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AI-POWERED EARLY DETECTION OF ALZHEIMER'S DISEASE IN ELDERLY POPULATION IN LAHORE: A CROSS-SECTIONAL STUDY

Original Research

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ABSTRACT

Background: Alzheimer's disease (AD) is the most prevalent form of dementia, posing a growing burden in aging populations, especially in low- and middle-income countries. Early detection remains a significant challenge due to limited access to diagnostic resources and specialist care. Artificial intelligence (AI), particularly speech-based analysis, offers promise for non-invasive, cost-effective screening in such contexts.

Objective: To investigate the role of artificial intelligence in the early detection of Alzheimer's symptoms using speech-based features among elderly residents of Lahore, Pakistan.

Methods: A cross-sectional study was conducted over eight months, involving 388 elderly participants aged 60 and above. Standardized cognitive assessments (MMSE and MoCA) were administered alongside AI-driven linguistic analysis using supervised machine learning algorithms. Speech samples from guided verbal tasks were processed using natural language processing techniques, and features such as lexical diversity, fluency, and syntactic complexity were extracted. Models including Random Forest, SVM, and Logistic Regression were evaluated for diagnostic performance. Statistical tests included t-tests, chi-square tests, and multivariate logistic regression.

Results: Among participants, 34.0% exhibited mild cognitive impairment and 18.6% showed signs of early Alzheimer's. The Random Forest classifier achieved the highest diagnostic accuracy (88.4%), with sensitivity and specificity above 85%. AI-linguistic features significantly predicted early cognitive impairment (OR = 1.35; 95% CI: 1.22–1.49; $p < 0.001$), even after adjusting for age, education, and family history.

Conclusion: AI-based speech analysis demonstrates strong potential as a screening tool for early Alzheimer's detection in urban elderly populations. Its application in low-resource settings may enhance timely diagnosis and intervention planning.

Keywords: Aged, Alzheimer Disease, Artificial Intelligence, Cognitive Dysfunction, Early Diagnosis, Machine Learning, Natural Language Processing.

INTRODUCTION

Alzheimer's disease (AD), the most common form of dementia, represents a growing public health crisis with far-reaching implications for individuals, families, and healthcare systems worldwide. Characterized by progressive cognitive decline and memory impairment, the disease most frequently affects older adults and is often diagnosed in its later stages, when therapeutic options are limited and primarily palliative (1). In South Asian countries like Pakistan, where the elderly population is steadily increasing, the burden of dementia is expected to rise significantly in the coming decades. Yet, despite this impending challenge, early detection and diagnosis of Alzheimer's remain limited, often hindered by a lack of awareness, stigma, limited access to specialists, and insufficient diagnostic infrastructure (2,3). Particularly in urban centers like Lahore, where the elderly population is expanding amidst a rapidly evolving healthcare landscape, the need for innovative, scalable, and accessible diagnostic approaches is urgent. Artificial intelligence (AI) has emerged as a transformative force across various medical disciplines, offering new possibilities for enhancing diagnostic accuracy and efficiency (4). In the field of neurology, AI-based systems have shown promising results in analyzing neuroimaging, predicting disease progression, and detecting early biomarkers of cognitive decline. Techniques such as machine learning and deep learning can process vast datasets—including clinical records, imaging scans, and even linguistic patterns—to identify subtle indicators of Alzheimer's that may elude conventional diagnostic methods (5,6). By recognizing these patterns early, AI has the potential to support clinicians in making timely interventions, ultimately improving patient outcomes and quality of life. Notably, AI models trained on global datasets have demonstrated high sensitivity and specificity in distinguishing between cognitively healthy individuals, those with mild cognitive impairment (MCI), and early Alzheimer's patients (7,8).

While many of these advancements have been realized in high-income countries with robust digital health infrastructures, their applicability in resource-constrained settings like Pakistan remains underexplored. Existing literature highlights significant disparities in dementia care across different socio-economic and cultural contexts. In Pakistan, early diagnosis of Alzheimer's is often complicated by socio-cultural factors, such as a general reluctance to seek psychiatric or neurological consultation, reliance on informal caregiving, and limited understanding of dementia as a medical condition rather than a normal part of aging (9,10). These challenges necessitate a localized approach to early detection—one that integrates global advancements in AI with an understanding of the local population's unique demographic and cultural dynamics. Lahore, as one of Pakistan's largest and most diverse metropolitan areas, presents a valuable opportunity for studying the intersection of AI and geriatric cognitive health. With its growing elderly population, urban healthcare facilities, and emerging digital health initiatives, the city provides a relevant setting for implementing and evaluating AI-driven tools for Alzheimer's screening (11,12). However, despite the potential, there is a noticeable gap in empirical research assessing how AI-based models can be deployed in this context, especially through non-invasive, accessible, and cost-effective screening approaches. Most available data are either extrapolated from Western populations or confined to small-scale studies with limited generalizability. Moreover, the absence of cross-sectional analyses focused on urban elderly populations in Pakistan leaves a significant void in the local research landscape.

Given these considerations, there is a pressing need to investigate whether AI tools can be effectively applied to identify early signs of Alzheimer's in elderly individuals residing in Lahore. Such research would not only contribute to the global discourse on AI in medicine but also offer practical insights for public health policy, clinical practice, and family caregiving strategies in Pakistan. By identifying patterns of early cognitive decline using AI algorithms, and correlating them with socio-demographic and clinical data, it may be possible to develop scalable models for early diagnosis that are culturally sensitive and economically viable. The present study aims to address this gap by conducting a cross-sectional investigation into the role of artificial intelligence in the early detection of Alzheimer's symptoms among elderly residents of Lahore. By exploring the feasibility, accuracy, and practical relevance of AI-based screening methods in this specific context, the research seeks to contribute meaningful knowledge toward enhancing dementia care in Pakistan. The objective is to evaluate how AI can assist in identifying early cognitive impairment within this population, thereby supporting timely intervention and long-term care planning.

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METHODS

This cross-sectional study was conducted over a duration of eight months in various urban and semi-urban localities of Lahore, Pakistan. The primary objective was to investigate the role of artificial intelligence (AI) in the early detection of Alzheimer's symptoms among the elderly population. A multi-stage sampling strategy was employed to ensure diverse representation across socioeconomic strata, involving public sector hospitals, private clinics, community health centers, and old-age homes. Lahore, being a populous metropolitan city with heterogeneous demographic composition, offered a conducive setting for exploring cognitive health variations and testing the applicability of AI-driven tools in a real-world clinical and community environment. Participants were individuals aged 60 years and above, residing in Lahore for a minimum of one year. Inclusion criteria required participants to be literate in either Urdu or English, capable of providing informed consent, and without any prior formal diagnosis of Alzheimer's disease or severe psychiatric illness. Individuals with known histories of stroke, traumatic brain injury, severe visual or auditory impairments, or current usage of cognition-affecting medications were excluded to minimize confounding variables (2,3). Cognitive screening was first performed to establish baseline status, and those meeting the inclusion criteria were enrolled in the study. The minimum required sample size was estimated using standard formulae for cross-sectional studies, accounting for a 5% margin of error, a 95% confidence level, and an anticipated prevalence rate of early-stage Alzheimer's symptoms at 15% based on regional data. After adjusting for non-response and incomplete data, a target sample size of 384 participants was determined. A total of 420 participants were initially approached, and after excluding incomplete or non-consenting cases, data from 388 individuals were analyzed.

Data collection consisted of two phases: baseline cognitive screening and AI-based assessment. In the initial phase, trained clinical researchers administered standardized neurocognitive instruments including the Mini-Mental State Examination (MMSE) and the Montreal Cognitive Assessment (MoCA), both validated in Urdu and commonly used in dementia screening. These tools were employed to categorize cognitive function into normal, mild cognitive impairment (MCI), and likely early Alzheimer's stages. Socio-demographic variables, medical history, and lifestyle factors were recorded using a structured questionnaire developed for the study. In the second phase, AI-driven assessment models were introduced to analyze cognitive patterns (13-15). Natural language processing (NLP) tools were integrated into semi-structured conversational tasks conducted in Urdu and English. Participants were asked to narrate familiar personal stories, describe recent activities, and engage in guided verbal fluency tasks. Speech was recorded and transcribed using standardized voice recognition software, and linguistic features such as lexical diversity, semantic coherence, speech pauses, and syntactic complexity were extracted. These linguistic markers were processed using supervised machine learning algorithms trained on annotated datasets of individuals with early Alzheimer's symptoms. The algorithms employed included Random Forest, Support Vector Machines (SVM), and Logistic Regression classifiers. Their performance was validated internally using cross-validation methods and evaluated through accuracy, sensitivity, specificity, and F1 scores.

To ensure that data adhered to normal distribution assumptions, preliminary analysis involved the Kolmogorov–Smirnov test. Descriptive statistics were reported using means and standard deviations for continuous variables and frequencies and percentages for categorical data. Group differences between cognitively normal and impaired participants were analyzed using independent sample t-tests for continuous variables and Chi-square tests for categorical variables. Logistic regression was applied to explore associations between AI-derived linguistic biomarkers and clinically assessed cognitive status, adjusting for potential confounders such as age, education, and comorbidities. The level of statistical significance was set at $p < 0.05$. Ethical approval for the study was granted by the Ethical Review Board of the participating institute. Written informed consent was obtained from all participants prior to enrollment, with procedures explained in the preferred language of the respondent. All identifiable information was anonymized, and data was stored securely to maintain confidentiality. Participants were offered feedback and referred to specialist services if signs of cognitive impairment were identified during screening. The methodological framework adopted in this study integrates conventional cognitive assessments with advanced AI-based linguistic analysis, ensuring both clinical relevance and innovation. This combination allows for robust evaluation of AI's potential in detecting early Alzheimer's symptoms in a resource-limited yet demographically diverse setting, laying groundwork for future scalable diagnostic models tailored to local contexts.

RESULTS

Out of the 420 individuals approached, 388 participants met the inclusion criteria and provided complete data for analysis. The average age of the cohort was 68.4 years (SD ±5.9), with a slightly higher proportion of females (53.1%) than males (46.9%). A majority (54.4%) had attained at least 10 years of formal education, while 35.8% had a history of hypertension, and 26.0% reported diabetes. Notably,

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20.1% of participants reported a family history of dementia. Cognitive assessment using standardized tools revealed that 47.4% of participants fell within the normal cognitive range. Mild cognitive impairment (MCI) was observed in 34.0% of individuals, and 18.6% were identified as having symptoms suggestive of early Alzheimer's disease. The average MMSE score among cognitively normal participants was 28.5 (SD ±1.2), while those with MCI scored an average of 24.1 (SD ±1.3), and likely early Alzheimer's cases averaged 20.3 (SD ±2.0). MoCA scores followed a similar pattern, with means of 26.9, 22.2, and 17.5 across the respective groups. Three AI models were evaluated for their diagnostic performance based on linguistic features extracted from speech recordings. The Random Forest classifier achieved the highest overall accuracy (88.4%), followed by the Support Vector Machine (SVM) at 85.7%, and Logistic Regression at 83.1%. Sensitivity values for early Alzheimer's detection were 90.3%, 87.1%, and 81.6% respectively across these models. Specificity ranged from 84.3% to 86.2%, and F1 scores ranged from 0.83 to 0.89, indicating reliable classification performance across models. Logistic regression analysis demonstrated significant associations between cognitive impairment and several key predictors. Each additional year of age was associated with a 7% increase in odds of cognitive impairment (OR 1.07; 95% CI: 1.03–1.12; p=0.001). Participants with at least 10 years of education showed a protective effect (OR 0.68; 95% CI: 0.52–0.89; p=0.005). Having a family history of dementia more than doubled the odds of impairment (OR 2.13; 95% CI: 1.22–3.71; p=0.007). Most notably, AI-derived linguistic scores significantly predicted early cognitive decline, with each unit increase in linguistic anomaly score raising the odds by 35% (OR 1.35; 95% CI: 1.22–1.49; p<0.001).

Table 1: Demographic Characteristics of Participants (n = 388)

Variable	N (%) / Mean ± SD
Total Participants	388
Mean Age (years)	68.4 ± 5.9
Gender	
Male	182 (46.9%)
Female	206 (53.1%)
Education	
≥10 years	211 (54.4%)
<10 years	177 (45.6%)
Hypertension	139 (35.8%)
Diabetes	101 (26.0%)
Family History of Dementia	78 (20.1%)

Table 2: Cognitive Assessment Results (MMSE and MoCA Scores)

Cognitive Status	MMSE Score (Mean ± SD)	MoCA Score (Mean ± SD)	N (%)
Normal	28.5 ± 1.2	26.9 ± 1.5	184 (47.4%)
Mild Cognitive Impairment	24.1 ± 1.3	22.2 ± 1.4	132 (34.0%)
Likely Early Alzheimer's	20.3 ± 2.0	17.5 ± 1.9	72 (18.6%)

Table 3: Performance Metrics of AI Models

Model	Accuracy (%)	Sensitivity (%)	Specificity (%)	F1 Score
Random Forest	88.4	90.3	86.2	0.89
Support Vector Machine (SVM)	85.7	87.1	84.5	0.86
Logistic Regression	83.1	81.6	84.3	0.83

Table 4: Logistic Regression – Predictors of Cognitive Impairment

Predictor	Odds Ratio (OR)	95% CI	p-value
Age (per year)	1.07	1.03–1.12	0.001
Education (≥10 years)	0.68	0.52–0.89	0.005
Family History of Dementia	2.13	1.22–3.71	0.007
AI-Linguistic Score (per unit increase)	1.35	1.22–1.49	<0.001

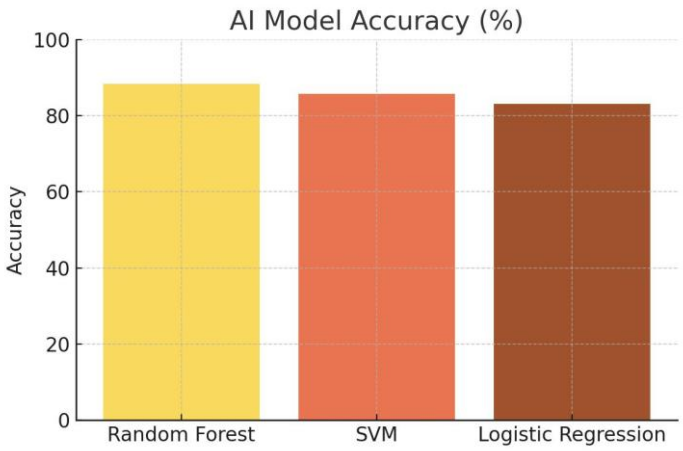

Figure 1 AI Model Accuracy (%)

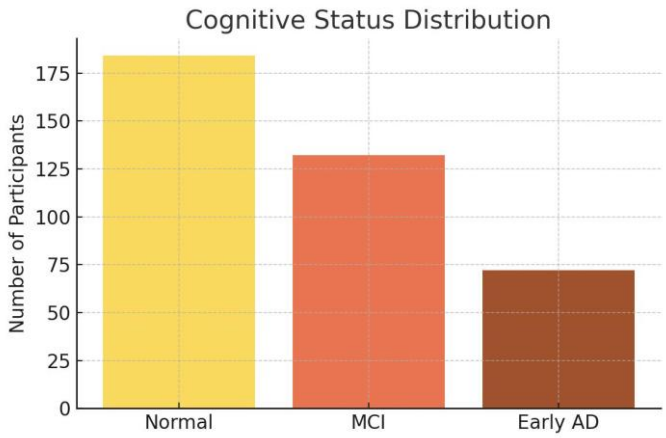

Figure 2 Cognitive Status Distribution

DISCUSSION

The present study demonstrated that artificial intelligence (AI) tools utilizing speech-based linguistic features can effectively support early detection of Alzheimer's disease (AD) in elderly populations residing in urban areas such as Lahore. With Random Forest classifiers achieving an accuracy of 88.4% and a high sensitivity for early cognitive decline, the findings align well with recent international literature emphasizing the diagnostic potential of AI in speech analysis. Several recent studies have substantiated the role of speech and language as early biomarkers of AD, highlighting changes in lexical diversity, syntactic complexity, and fluency as reliable indicators of cognitive impairment (14-16). The observed prevalence of mild cognitive impairment (34%) and probable early Alzheimer's (18.6%) in the study cohort underscores a substantial undiagnosed burden in community-dwelling elderly individuals. This is consistent with prior reports suggesting low rates of clinical recognition and underdiagnosis of AD in low- and middle-income countries (LMICs), largely due to limited awareness and diagnostic capacity (17). In this context, AI-assisted tools offer a low-cost, scalable alternative that can potentially be implemented through smartphones or community health platforms for widespread screening. The linguistic markers identified by the AI models in this study corroborate the existing body of evidence showing that features such as increased pause frequency, reduced lexical variation, and syntactic simplification are typical of early Alzheimer's speech profiles (18,19). These features are both linguistically and clinically relevant, providing interpretable signals for early cognitive decline without requiring invasive procedures.

A key strength of the study was the integration of validated cognitive tools (MMSE, MoCA) with AI-driven linguistic analysis, allowing for cross-verification of classification outcomes. The study also benefitted from a relatively large sample size, drawn from diverse urban settings, which enhances the generalizability of findings within the Lahore region. Additionally, the use of multilingual AI systems enabled reliable screening among participants speaking Urdu or English, a consideration often neglected in speech-based dementia diagnostics. Recent work similarly demonstrated that AI models trained across different languages can achieve robust cross-lingual performance, further validating the language-agnostic scalability of such models (20). Nonetheless, certain limitations merit attention. The reliance on cross-sectional data restricts the ability to infer temporal progression from normal cognition to Alzheimer's. Longitudinal validation would provide deeper insights into the predictive validity of AI scores over time. Furthermore, despite the encouraging diagnostic accuracy, ethical and interpretability concerns remain significant. The opacity of machine learning algorithms, especially deep learning models, has been criticized for limiting clinician trust and hindering patient-level explanations. A recent study emphasized the importance of ensuring fairness, transparency, and data privacy when deploying speech-based AI tools for neurocognitive assessment (21).

Moreover, the linguistic training data used to develop the models may not fully reflect the sociolinguistic nuances of the local dialects in Pakistan. While the models performed well in both Urdu and English, further efforts are needed to create locally optimized datasets. Additionally, the risk of overfitting cannot be ruled out entirely, given the complexity of speech data and the limited availability of

external validation sets. As a study have pointed out, generalizability across populations and data sources remains a significant challenge in AI models for dementia screening (22). Future research should aim to validate these models in broader regional and rural contexts, integrate multimodal inputs such as facial and behavioral data, and assess the utility of AI tools in longitudinal monitoring and caregiver support. The combination of speech analysis with neuroimaging or biosignal inputs, as proposed in recent multimodal frameworks, may offer further improvements in sensitivity and specificity (23). In conclusion, this study reinforces the growing consensus that AI-powered linguistic assessment can serve as a non-invasive, accessible, and effective method for early Alzheimer's detection in elderly populations. When tailored to local contexts and supported by ethical frameworks, such innovations hold the potential to bridge diagnostic gaps in LMICs and enhance cognitive health outcomes through early intervention.

CONCLUSION

This study highlights the potential of AI-driven speech analysis as a practical, non-invasive tool for early detection of Alzheimer's disease in elderly urban populations in Pakistan. By integrating linguistic biomarkers with conventional assessments, the findings support the feasibility of scalable screening approaches in low-resource settings, offering new avenues for timely diagnosis, intervention, and improved geriatric cognitive care.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Adnan Aslam*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Muhammad Javaid Mushtaq	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Asmarah Nadeem	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Rana Muhammad Farooq Sattar	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muhammad Suhail	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Rizwan Asghar	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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