Impact of AI-Powered Speech-to-Text and Gesture Recognition Tools on Improving Accessibility for Non-Verbal Autistic Individuals

Esther Oyindamola Oyanibi[1] , Yusuff Bolaji Ajegbile[2,]Adedoluwa Adeniyi[3] , Gbenga Gbaja[4 ,] Akinode John Lekan[5]

[1]SC Johnson College of Business, Cornell University Ithaca, New York, USA

[2]Department of Health and Human Kinetic, University of Ibadan, Nigeria

[3]Leeds City University Ibadan,College of Applied Science,Department of Software Engineering

[4]Humber College,Canada.

[5]Computer Scienc Department ,Feferal Polythechnic Ilaro,Nigeria.

Abstract

Communication barriers represent a significant challenge for individuals on the Autism Spectrum, particularly those who are non-verbal or minimally verbal. These barriers restrict opportunities for meaningful social participation, personal expression, and autonomy across educational, therapeutic, and community settings. This paper explores the transformative potential of artificial intelligence (AI)-powered assistive technologies, specifically advanced speech-to-text and gesture-recognition systems, as sophisticated augmentative and alternative communication (AAC) tools. The study argues that integrating these multimodal AI interfaces can significantly enhance accessibility and independence by providing adaptive, real-time mechanisms for converting non-verbal and minimally verbal intent into clear, understandable output. Theoretically grounded in the human activity assistive technology model and the neurodiversity perspective, this paper examines how user-centered AI development can overcome limitations inherent in traditional AAC. Critical analysis also addresses pressing ethical concerns, including data privacy, interpretive reliability, and the mitigation of algorithmic bias, to ensure that these powerful tools are developed and deployed responsibly. Ultimately, the paper concludes that ethically grounded, highly personalized AI systems are vital catalysts for human empowerment and social justice, promoting equitable participation for non-verbal autistic individuals in society.

Introduction

Individuals diagnosed with Autism Spectrum Disorder (ASD) frequently encounter significant challenges related to social interaction and communication, which are core diagnostic characteristics (Lord et al., 2018; Zisk & Dalton, 2019). Critically, a substantial proportion of this population faces severe communication deficits, with approximately half of autistic individuals failing to attain fluent speech and a quarter lacking functional speech (Zisk & Dalton, 2019). This population, often described as non-verbal or minimally verbal, relies heavily on Augmentative and Alternative

Communication (AAC) systems to bridge communication gaps (Holyfield et al., 2017; Mirenda, 2003). While traditional AAC methods, such as Picture Exchange Communication Systems (PECS) or manual communication boards, offer foundational support, they often struggle to provide the adaptability, personalization, and responsiveness required for fluent, context-aware interaction (Donato & Arthur-Kelly, 2018; Trembath & Erickson, 2016).

The inability to communicate efficiently significantly impacts quality of life, access to education, therapeutic outcomes, and participation in community life (Cummins et al., 2020; Nicolaidis et al., 2015; Zisk & Dalton, 2019). Communication barriers faced by autistic adults can severely impact relationships, employment prospects, and health interactions (de Marchena et al., 2024; Szechy et al., 2024; Nicolaidis et al., 2015). Addressing these profound challenges necessitates innovative technological solutions that leverage human-computer interaction to create personalized, adaptable tools (Kooli & Chakraoui, 2024; Wobbrock, 2017).

The rapid intersection of Artificial Intelligence (AI) and human-computer interaction is fostering considerable innovation in accessibility technology, offering intuitive and personalized solutions tailored to users' specific needs (Almufareh et al., 2024; Kooli & Chakraoui, 2024; Zdravkova et al., 2022). AI has the capability to enhance AAC systems by integrating predictive text, advanced speech recognition, and sophisticated gesture interpretation, leading to systems that are more responsive and aligned with individual user behaviours (Omoyemi, 2024; Sennott et al., 2019).

AI-driven interfaces, particularly those utilizing Natural Language Processing (NLP) and speech recognition, are crucial in advancing inclusive practices for individuals with cognitive and physical disabilities (Barua et al., 2022; Kooli & Chakraoui, 2024). Speech recognition technology converts spoken input directly into text in real-time (Kooli & Chakraoui, 2024), a capability that has proven effective in empowering young writers with special educational needs (Kambouri et al., 2023). For individuals who may have distorted or non-standard speech patterns, advanced Automatic Speech Recognition (ASR) systems are necessary, although existing commercial ASR often struggles with speech distortions (Radford et al., 2023; Sanguedolce et al., 2023).

Complementing speech recognition, AI-powered gesture recognition systems are revolutionizing non-verbal communication. Gesture recognition, enabled by computer vision or wearable sensors, offers a vital channel for expression that bypasses traditional verbal barriers (Oudah et al., 2020; Omoyemi, 2024). For autistic individuals, who often use fewer communicative gestures than typically developing peers (Ullah et al., 2021), systems capable of recognizing complex gestures, including sign language, are essential accessibility tools (Ullah et al., 2023). For instance, vision-based approaches use deep learning to recognize hand gestures, converting them into text or speech output (Sharma & Singh, 2021). The feasibility of using wearable-sensor-based platforms to accurately recognize 24 daily gestures performed by autistic children has been demonstrated with high accuracy (over 91%) (Siddiqui et al., 2021; Ullah et al., 2023).

The most promising area lies in multimodal systems that combine different input mechanisms. Future advancements promise to enable students with physical disabilities to interact with content using spoken commands or gestures (Almufareh et al., 2024; Dai & Ke, 2022). These integrated systems allow individuals with limited mobility to

navigate digital platforms and engage with materials effectively using simple gestures or voice commands, enhancing participation and inclusivity (Kooli & Chakraoui, 2024). This multi-modal approach helps ensure that AAC is truly augmentative, supporting a diversified set of interactions (Ibrahim et al., 2020). To be effective, assistive AI must prioritize usability and align with the lived experiences of autistic individuals. Traditional AAC devices sometimes detrimentally obscure intuitive, non-verbal, and culturally significant communication pathways (Lau et al., 2024). Instead of replacing the user's natural communication methods, effective AAC should scaffold and augment pre-existing communication abilities (Lau et al., 2024). When technology attempts to generate synthetic dialogue, it can potentially replace the minimally verbal user's natural voice, raising concerns about agency (Lau et al., 2024; Veaux et al., 2013).

A key challenge in AI implementation is ensuring accuracy and interpretive reliability. Studies highlight limitations related to the accuracy of AI algorithms and difficulties in interpreting complex text or certain multimedia formats (Kooli & Chakraoui, 2024). For image-based AAC features, misclassification of objects by AI-enhanced systems is a recognized problem, necessitating careful user validation (Lau et al., 2024).

Usability studies on technologies like voice assistants highlight significant barriers, even for neurodiverse individuals, including cognitive load during use, difficulties with speech interpretation, and a lack of nonverbal control mechanisms (Esquivel et al., 2024). AI tools must adapt to users who may struggle with motor skills or fine motor control (Omoyemi, 2024).

Furthermore, the design must be sensitive to the sensory profile common in ASD (Robertson & Baron-Cohen, 2017). Research suggests that audio-visual integration in speech may be atypical in autism (Smith & Bennetto, 2007; Stevenson et al., 2018; Turi et al., 2016). Autistic individuals exhibit differences in multisensory processing, which may improve by early adulthood, suggesting that complex visual information, such as iconic gestures, should be carefully integrated into technology design (Mazzini et al., 2024). Systems must accommodate customizable sensory settings to reduce or eliminate overwhelming stimuli, supporting concentration, motivation, and trust (Fletcher-Watson & Bird, 2020).

In summary, the implementation of AI in AAC systems demands a shift toward inclusive, user-centered assistive AI that respects individual preferences, optimizes multimodal input, maintains stringent accuracy, and proactively mitigates sensory and usability challenges to truly empower non-verbal autistic individuals.

Theoretical Frameworks

The development and deployment of AI-powered AAC tools are best understood through two complementary theoretical lenses: the Human Activity Assistive Technology (HAAT) model and the social model of disability combined with the neurodiversity paradigm.

The Human Activity Assistive Technology (HAAT) model provides a holistic framework for considering the interaction between four components: the Human (the user's physical, cognitive, emotional, and expertise capabilities), the Activity (self-care, productivity, leisure), the Context (physical, cultural, institutional), and the Assistive

Technology (interfaces, processor, output) (Cook & Polgar, 2015; Elsahar et al., 2019). This model mandates that technology development should prioritize the activities and abilities of the user, ensuring that the final solution optimizes communication based on individual needs and the environment of use (Elsahar et al., 2019). Applying HAAT to non-verbal autistic individuals means recognizing that AAC technology must be personalized, adaptable, and contextually aware, rather than relying on standardized solutions (Patel & Radhakrishnan, 2007).

The integration of the social model of disability (Shakespeare et al., 2006) and the neurodiversity paradigm (Kapp et al., 2013) is also critical. These perspectives emphasize that disability is often caused by unaccommodating environments and social structures, rather than solely by individual deficits (Wobbrock, 2017). For autistic communication, this implies accepting and accommodating communication differences, viewing them not necessarily as deficits (de Marchena et al., 2024). Therefore, AI-driven AAC tools must be designed to enhance user autonomy, equity, and participation (Kooli & Chakraoui, 2024), centering the needs of the individual in the design, rather than seeking to normalize communication differences (Lau et al., 2024). AAC should serve as an empowering tool to encourage users to pursue independence and life-affirming activities (Dietz et al., 2020).

Review of Related Works

Yu et al.(2024) introduced QuickPic AAC, an AI-based application designed to enable the just-in-time generation of topic-specific communication displays for individuals who are minimally speaking . This work highlights how AI can accelerate AAC usability by making communication displays contextually relevant and rapidly accessible, directly addressing the speed and efficiency limitations of traditional symbol navigation .

 Cairney et al(2024) conducted a norming study investigating the interpretations of meaningful and ambiguous hand gestures in autistic and non-autistic adults . This foundational research is crucial for developing accurate AI gesture recognition algorithms, as it reveals nuances in how hand movements are produced and perceived within the autistic population .

Mazzini, Seijdel, and Drijvers (2024) published a short report demonstrating that autistic individuals benefit from gestures during degraded speech comprehension . This finding suggests that gestures provide complementary visual information, alleviating the demand for simultaneous cross-modal processing, reinforcing the value of multimodal AI interfaces that combine visual (gesture) and audio (speech/text output) modalities.

Esquivel et al., 2024) reviewed the utilization of voice assistants among the disability community for independent living. The study identified persistent barriers, including challenges related to speech interpretation and the lack of nonverbal control, even in general voice assistant usage by neurodiverse individuals. This reinforces the urgent need for AI-driven AAC systems to explicitly integrate nonverbal input like gesture recognition to overcome these barriers.

Díaz and Nussbaum (2024) explored the application of AI for teaching and learning in schools, stressing the necessity of "pedagogical intelligence" . This work advocates for thoughtful integration of AI that goes beyond mere technological novelty, ensuring that AI-assisted tools meaningfully enhance pedagogical practices for students with special needs.

Ibrahim, Clarke, Vasalou, and Bezemer (2024) examined the role of common ground in AAC, focusing on how children who use AAC and teaching staff shape interaction in the multimodal classroom. Their findings highlight the importance of designing AAC that facilitates relational technologies and communal engagement, aligning with principles of user-centered and interdependent design .

Szechy, Turk, and O'Donnell (2024) discussed employment challenges for autistic adults, emphasizing the role of the "Double Empathy Problem" in workplace perceptions and communication failures . This context underscores that effective AI-AAC tools are not just technological fixes but essential accommodations needed to ensure successful social outcomes and parity in demanding environments like the workplace .

Key Ethical Dimensions

The implementation of AI-powered communication tools necessitates rigorous ethical consideration across several dimensions to ensure responsible and empowering technology development.

Privacy and Data Security : A primary concern is the privacy and security of sensitive personal and educational data, especially when AI systems interact with student progress information and communications (Kooli & Chakraoui, 2024). Because AAC devices handle deeply personal data pertaining to communication intent and behavioral patterns, robust data protection measures are paramount (Hamidi et al., 2018; Kooli, 2023). Users often worry about their personal data being used without consent, data breaches, and general personal data processing (Valencia et al., 2020; Lau et al., 2024). Establishing harmonized standards for ethical AI in education is crucial for mitigating these risks (Kooli & Chakraoui, 2024).

Accuracy and Interpretive Reliability: The effectiveness and trustworthiness of AI-AAC hinges on its accuracy. Failures in accuracy can create new barriers, especially when sophisticated deep learning algorithms misinterpret complex text or misclassify physical inputs like gestures (Kooli & Chakraoui, 2024; Lau et al., 2024). Interpreting non-verbal input reliably requires minimizing algorithmic errors, particularly when translating gestures or atypical speech patterns (Youssef et al., 2023). Case studies have shown that AI-enhanced AAC apps sometimes fail to accurately classify photographed objects, demonstrating a critical area for improvement in interpretive reliability (Lau et al., 2024).

Autonomy and Potential Over-reliance: Ethical AI must support user autonomy, respecting the individual's conversational agency and preferences (Sennott et al., 2019; Valencia et al., 2020). However, caution must be exercised regarding the risk of over-reliance on AI-driven assistive technologies (Kooli & Chakraoui, 2024). Compulsive engagement with AI systems risks diminishing critical thinking, creative independence, and social withdrawal, sometimes termed Generative AI Addiction Syndrome (GAID) (Kooli & Chakraoui, 2024). Developers must balance AI capabilities with human interaction and ensure that the technology augments, rather than detrimentally replaces, natural communication methods (Ibrahim et al., 2020; Lau et al., 2024).

Algorithmic Bias: A persistent challenge in AI development is algorithmic bias, particularly against marginalized groups (Guo et al., 2020; Lyerly, 2023). Bias can manifest when AI models are trained on datasets that fail to represent the diverse communication styles, expressions, and needs of autistic individuals (Kooli & Chakraoui, 2024). Studies have shown, for example, that AI language models sometimes exhibit bias against individuals with disabilities (Lyerly, 2023). In visual AI, models may depict disabled people primarily through the lens of their limitations (Mack et al., 2024; Urbina et al., 2024). Addressing these biases requires centering the needs of disabled individuals in the design, deployment, and evaluation processes (Kooli & Chakraoui, 2024).

Contexts of Use

AI-powered AAC tools offer critical support across multiple environmental contexts, moving beyond specialized settings to enhance daily life and community integration.

Educational Settings

In education, AI tools significantly contribute to inclusive learning environments by supporting students with cognitive and language disabilities (Kooli & Chakraoui, 2024; Zdravkova et al., 2022). Natural Language Processing (NLP) interfaces assist students with Autism Spectrum Disorder (ASD) by simplifying language, offering contextual definitions, and providing personalized support (Kooli & Chakraoui, 2024; Jaliaawala & Khan, 2020). Speech-to-text conversion aids young people with Special Educational Needs (SEND) in writing tasks, fostering greater independence in literacy (Kambouri et al., 2023). AI-enabled voice command interfaces and gesture recognition systems allow students with physical challenges to navigate digital content and participate in virtual discussions seamlessly (Kooli & Chakraoui, 2024).

Therapeutic and Clinical Settings

AI and robotics play an increasing role in therapeutic interventions for children with ASD. Socially Assistive Robots (SARs) are programmed to recognize and respond to human emotions, providing a safe, non-judgmental interactive space for therapy related to social interaction and emotion recognition (Nadeem et al., 2024; Rashidan et al., 2021). Deep learning approaches combined with human action recognition algorithms are used with robots to enhance skills like clapping imitation in children with ASD (Alnafjan et al., 2024; Santos et al., 2021). The use of these structured, technological tools can provide tailored support that is crucial for cognitive processing conditions associated with autism (Kooli & Chakraoui, 2024).

Home and Community Settings

AI tools enhance independence and participation in daily life activities. Voice assistant technology is utilized by individuals with disabilities for interface control, reminders, and environmental control (Esquivel et al., 2024). However, access barriers, such as lack of infrastructure and limited internet connectivity, can hinder equitable deployment of these tools in underserved settings (Kooli & Chakraoui, 2024). In the community, where communication often involves strangers and stressful contexts, AI-AAC devices must facilitate seamless interaction (Lau et al., 2024). Wearable AAC displays, for instance, can discreetly indicate an individual's invisible disability and serve as a non-verbal communication prop, maximizing social engagement without the stigma associated with prominent tablet-based AAC devices (Lau et al., 2024).

AI-Powered Text-to-Speech

Text-to-speech (TTS) synthesis, when integrated with AI-powered gesture recognition, forms a robust system for gesture-to-speech synthesis, supporting adaptive, real-time communication for non-verbal individuals.

This process involves using computer vision or wearable sensors to capture non-verbal movements, classify them using sophisticated deep learning algorithms, and instantly convert the resulting information into spoken language (Deng et al., 2023; Omoyemi, 2024; Ullah et al., 2023). Deep learning models are capable of processing video data or sensor input (accelerometer and gyroscope data) to recognize and classify a diverse set of gestures, including sign language signs (Siddiqui et al., 2021; Ullah et al., 2023). For example, sensor-based Internet of Things (IoT) platforms placed on the body can achieve recognition accuracies exceeding 96% for complex gestures, significantly improving the recognition rate compared to methods relying solely on general hand movements (Ullah et al., 2023).

The resultant text is then vocalized using synthesized speech. Unlike digitized speech (pre-stored recordings), synthesized speech is generated dynamically via mathematical algorithms, providing flexibility and enabling users to create output messages in real-time (Elsahar et al., 2019). This TTS capability is vital for enabling free personal expression and allowing for the potential of personalized synthesized voices, promoting user identity (Veaux et al., 2013).

For effective real-time communication, the system must operate with minimal latency (Lau et al., 2024). Multimodal input, combining acoustic data, visual data (e.g., lip movements), and gesture input, is necessary to support robust communication,

especially when processing degraded or dysphonic speech (Ballard et al., 2019; Sanguedolce et al., 2023; Rohlfing et al., 2021). When integrated seamlessly, gesture-to-speech synthesis translates tacit or difficult-to-interpret non-verbal cues into audible language, allowing non-verbal autistic individuals to interact with greater speed and clarity in complex social exchanges.

Policy and Design Implications

Achieving equitable and effective deployment of AI-AAC systems demands strategic policy and design considerations that prioritize neurodiversity and user safety.

Participatory Design and Personalization

Effective technology must be developed through direct engagement with end-users and stakeholders, aligning with participatory design principles (Lau et al., 2024; Tönsing et al., 2022). Accessible co-design methodologies must be employed to overcome barriers associated with communication and cognitive fatigue often experienced by individuals with complex communication needs (Lau et al., 2024; Nicolaidis et al., 2020). This involves reducing reliance on language-based processes and using tangible prototyping methods (Lau et al., 2024). The goal is to maximize personalization, ensuring that AI algorithms and feature sets are highly adaptive to the user's specific learning styles, preferences, and existing communication abilities (Barua et al., 2022; Kooli & Chakraoui, 2024).

Neurodiversity-Informed Evaluation

Policy frameworks must mandate neurodiversity-informed evaluation protocols. Researchers should conduct longitudinal studies to assess the sustained impact of AI on the psychological well-being, academic achievement, and digital literacy of individuals with disabilities (Kooli & Chakraoui, 2024). Comparative research across diverse socio-economic and cultural contexts is necessary to ensure global inclusivity and prevent systemic disparities from being replicated or exacerbated by technological solutions (Kooli & Chakraoui, 2024). Evaluation should specifically gauge user perceptions and agency to confirm that the technology is truly empowering rather than isolating (Kooli & Chakraoui, 2024).

Privacy Safeguards and Ethical Standards

International collaboration is essential to develop harmonized standards for ethical AI in education and therapy (Kooli & Chakraoui, 2024). Policymakers must establish robust privacy safeguards and clear regulatory frameworks for data governance, especially regarding sensitive user information collected by adaptive learning systems (Kooli & Chakraoui, 2024; Kooli, 2023). Furthermore, policy and pedagogical guidelines are needed to address behavioral concerns like potential over-reliance on AI, requiring educator training and digital literacy programs to promote mindful use (Kooli & Chakraoui, 2024). Design must integrate "human-centered policies and thoughtful implementation" to mitigate algorithmic bias and infrastructural inequities that hinder equitable access (Kooli & Chakraoui, 2024; Guo et al., 2020).

Conclusion

AI-driven assistive technologies, specifically AI-powered speech-to-text and gesture recognition systems, offer a transformative promise for improving accessibility and autonomy for non-verbal autistic individuals. By converting non-verbal and minimally verbal input into clear, synthesized speech, these ethically grounded AI tools enhance accessibility by providing adaptive, real-time means of self-expression and participation (Omoyemi, 2024; Ullah et al., 2023). They facilitate meaningful engagement in educational, therapeutic, and community settings, often overcoming the limitations of traditional AAC devices by offering personalized, multimodal interfaces (Kooli & Chakraoui, 2024; Zdravkova et al., 2022).

Notably, enhancing communication leads directly to increased autonomy, supporting improved outcomes related to social relationships and purpose across all levels of need (de Marchena et al., 2024). However, realizing this potential requires vigilant adherence to ethical principles, including the implementation of robust privacy safeguards, the mitigation of algorithmic bias through inclusive design, and continuous evaluation informed by the principles of neurodiversity (Kooli & Chakraoui, 2024; Lau et al., 2024). By centering the needs of autistic users in the design, deployment, and evaluation of these systems, AI serves as a powerful catalyst for human empowerment and social justice, ensuring true inclusion (Kooli & Chakraoui, 2024).

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