AURA: An AI-Powered Multimodal Prototype for Adaptive Apraxia of Speech Therapy and Communication Support

Omotayo Emmanuel Omoyemi[0009-0003-6625-680X] and Rachel K. Johnson [0000-0003-2479-2965]

[1] University of Derby, Derby, UK
[2] Old Dominion University, Norfolk, VA, USA

Abstract. Apraxia of Speech (AOS) is a motor speech disorder that significantly limits communication and requires intensive, long-term therapy. Access to consistent treatment is often constrained by shortages of speech-language pathologists, high costs, and limited opportunities for continuous monitoring outside clinical settings. Recent advances in Artificial Intelligence (AI) provide new opportunities to support scalable and personalized speech therapy.

This paper presents AURA (Adaptive Understanding and Relearning Assistant for Apraxia), a multimodal AI framework designed to support speech therapy, progress monitoring, and communication for individuals with AOS. The system integrates speech analysis, machine learning–based error detection, reinforcement learning for adaptive therapy, and multimodal Augmentative and Alternative Communication (AAC) support. An initial research prototype has been developed to demonstrate the feasibility of the proposed architecture and workflow.

We describe the system architecture, its alignment with evidence-based motor learning principles, and a phased evaluation plan involving expert review, simulated testing, and pilot studies. The proposed framework aims to improve therapy accessibility, engagement, and data-driven intervention for individuals with AOS.

Keywords: Artificial intelligence · Apraxia of speech · Speech therapy · Augmentative and alternative communication

1 Introduction

Apraxia of Speech (AOS) is a neurological motor speech disorder that affects the brain's ability to plan and coordinate the movements required for speech production, despite intact language comprehension and muscle strength [23, 6]. The condition occurs in both children and adults and may result from stroke, brain injury, or progressive neurological disease [1]. Individuals with AOS often experience inconsistent speech errors, disrupted prosody, and difficulty initiating speech, which can significantly limit everyday communication and social participation [19].

Early and intensive intervention is critical for improving speech outcomes in acquired Apraxia of Speech, where motor-learning–based therapy requires frequent and structured practice to support recovery [19]. However, effective therapy typically requires frequent, highly personalized sessions with speech-language pathologists (SLPs). In practice, access to intensive speech therapy is often constrained by shortages of specialists, high treatment costs, and geographic barriers, leading to inconsistent and inequitable care across both developmental and acquired speech disorders [8, 19]. In addition, traditional assessment and therapy methods rely heavily on subjective clinician judgement and in-person sessions, limiting opportunities for continuous monitoring, objective evaluation, and scalable long-term support [18].

Recent advances in Artificial Intelligence (AI) present new opportunities to address these limitations. Progress in speech recognition, machine learning, and natural language processing has enabled systems capable of analysing atypical speech, providing real-time feedback, and supporting augmentative and alternative communication (AAC) [16, 9]. AI-driven platforms have the potential to facilitate remote monitoring, automated progress tracking, and adaptive therapy delivery tailored to individual performance [5]. Despite this progress, current research remains fragmented, and challenges remain around data availability, model reliability, and clinical validation of AI systems for speech disorders [17].

To address this gap, this paper presents AURA (Adaptive Understanding and Relearning Assistant for Apraxia), an AI-powered multimodal framework designed to support diagnosis, therapy, and communication for individuals with AOS. AURA integrates speech analysis, adaptive learning, and multimodal interaction to support the development of personalized therapy, real-time feedback, and remote progress monitoring. Rather than replacing clinicians, the system is designed to complement speech-language therapy and extend access to support beyond traditional clinical settings.

The contributions of this paper are threefold:

1. A synthesis of recent research on AI support for speech-language pathology and identification of gaps in AI support for Apraxia of Speech.
2. The design and implementation of AURA, an early-stage multimodal AI prototype for adaptive speech therapy and communication support.
3. A reproducible open-source implementation and a structured evaluation roadmap to guide future clinical validation.

This paper presents an early-stage research prototype and roadmap rather than a clinically validated system.

2 Related Work

2.1 Challenges in Apraxia of Speech therapy

Apraxia of Speech (AOS) presents unique challenges for both diagnosis and intervention due to its highly variable and inconsistent speech patterns. Unlike disorders caused by muscle weakness or language impairment, AOS primarily affects motor planning and sequencing, making accurate assessment and treatment particularly complex [2, 6] Current clinical practice relies heavily on perceptual evaluation and repeated in-person therapy sessions led by speech-language pathologists (SLPs), often requiring long-term, high-intensity intervention [19, 20].

Despite the effectiveness of established therapy approaches, access to consistent treatment remains limited. Shortages of trained speech-language pathologists, high therapy costs, and geographic barriers restrict access to care for individuals with both acquired and developmental speech disorders, many of whom require frequent and intensive intervention [8, 19]. In addition, traditional assessment methods often rely on subjective judgement and episodic observation, which can make it difficult to track subtle progress or provide continuous feedback outside clinical environments [18]. These limitations have motivated increasing interest in technology-assisted therapy and remote support tools.

2.2 Artificial Intelligence in Speech and Language Disorder

Artificial Intelligence (AI) has increasingly been explored as a tool for supporting diagnosis, monitoring, and intervention across speech and language disorders. Recent reviews highlight the growing role of AI-driven speech analysis, automated feedback systems, and remote therapy platforms in speech-language pathology [5, 16, 9]. Machine learning and automatic speech recognition have demonstrated the ability to analyze a typical speech patterns and support scalable intervention, although clinical validation and integration remain ongoing challenges [12, 17]. Recent work has also shown the potential of AI-driven speech and voice recognition tools to improve speech clarity and support personalized therapy for children with apraxia and stuttering [13].

AI-driven conversational agents and natural language processing techniques have also been explored as tools for interactive therapy and communication support, particularly for individuals with communication impairments [4]. Reinforcement learning approaches show promise for adapting therapy tasks to individual performance and maintaining long-term engagement in digital health interventions [4]. Recent clinical studies also report improvements in speech production using AI-assisted therapy tools, highlighting the potential of AI to complement traditional speech-language intervention [3]. AI-based rehabilitation research in related speech disorders, such as aphasia, further demonstrates the growing role of speech recognition and natural language processing in therapy and recovery support [22].

Computer vision and multimodal interaction technologies further extend these capabilities by enabling systems to analyze facial movements, gestures, and visual cues relevant to speech production and communication [7, 16, 4]. Such multimodal approaches are particularly relevant for users of augmentative and alternative communication (AAC) systems and highlight the potential for integrated therapy platforms.

2.3 Research gap towards multimodal therapy for AOS

Despite rapid progress in AI-based speech therapy tools [3, 5] and multimodal AAC systems [4], research specifically focused on Apraxia of Speech remains limited.
Recent research has begun exploring multimodal AI systems for AAC and communication support [21], further highlighting the need for integrated frameworks tailored to specific disorders such as AOS.
Although AI applications in speech and language disorders have expanded rapidly, research specifically focused on Apraxia of Speech remains limited. Existing work often addresses isolated components of therapy, such as speech recognition, conversational agents, or AAC tools, rather than integrated systems designed to support the full therapy workflow.
AOS therapy requires intensive repetition, structured feedback, and continuous adaptation to individual performance [20]. However, there is a lack of unified AI frameworks that combine speech analysis, adaptive learning, and multimodal communication support into a single platform tailored to the needs of individuals with AOS.
This gap highlights the need for integrated, clinically informed systems capable of delivering personalized therapy, supporting remote monitoring, and augmenting communication in real-world settings. The AURA framework proposed in this paper aims to address this need by combining speech analysis, reinforcement learning, and multimodal interaction within a single adaptive therapy platform.

3 AURA System Overview

To address the limitations of existing therapy and assessment tools, we present AURA (Adaptive Understanding and Relearning Assistant for Apraxia) and its initial prototype, an AI-powered multimodal framework designed to support speech therapy, progress monitoring, and communication for individuals with Apraxia of Speech (AOS). The system is intended to complement clinical practice by extending therapy beyond the clinic and enabling continuous, personalized support in home and educational settings.
In the current prototype, AURA primarily targets AOS speech-therapy workflows; gesture-based AAC is included as a modular extension to support users with limited speech and is presented as future work for clinical validation.

3.1 Vision

The central vision of AURA is to provide an integrated platform that combines speech analysis, adaptive learning, and multimodal interaction to support the full therapy workflow for AOS. An early proof-of-concept prototype has been implemented to demonstrate the feasibility of this approach. Rather than focusing on a single task such as speech recognition or AAC, AURA is designed as a unified system that can:

- deliver intensive and personalized therapy exercises,
- provide real-time feedback and performance tracking,

- support communication when speech production is limited,
- enable remote collaboration between clinicians, caregivers, and users.

By integrating these capabilities, AURA is designed to improve therapy accessibility, increase engagement, and enable more data-driven intervention.

3.2 System Architecture Overview

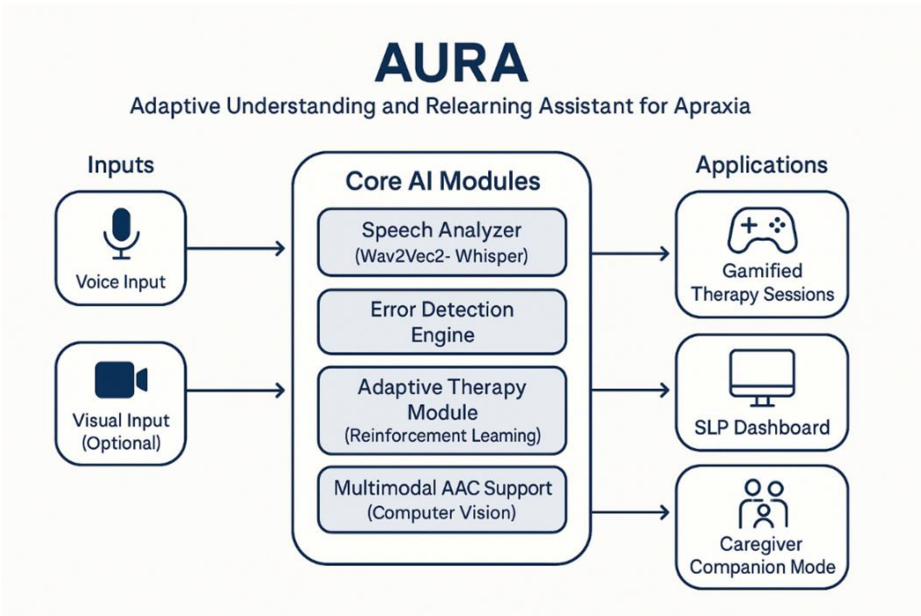

Fig. 1. AURA system architecture showing the input layer (voice and optional visual input), core AI processing modules (speech analysis, error detection, adaptive therapy, and multimodal AAC), and user-facing applications including gamified therapy, clinician dashboard, and caregiver companion tools.

As illustrated in Fig. 1, AURA is structured around three functional layers: input, AI processing, and applications.

- Input Layer: The system captures speech input and, when available, visual input such as lip or gesture movements.
- AI Processing Layer: Captured data is analyzed using specialized AI modules, including speech recognition, error detection, adaptive therapy selection, and multimodal communication support.
- Application Layer: The processed outputs support multiple user-facing applications, including gamified therapy activities, a clinician dashboard, and caregiver support tools.

This layered design enables flexible deployment across mobile and web platforms while supporting both therapy and communication scenarios.

3.3 Interaction Workflow

AURA operates as a continuous feedback loop. Users provide speech input during therapy exercises, which is analyzed in real time to detect motor planning errors and performance patterns. Based on this analysis, the system adapts therapy tasks to match the user's current ability level or provides multimodal communication support when verbal output is limited. The resulting feedback updates user profiles and guides future interactions, enabling continuous personalization over time.

3.4 Key Contribution

The AURA framework makes the following contributions:

- Multimodal AI-driven therapy: Integration of speech analysis, reinforcement learning, and multimodal interaction within a single platform tailored to AOS.
- Adaptive therapy delivery: Real-time adjustment of therapy tasks based on user performance to support sustained engagement and progressive skill development.
- AI-enhanced AAC support: Multimodal input processing enabling communication support for users with limited verbal output. Remote monitoring and collaboration:
- Clinician and caregiver tools for tracking progress and supporting therapy outside clinical settings.

Together, these components position AURA as a scalable framework for AI-assisted speech therapy and communication support.

4 System Architecture

This section describes the core AI modules that enable AURA to analyze speech, adapt therapy, and support multimodal communication. Fig. 2 illustrates the interaction workflow of the system.

4.1 Speech Analysis Module

The speech analysis module processes user voice input and extracts feature relevant to Apraxia of Speech (AOS). The system uses a transformer-based automatic speech recognition model (e.g., Wav2Vec2 or Whisper) fine-tuned for atypical and disordered speech. These models are well suited to low-resource speech environments and learn robust representations from limited labelled data.
Audio input is analyzed to extract acoustic and phonetic features such as pitch, timing, and spectral characteristics. These features form the foundation for detecting

articulation errors, monitoring progress, and generating real-time feedback during therapy exercises.

4.2 Error Detection Module

Following speech analysis, an error detection module identifies patterns associated with AOS, including mispronunciations, omissions, timing deviations, and prosodic irregularities. This component combines acoustic feature extraction with machine-learning-based classification models to evaluate speech performance at both the phoneme and word levels.

The output of this module supports the generation of performance scores and error profiles that guide therapy adaptation and clinician monitoring. By automating this process, AURA is designed to support more objective and consistent assessment compared to purely perceptual evaluation.

4.3 Adaptive Therapy Module

AURA includes an adaptive therapy engine that personalizes therapy tasks based on user performance. Reinforcement learning techniques are used to dynamically adjust task difficulty, repetition frequency, and feedback timing.

The adaptive engine is designed to:

- maintain user engagement,
- ensure appropriate task difficulty,
- support gradual progression toward independent speech production.

This approach aligns with evidence-based motor learning principles and is intended to support therapy that evolves as users improve.

4.4 Multimodal AAC Module

For users with limited or inconsistent speech, AURA incorporates multimodal Augmentative and Alternative Communication (AAC) support. This module integrates computer vision techniques to analyze visual cues such as lip movements and simple gestures.

Multimodal inputs can trigger speech synthesis or predictive text generation, enabling users to communicate even when verbal output is not reliable. Machine learning techniques have shown promise for improving predictive AAC systems and supporting speech and gesture-based communication workflows [14]. This capability allows AURA to support both speech therapy and everyday communication within a single platform.

In the current prototype, AAC support is implemented as a basic interface component; real-time gesture sensing and clinically validated gesture-to-speech translation are planned extensions.

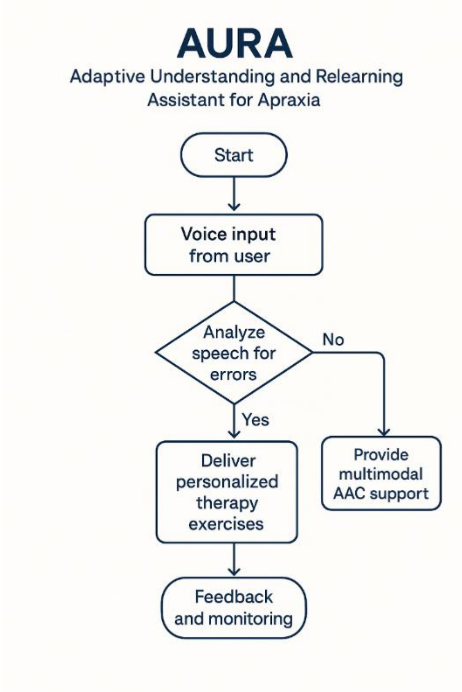

Fig. 2. AURA interaction workflow.

5 Clinical alignment with motor learning guided therapy

5.1 Why Motor Learning matters in AOS therapy

Effective treatment for Apraxia of Speech (AOS) is strongly grounded in the Principles of Motor Learning, which emphasize intensive practice, structured feedback, and gradual progression toward independent speech production [15, 10, 11]. Unlike language disorders that primarily affect comprehension or vocabulary, AOS therapy focuses on rebuilding motor programs for speech through repeated and carefully structured practice.

Motor Learning Guided (MLG) therapy has become an established evidence-based approach for acquired AOS. It emphasizes repeated production attempts, delayed feedback, randomized stimulus presentation, and staged reduction of clinician support [10, 11]. These principles are particularly relevant for technology-assisted therapy, where consistent repetition, objective feedback, and adaptive progression can be delivered at scale.

5.2 Implementation in AURA

The design of AURA's adaptive therapy engine is directly informed by the MLG protocol. The system translates key therapy principles into computational mechanisms:

- Repeated practice: Automated therapy sessions support high-frequency articulation exercises outside clinical settings.
- Delayed and adaptive feedback: AI-controlled feedback timing encourages self-monitoring and independent motor planning.
- Randomized task presentation: Therapy tasks are dynamically generated to promote generalization of speech skills.
- Staged progression: Reinforcement learning is used to gradually reduce system assistance as user performance improves.
- Performance tracking: Automated analytics support baseline assessment and long-term progress monitoring for clinicians.

By embedding established therapy principles into the system design, AURA is intended to complement the work of speech-language pathologists while maintaining alignment with evidence-based clinical practice.

6 Prototype and Evaluation Plan

To assess the feasibility and potential impact of AURA, we present a phased development and evaluation strategy that combines an initial prototype implementation with a roadmap for expert validation and real-world testing.

6.1 Prototype development

An initial research prototype of AURA has been developed to demonstrate the feasibility of the proposed architecture and end-to-end workflow. The prototype integrates speech input, AI-based feedback, and adaptive therapy logic within an interactive web interface.

The current implementation focuses on validating the system pipeline using sample audio inputs and simulated testing scenarios rather than large-scale clinical datasets. This approach enables early-stage evaluation of system behaviour, interaction design, and technical integration while preparing the platform for future data collection and clinical studies.

The prototype demonstrates the feasibility of combining speech analysis, adaptive therapy, and multimodal interaction within a single platform.

6.2 Prototype Implementation

A proof-of-concept implementation of AURA has been developed to demonstrate the practicality of the proposed architecture. The prototype provides an interactive interface for speech input, feedback generation, and basic AAC-style communication support. The implementation is available as an open-source project to support reproducibility and future research development: https://github.com/tayo4christ/aura-apraxia-aac
The repository documents a broader target architecture, installation instructions example evaluation scripts to support reproducibility; however, the current implementation evaluated in this paper focuses on the speech-based AOS pipeline, with gesture-based AAC features included as an exploratory module.
The current prototype focuses on validating the end-to-end workflow and user interaction model rather than full clinical deployment. Example interface screens and interaction workflows are illustrated in Fig. 3 and 4, demonstrating the feasibility of the proposed system in a real application context.

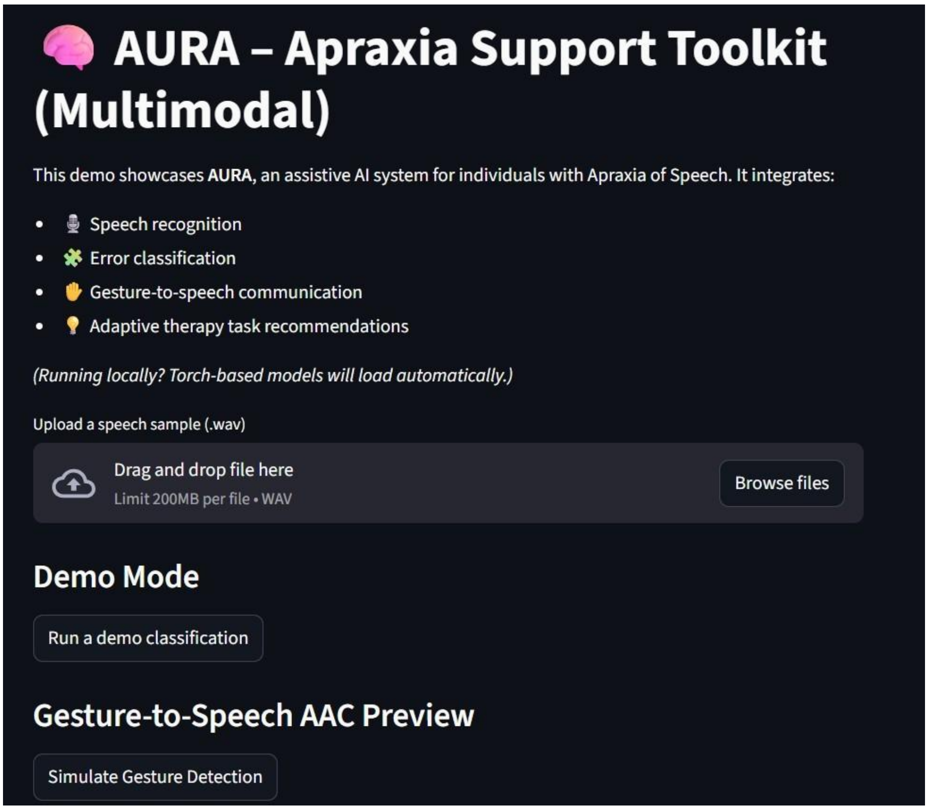

Fig. 3. AURA prototype interface demonstrating speech upload, transcription output, error classification results, and adaptive therapy task recommendation.

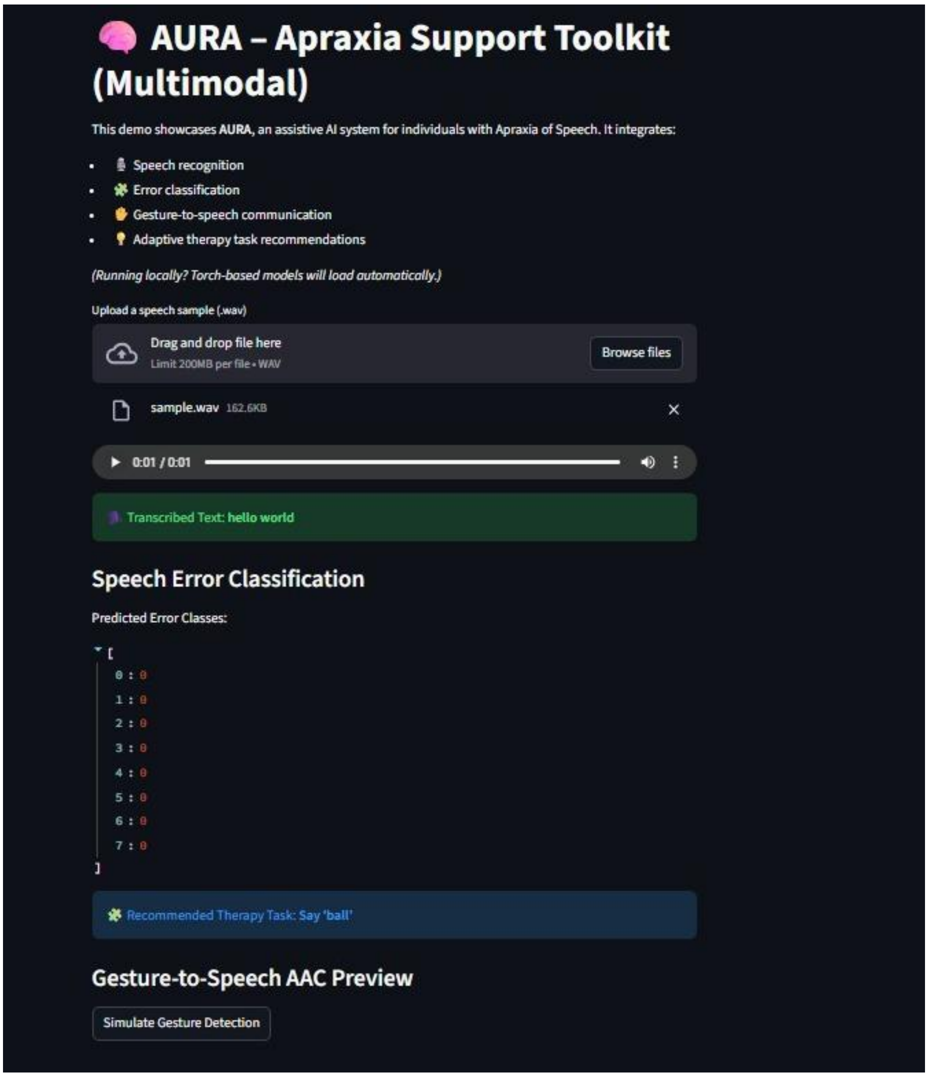

Fig. 4. AURA prototype interface showing the speech-based demo workflow and an exploratory gesture-based AAC module presented as an optional extension.

To clarify the current scope of the research prototype, the following components are implemented and demonstrated in the present system:

Implemented in the current prototype:

- Speech upload and transcription workflow
- Baseline speech error classification demonstration
- Initial adaptive therapy task recommendation logic
- AAC-style interface preview for multimodal communication support

Planned extensions:

- Real-time gesture input and multimodal sensing
- Clinically validated scoring and therapy outcome metrics
- Expansion to larger, ethically sourced speech datasets

The current prototype is implemented as a Streamlit-based web application integrating multiple AI modules through a Python pipeline. The architecture follows the speech-based processing workflow described in Section 4, including speech recognition, error classification, and adaptive therapy logic. The repository also includes system diagrams, documentation, and evaluation scripts to support reproducibility and future development. Detailed setup instructions and module descriptions are provided in the project repository.

6.3 Expert review and iterative design

Following prototype development, the system will undergo expert review by speech-language pathologists and assistive technology specialists. Semi-structured interviews and usability walkthroughs will evaluate:

- relevance and appropriateness of therapy tasks
- clarity of system feedback
- usability of the interface
- clinical acceptability of the workflow

Feedback from domain experts will guide iterative refinement of the system design and ensure alignment with clinical practice.

6.4 Simulated testing

Initial testing will be conducted using simulated user inputs to evaluate core system functionality without involving vulnerable populations in early-stage development. Recorded speech samples will be used to assess speech recognition performance and error detection accuracy, while controlled interaction scenarios will evaluate the adaptive therapy engine.

Performance will be assessed using established quantitative metrics, including:

- Speech recognition performance: Word Error Rate (WER) and Phone Error Rate (PER)
- Error classification performance: Precision, recall, F1-score, and confusion matrix analysis
- System efficiency: Average inference time and response latency during interaction
- Therapy adaptation behaviour: Consistency and stability of task difficulty adjustments in simulated sessions

These metrics will provide an initial technical evaluation of the system prior to expert review and pilot studies.

6.5 Pilot study with real users

Following refinement and ethics approval, a small-scale pilot study will be conducted in collaboration with a speech clinic or academic partner. The study will involve a small cohort of individuals with AOS, their caregivers, and assigned speech-language pathologists.

The pilot will evaluate usability, engagement, and preliminary therapeutic impact over a short-term study period. Both quantitative performance metrics and qualitative user feedback will be collected to assess AURA's potential as a complementary tool for speech therapy.

7 Challenges and Ethical Considerations

While AURA presents a promising approach to AI-assisted speech therapy, several technical, practical, and ethical challenges must be addressed to ensure safe and equitable deployment.

7.1 Data Availability and Model Reliability

A major challenge in developing AI systems for Apraxia of Speech (AOS) is the limited availability of large, high-quality datasets. AOS speech varies significantly across individuals, making it difficult to train models that generalize well across age groups, severity levels, and linguistic backgrounds. Insufficient or unrepresentative data may lead to reduced model accuracy or biased performance. Future work must therefore prioritize the collection of diverse and ethically sourced datasets.

These challenges are widely recognized in recent work on AI-based diagnosis of speech and language disorders [17].

Recent reviews highlight data bias, model reliability, and clinical validation as key challenges for AI deployment in speech-language pathology [16, 9]

7.2 Bias, Accessibility and Inclusivity

Speech recognition systems are often trained on fluent adult speech and may perform poorly on disordered or non-standard speech patterns. Ensuring fairness across different accents, languages, and user groups is essential. In addition, accessibility considerations such as device availability, digital literacy, and language support must be addressed to avoid widening existing healthcare inequalities.

7.3 Privacy and Data protection

AURA relies on sensitive voice and behavioural data, particularly when used by children or vulnerable populations. Strong data governance is required to ensure informed consent, secure storage, anonymisation, and compliance with data protection

regulations such as GDPR. Users must retain control over how their data is collected, stored, and shared.
To support privacy-preserving deployment, the prototype is designed to allow local execution on user devices where possible, reducing the need for cloud-based data transmission. Audio recordings are not intended to be stored by default, and any future data collection will follow explicit consent procedures with clear options for withdrawal. Planned deployments will incorporate secure data handling practices, including encrypted storage and controlled access to sensitive data. These measures aim to ensure that future clinical studies and real-world deployments prioritize user privacy and data protection.
These concerns reflect broader discussions around the ethical deployment of AI in speech-language pathology and the need for safeguards in real-world clinical use [16, 9].

7.4 Clinical Oversight and responsible use

AI systems should complement not replace professional speech-language therapy. Without appropriate clinical oversight, there is a risk of over-reliance on automated feedback or misinterpretation of results. AURA is therefore designed as a supportive tool that enables clinicians, caregivers, and users to collaborate rather than substitute professional care.
Addressing these challenges is essential for developing trustworthy and clinically responsible AI systems for speech therapy.
In addition, safeguards are required to reduce the risk of reinforcing incorrect speech patterns through automated feedback. AURA is not intended to function as a diagnostic or standalone therapeutic tool, and all therapy goals are expected to be defined in collaboration with qualified speech-language pathologists. The system is designed to provide assistive and supportive feedback rather than definitive clinical judgement. Where model confidence is low, AURA defaults to neutral prompts and flags samples for clinician review rather than issuing corrective feedback. This conservative feedback strategy helps ensure that AI-generated guidance complements professional oversight and reduces the risk of inappropriate intervention.

8 Conclusion and Future work

This paper presented AURA, a multimodal AI framework designed to support speech therapy, monitoring, and communication for individuals with Apraxia of Speech. By integrating speech analysis, adaptive learning, and multimodal interaction, the system aims to extend therapy beyond clinical environments and has the potential to provide more accessible, personalized, and data-driven support.
AURA contributes a unified architecture that combines AI-driven speech analysis, reinforcement learning based therapy adaptation, and multimodal AAC support within a single platform. The proposed development and evaluation roadmap outline a realistic pathway toward expert validation and pilot testing with real users.

Future work will focus on extending the current prototype, collecting ethically sourced AOS speech datasets, and conducting pilot studies to evaluate usability and therapeutic impact. Long-term research will explore multilingual support, integration with clinical workflows, and large-scale clinical validation.

Advances in AI present an opportunity to transform how speech disorders are supported. Systems such as AURA have the potential to complement clinical practice and improve access to therapy for individuals who may otherwise face significant barriers to care, while supporting future interdisciplinary collaboration between AI researchers and speech-language pathology professionals.

The open-source release of the AURA prototype aims to support reproducibility and encourage collaboration between AI researchers and speech-language pathology professionals.

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