen the study. Incorporating conversational speech analysis may assess cognitive changes independent of comorbid conditions.

Conclusions

The BeCare Neuro App could function as a screener for the general population for early cognitive impairment, helping direct frontline clinicians select patients requiring further evaluation, reaching greater numbers at risk for developing or in early stages of dementia, changing patient outcomes. and aligning with ongoing research into AI's role in cognitive assessment and Alzheimer's detection [36-39]. Because approximately 90% of the U.S. population and 60% of the global population owns a smartphone, BeCareLink's highly sensitive and easily accessible screening for cognitive impairment can be an invaluable tool for community outreach through community -based digital health screening and can serve to help direct public health policy.

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BeCareLink designed and conducted the study, analyzed and interpreted the data, and prepared and reviewed the manuscript.

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