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A Review of The Use of Artificial Intelligence to Enhance the Practice of Speech Language Pathology

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ABSTRACT

Artificial intelligence (AI) is a highly advanced and versatile technology that has found a place in many fields – academic, professional, and personal. This systematic review focuses on the use of AI to enhance the field of speech-language pathology (SLP). Via the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) method, 63 sources have been identified, analyzed, and accepted to determine current uses of AI in the field of SLP. The impact of AI on the field of SLP was considered in relation to the phases of clinical service delivery: screening, assessment, diagnosis, and intervention. The review specifically examined populations of individuals with the following diseases or disorders: autism spectrum disorder, dysarthria, developmental language disorder, Parkinson's Disease, Alzheimer's Disease, dysphagia, stroke, literacy impairments, and hearing loss. Within each phase of service delivery and among each clinical population, AI served to enhance the accuracy and efficiency of speech-language pathologists' practice. As greater consideration is placed on the perception of AI in service delivery and further experimentation with larger sample sizes is conducted, AI has the potential to enhance the field of SLP.

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INTRODUCTION

As this thesis is written in February of 2023, literature cannot keep up with the advancements being made in technology. A literature review was completed in November of 2022, and a mere three months later it is not as comprehensive as it once was. Today, headlines swirl in the media about a new, intelligent software known as ChatGPT.

> *"ChatGPT is a large language model that has been trained on a massive amount of text data using a technique called 'deep learning'. It uses a neural network called a 'transformer' to process and analyze sequences of words in natural language. When you ask a question or make a statement to ChatGPT, it uses its understanding of language and the patterns it has learned from the training data to generate a response. This allows ChatGPT to respond to questions, generate text, and engage in conversations in a way that sounds like it was written by a human. Overall, ChatGPT is a powerful tool that can help people find answers to their questions, learn new things, and even engage in interesting conversations. While it's not perfect and can sometimes make mistakes, it's a remarkable example of how artificial intelligence can be used to make our lives easier and more enjoyable."*

The above paragraph was entirely written by ChatGPT from the prompt, "explain what ChatGPT is and how it works." Where an individual would typically have to conduct their own research on the software and mentally digest how it works prior to crafting an original paragraph (perhaps a 20-30 minute process), this took approximately five seconds. In the same way, the software could have been prompted to write 10,000 words and done so in a matter of minutes, as compared to hours for a human being. This groundbreaking technology has the potential to change education and a number of occupational fields, including healthcare. To reaffirm a point made by ChatGPT above, this software is just one example of artificial intelligence's use and accessibility.

Stanford professor John McCarthy first defined artificial intelligence as, "the science and engineering of making intelligent machines" (Manning, 2020). Artificial intelligence (AI) tends to be an ambiguous term that lacks an accepted definition. Today, AI is generally thought of as a field of computer science which creates machines that perform tasks with human-like intelligence.

An important classification to be made is how “intelligence” – another vague term – is defined. Merriam Webster defines intelligence as, “the ability to apply knowledge to manipulate one’s environment or to think abstractly as measured by objective criteria (such as tests)” (*Merriam Webster’s*, 2023). Note, intelligence is not knowledge capacity, efficiency, or accuracy. Rather, intelligence is a human complexity that includes abstract thought, original ideas, emotional capacity, and the ability to acquire and adapt to knowledge from external environments.

Following this, an AI machine is not intelligent because of its speed or random-access-memory (RAM). AI is intelligent because it is designed to extract pre-established human information; its “intelligence” *mirrors* human intelligence. AI’s capabilities might be more efficient and accurate than humans (humans are inherently flawed and cannot perfectly follow algorithms), but its entire knowledge base comes from human intelligence. The definition of AI will become more specific and complex as technology continues to advance, but human-designed machines will not surpass the capacity of human intelligence until AI possesses a consciousness and awareness that surpasses humans. Rather, developers’ imminent hope is for AI to reach a level of intelligence comparable to that of humans.

West (2018) recognizes three qualities that are foundational to AI: intentionality, intelligence, and adaptability. Unlike passive machines that perform a finite number of programmed tasks, AI machines are designed to make intentional decisions based on a variety of stimuli. AI programmers design codes to be broad and inclusive of all information; AI designed with bias will not be representative of the true corpus of intelligence. Lastly, effective AI is capable of adjusting to changing conditions and adapting outcomes accordingly (West, 2018). The complexities of AI are not simply defined by these three qualities; however, they are comprehensible factors that distinguish AI from other non-intelligent advanced technology systems.

Spanning across fields, the potential of AI is endless. In the field of speech-language pathology (SLP) specifically, AI impacts the administration of therapeutic processes and has changed the dynamic of traditional therapy in many cases. AI is used to enhance the lives of patients and clinicians through utilization in the screening, assessment, diagnosis, and intervention phases.

The purpose of the systematic review is to assess the current situation of AI in the world of SLP. The review defines and provides examples of different forms of AI (i.e, automatic speech recognition, voice assistant, etc.) and shows its versatility across demographics of the field. The review delves into the ways through which AI technology may enhance SLP sessions directly and indirectly, as well as the functional, daily benefits of AI for people with speech-language disorders. Speech and language disorders are complex and diverse, creating obstacles to the use of technology. Nonetheless, AI is a promising tool in the field of speech-language pathology, and the review explores how far this technology can realistically advance.

METHOD

To best analyze the impact of AI in the field of SLP, I reviewed a substantial corpus of sources from databases utilizing the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA). The PRISMA Flow Chart in Figure 1 organizes my method of identifying sources. My search utilized the Penn State University Library, ProQuest, PubMed, an advanced Google search, and field experts. My search terms included, "'speech-language therapy' and 'artificial intelligence'", "'speech-language pathology' and 'artificial intelligence'", and "'vocal biomarkers' and 'speech-language pathology'". Initial searches with the targeted terms yielded a total of 359 sources. After initial screening, 25 duplicates were identified and removed. The remaining 334 sources were screened by titles. 173 sources were then excluded for irrelevance. The remaining 161 sources were screened by abstracts, and 52 were excluded for irrelevance and lack of mention of desired search terms. 109 sources were retrieved for a full-text analysis of eligibility based upon inclusion and exclusion criteria.

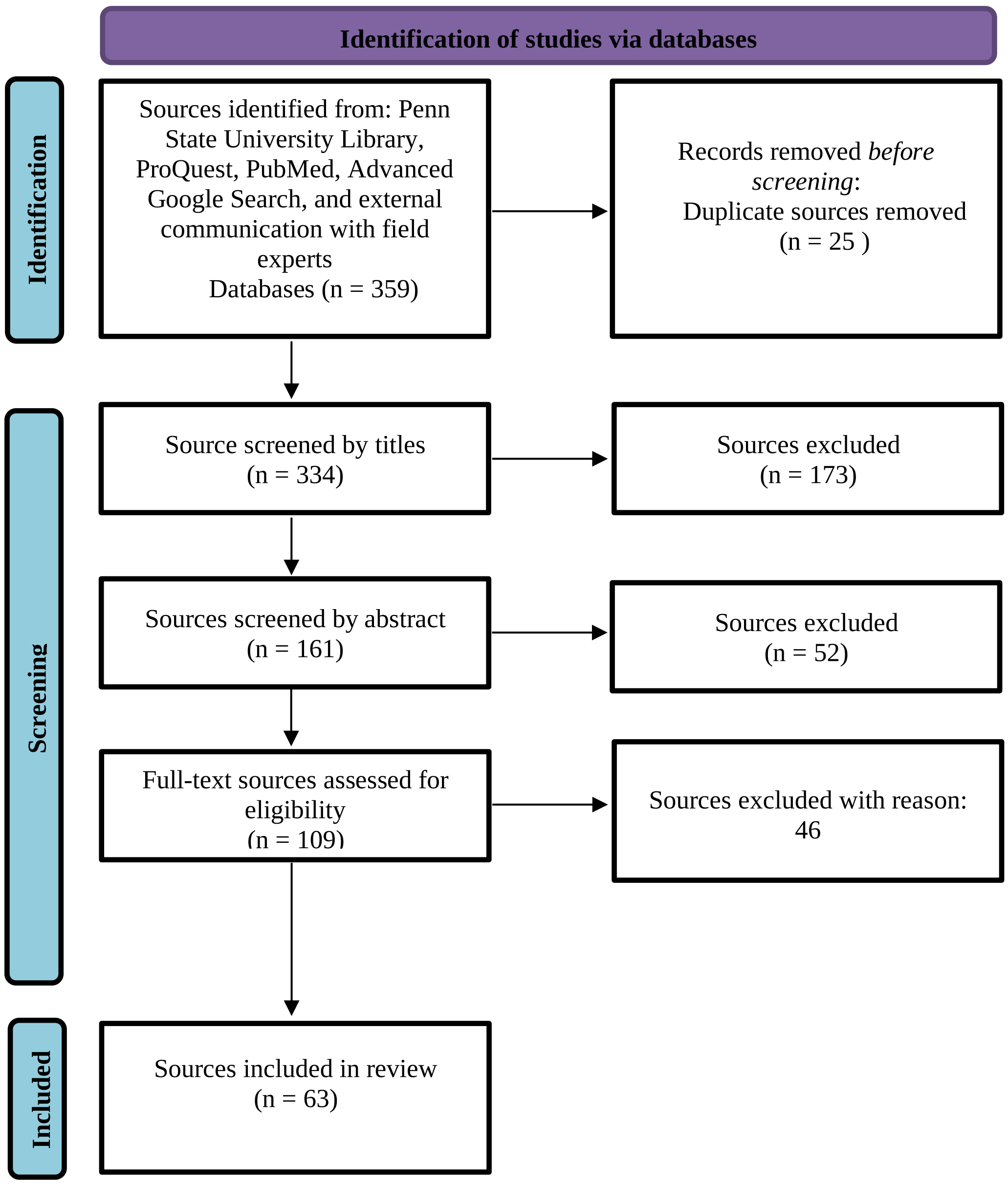
For a source to be included, a form of AI within the field of SLP must be utilized. The form of AI included in the review was automatic speech recognition (or voice assistant), virtual reality, technological applications, robots, serious games, emotional and facial recognition, or vocal biomarker and predictive algorithms. Additionally, the purpose of the AI being employed had to fall into one of the following categories of diseases and disorders: autism spectrum disorder, dysarthria, developmental language disorder, Parkinson's Disease, Alzheimer's Disease, dysphagia, stroke, literacy impairments, or hearing loss. The identified categories are among the most commonly-treated populations of speech-language pathologists and have subsequently become the predominant populations included in initial AI research and implementation.

If a source did not utilize one of the previously mentioned forms of AI or did not impact one of the mentioned categories of diseases and disorders, then the source was excluded from the review. Sources that were not related to the field of SLP or did not primarily employ the use of AI were excluded. Furthermore, sources that were original studies of since-revisited studies were excluded – rather, the more recent study was included. Finally, sources that were either too lengthy in nature or primarily focused on technical AI algorithms as opposed to clinical applications were excluded from the review.

On the basis of the defined inclusions and exclusions, 46 sources were excluded, and 63 sources remained. This review definitively includes 63 sources that discuss AI in relation to the field of SLP. I have thoroughly analyzed the 63 sources and compared the various uses of AI in relation to parts of clinical service delivery. This review was performed under a time constraint, and the corpus of sources is therefore not comprehensive of all literature available on the subject. However, the review is a representation of the current status of AI in SLP, as well as the future potential of AI in SLP.

Figure 1

PRISMA Flow Chart



Note: Adapted from: Page et al. 2021

RESULTS AND DISCUSSION

Types of Artificial Intelligence

Automatic Speech Recognition

Automatic speech recognition (ASR) is a software's ability to translate human speech into a written text format (IBM, n.d.). Other names used to refer to ASR include "speech-to-text", "speech recognition", and "computer recognition." Put simply, the algorithm receives speech input, performs feature extraction, decodes the content, and transcribes to a written form. ASR has been around for many years; however, technological advancements involving AI allows for more versatile uses. Users have grown very accustomed to and dependent upon smartphones embedded with artificially intelligent ASR. When users prompt Google, Apple, and Amazon devices with, "Okay Google…," "Hey Siri…," or, "Alexa…," ASR is activated and translates human speech in real-time. Beyond the many everyday uses, ASR serves functional purposes in the healthcare world as well.

Voice Assistant

Voice Assistant (VA) is slightly different from ASR, but uses overlapping technology. For this reason, ASR and VA will be grouped into the same section; however, the terms will not be used interchangeably. VA is a software's ability to recognize a specific voice, but the software might also translate the speech to a written text format using ASR. However, in order to initially prompt a VA, the user's voice must be recognizable to the device. This differentiation can be best explained by Apple's Siri only responding to the device owner. If Siri were not powered by VA, then every person's Siri would activate given a prompt from anyone; one person saying, "Hey Siri," could light up every iPhone in the room. Instead, the device owner's Siri recognizes the owner's specific voice and is programmed to respond only to the owner. VA embedded with ASR is useful in SLP for individuals that communicate with devices.

Virtual Reality

Virtual Reality (VR) is a computer-simulated, immersive experience that builds on standard 3D technology. VR is also referred to as a Virtual Training Environment (VTE) in some cases. Users can move throughout an audio-visual virtual world that closely resembles real-life scenarios and settings. While not all VR uses AI, this review will include only artificially-intelligent VR. AI has been incorporated into VR software more recently in an effort to improve the clarity of environments and make settings more life-like. AI-equipped VR is often more adaptable and can provide real-time feedback. In the field of SLP, VR offers a unique and practical way to physically enhance therapy.

Technological Applications

For the purpose of this review, a technological application will be referred to as an "app". An app is a program that runs on a smartphone, smart tablet, or computer. Apps are accessible and affordable resources that in the case of healthcare, extend the boundaries of therapy. Apps enhance in-person delivery or reinforce a therapist's teachings via at-home practice. Not all apps utilize AI, but all apps referenced in this review employ the use of AI. This review includes apps that are in trial phases as well as those currently available in online app stores.

Robots

A robot is a machine programmed to mimic human-like functions and movements that can be carried out automatically. A robot is equipped with varying levels of technology, dependent upon its purpose and level of human resemblance. Not all robots utilize AI, but many of those emerging in the healthcare and therapy world utilize AI to be made customizable to patients. In terms of speech-language therapy, Robles-Bykbaev et al. (2015) define a robot as, “an intelligent environment that uses mobile devices to provide support during the SLT [speech-language therapy] process” (p. 529). Robots used in SLP are often designed to be social and communicative.

Serious Games

A serious game is a game designed primarily for educational purposes, not just entertainment. Serious games offer an educational and engaging learning method while utilizing innovative technology. Not all serious games use AI; however, the studies referenced in this review are assumed to use artificially-intelligent serious games, given their incorporation of adaptability, VR, VA, or ASR.

Emotional and Facial Recognition

Within the last 10 years, AI has been incorporated into emotional and facial recognition. This new wave of AI allows technology (specifically, smart devices) to read peoples’ facial expressions and make predictions based on what has been recognized. Emotional and facial recognition are versatile tools in the world of therapy, capable of predicting one’s neurological and psychiatric states or assisting in the communication of a nonverbal individual.

Vocal Biomarkers and Predictive Algorithms

As more insight is gleaned into the world of health and greater emphasis is placed on screening and early detection, vocal biomarkers and predictive measures using AI are becoming increasingly popular among healthcare personnel. Fagherazzi et al. (2021) explain a vocal biomarker as a, "feature (or combination of features) in the voice that has been identified and validated as associated with a clinical outcome" (Fagherazzi et al., Table 1). The human voice serves as a window into an individual's overall health, and small changes in a person's voice are indicative of internal changes.

Screening, Assessment, and Diagnosis

Populations

The following sections name populations that AI has assisted. The sections are structured with a definition of the disease or disorder and a reason AI might benefit both the population of interest and speech-language pathologist. Supporting sources will be introduced; however, more extensive information on the sources is given within the Applications of AI in Screening, Assessment, and Diagnosis.

Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is a developmental disorder marked by changes in the brain with no known cause as defined by the Centers for Disease Control and Prevention (CDC) (CDC, 2020). Although ASD manifests differently in every person, social challenges and issues with restrictive or repetitive behaviors and interests are common. ASD is an umbrella term for a spectrum of disorders. Symptoms and severity will vary across the spectrum of disorders; however, there are many crossovers of characteristics and tendencies.

Individuals with ASD often exhibit restricted and repetitive behaviors, such as ritualistic behaviors or movements to comfort themselves. There is often a large sensory component as well: increased sensitivity to touch, light, and sound. For the purpose of this review, a greater focus will be placed on the social communication challenges, as those are more relevant to speech-language therapy treatment. Published work more commonly analyzes the effect of AI on treatment for the social and communicative challenges of ASD.

Individuals with ASD often struggle with social communication and interaction with family, peers, and strangers. With one-third of individuals with ASD being nonverbal, there is a need for speech-language therapy (Autism Speaks, 2019). Those who are verbal may seem to have limited speech skills; however, the lack of social skills is what creates challenges. In fact, many people with ASD have unusually extensive vocabularies for their age, but their social challenges make it seem otherwise. For these reasons, a correct and early diagnosis is imperative to administration of the most effective therapy. ASD looks different in each individual, but knowing the hallmark characteristics is important for parents and clinicians. Table 1 organizes a list of common social challenges that an individual with ASD might experience.

Table 1

Social Communication Challenges Within ASD

Limited spoken language
Inappropriate use of language
Difficulty making and maintaining eye contact
Lack of awareness for social cues
Lack of awareness for conversational cues (i.e., turn-taking, personal space)
Difficulty understanding figurative language
Difficulty inflecting tone of voice
Difficulty showing facial expressions
Difficulty recognizing emotions in others and expressive own emotions

Currently, objectives and terminology of most published work in the field focus on either the umbrella of ASD, or Autism Disorder specifically. For the purpose of this review, AI is used to enhance therapy for ASD and Autism Disorder.

Given that no medical test screens for, assesses, and diagnoses ASD, diagnosis is a laborious and painstaking process for families and personnel involved. AI serves as a means to speed up the process of assessment and diagnosis so speech-language pathologists' time can be more valuably spent with early intervention. Mujeeb Rahman and Monica Subashini (2022), Alam et al. (2022), and Rahman et al. (2020) each acknowledge a need for quicker and more accurate screening and assessment procedures. The quicker a screening or assessment is, the sooner a diagnosis is made and the earlier intervention can begin. Early intervention should always be the goal, and Mujeeb Rahman and Monica Subashini explain, "Early diagnosis of ASD and an effective action plan plays a critical role in the child's long-term life outcome" (p. 2732). The AI-inspired framework for the three studies above is based on speed and accuracy. Tryfona et al. (2017) and Rahman et al. are also motivated by accessibility; these sources have aimed to engineer an affordable technology that quickly and accurately diagnoses ASD by type.

Dysarthria

The American Speech-Language-Hearing Association (ASHA) defines dysarthria as a motor speech disorder that causes weak muscles due to brain damage (ASHA, 2013). Humans use many different muscles in their face, throat, lips, and tongue in order to produce speech. When these muscles become weak, speech becomes more difficult and less intelligible. Dysarthria cases can range from mild to severe, and one's level of intelligibility and ease of production are dependent upon the severity. Dysarthria is caused by brain damage and is often secondary to other diseases such as Parkinson's disease, cerebral palsy, multiple sclerosis, etc. The etiology of a case of dysarthria will determine its prognosis. Many individuals with dysarthria will improve, but some will not and must learn compensatory strategies.

Dysarthria is a motor speech disorder; therefore, characteristics are presented within speech and are subjectively identified according to a listener's perception. One technique to identify dysarthria is a physical examination of the vocal cords and speech mechanism. This is slightly invasive and uncomfortable for the client, so other methods are preferred. Ijitona et al. (2017) employ the use of ASR and acoustical analysis in their study to make identification more comfortable, accurate, and objective.

Developmental Language Disorder

Developmental Language Disorder (DLD), also referred to as Specific Language Impairment (SLI), is defined by the National Institute on Deafness and other Communication Disorders (NIDCD) as a communication disorder that impacts a child's learning, understanding, and use of language (NIDCD, 2022). This neurodevelopmental disorder cannot otherwise be explained by hearing loss, autism, or lack of exposure to language. Although specific causes are unknown, the disorder is believed to be caused by something in one's genes (DLD can be hereditary) and the surrounding environment during brain development. Children with DLD reach typical language milestones late and generally do not use language as frequently as neurotypical children. When language is used however, many grammatical errors are often present. DLD is often mistaken as a behavioral issue, given that many children ignore directions and social interactions out of fear of not understanding or knowing how to properly respond.

The screening, assessment, and diagnosis process for DLD can be tedious for speech-language pathologists, and there is no medical test that concludes a diagnosis. Rather, results of screenings and behavioral assessments are subject to the discretion of the therapist. Depending on the age and cooperation of a child, a DLD assessment can take hours to complete, and subsequently score. As Ch'ng et al. (2021) explain, current technological solutions are not affordable, accessible, or within a speech-language pathologist's expertise. In a world of smart technology, there should be ways to make a more efficient use of speech-language pathologists' time; caseloads are increasing, and speech-language pathologists only have so much time in their week. Modern technology has found ways to integrate AI into practice, making diagnosis and treatment easier and more accurate for speech-language pathologists, but Ch'ng et al. explain how expensive and inaccessible that is. The form of AI being used for this purpose is often embedded in either eye-tracking or electroencephalogram (EEG), and Ch'ng et al. shared that these tools may cost anywhere from $10,000 to $25,000 – clearly out of a speech-language pathologist's means. To combat this, Ch'ng et al. propose an all-in-one web application to diagnose and treat DLD that will be *accessible* and *affordable* for speech-language pathologists. While this is just one example of AI being used to help individuals with DLD, it represents the overall need for this technology that drives many companies and researchers forward.

Assessing for DLD in bilingual speakers is particularly challenging. Current practice is to perform a dual-language test, and as Albudoor and Peña (2022) reaffirm, required personnel and resources are limited. Most standardized assessments for DLD are normed to monolingual English-speakers. According to Albudoor and Peña, only 8% of speech-language pathologists are bilingual. A monolingual, English-speaking speech-language pathologist is not qualified and does not have the resources to assess a bilingual speaker for DLD. This is where AI could potentially bridge the gap, and Albudoor and Peña's study is an example of a study working to do so.

Parkinson's Disease

The Mayo Clinic defines Parkinson's Disease (PD) as a progressive neurodegenerative brain disorder affecting the body's central nervous system (Mayo Clinic, 2022). PD is a result of nerve cells in the brain dying or becoming impaired, which in turn leads to a dopamine depletion. However, the cause of those nerve cells' death and impairment is still unknown. Symptoms of PD can include tremor, slow movement, rigidity, imbalance, and diminished prosody. Speech may sound slow or slurred with varying intonation patterns. Although individuals with PD have strong language and comprehension abilities, they might struggle to articulate what they are thinking.

Individuals with PD experience speech impairments as the disease progresses, so speech markers are often used in the diagnosis of the disease. As Ijitona et al. suggest many studies use speech tasks to analyze the relationship between speech characteristics and PD; however, there is a gap in research to suggest the best speech tasks – the ones most indicative of PD. Ijitona et al. propose the use of AI to improve interpretation of speech tasks, thereby improving classification of PD. Once PD can be better classified, speech-language pathologists may follow a standardized and accurate approach that uses AI to reach a diagnosis more quickly.

Alzheimer's Disease

Alzheimer's Disease is a progressive disease that impairs memory and cognition and impacts one's ability to function in daily life. According to Alzheimer's Association, Alzheimer's is the most common form of dementia, accounting for 60-80% of total cases (Alzheimer's

Association, 2023). Dementia is a broader umbrella term for symptoms of memory loss and is not a specific disease. Individuals who are above the age of 65 are at an increased risk for developing Alzheimer's, especially if family members have previously been diagnosed. When a person has Alzheimer's, their brain regions begin to shrink and lose volume; by the end of the disease, severe brain atrophy is present. The early stages of Alzheimer's consist of mild confusion and forgetfulness that may go unnoticed or be dismissed. As the disease progresses and the brain continues to shrink, memory loss and cognitive impairments grow more severe. Individuals might struggle to carry out activities of daily living (ADLs), feel disoriented in time and place, not be able to hold a conversation, and experience behavioral and personality changes.

Alzheimer's Disease is currently not a curable disease. Medications and therapy options can stave off symptoms and increase the amount of time that someone with Alzheimer's remains independent, but all options are compensatory. People with Alzheimer's Disease benefit from speech-language therapy, especially when initially diagnosed. Speech-language pathologists provide people with Alzheimer's strategies for remembering things of importance (i.e., family members, daily routines, personal interests) as well as practice maintaining language skills. A speech-language pathologist's role primarily consists of decreasing daily frustrations and maximizing the communicative time that remains.

Going forward, the speech-language pathologist might assume a more active role in the screening and diagnosis of Alzheimer's Disease through the use of speech analytics and vocal biomarkers. Bertini et al. (2022) share, "language has been recently subjected to growing interest, and literature suggests that language impairment is a promising sign to reveal early signs of cognitive decline." (Bertini et al., *Introduction*). Similarly, a study referenced in St George's University of London's Private Company Research Report (2022) is based off the idea that

Alzheimer's can be detected early from a simple speech-language sample. Although current treatment is not promising, more successful treatment outcomes might be achieved as a result of AI being introduced to the screening and diagnosis phase.

Dysphagia

Dysphagia, as explained by Mayo Clinic, is a swallowing disorder in which individuals have a difficult time transporting food and liquid from the mouths to the stomach (Mayo Clinic, 2018). Dysphagia can cause pain when trying to swallow, or an inability to swallow altogether. A person with dysphagia might feel as if they always have food stuck in their throat or experience acid reflux (and in turn, heartburn) from food being regurgitated back up the esophagus. Dysphagia has a range of causes and can affect any individual of any age.

Speech-language pathologists comprise the main healthcare personnel that assess and treat dysphagia. Typically, dysphagia diagnosis will follow a swallowing screening and test; the most common test is known as a videofluoroscopic swallow study (VFSS). A VFSS is performed by administering food and liquid mixed with barium, which, when swallowed, is visible on an X-Ray. This is a minimally-invasive test, but Coyle and Sejidíc (2020) offer a less-invasive solution for scenarios where VFSSs are undesired, unavailable, or not feasible. Coyle and Sejidíc employ the use of high-resolution cervical auscultation (an AI-powered, wearable sensor) that can detect a disordered swallow. With Coyle and Sejidíc's solution, diagnosis does not have to rely on human input, thereby increasing accuracy and saving speech-language pathologists' time. While modern VFSS is a fairly efficient and functional method, higher accuracy and minimized invasiveness is always desirable.

Applications of AI in Screening, Assessment, and Diagnosis

Automatic Speech Recognition

Although more commonly used in the intervention phase of treatment, ASR is beginning to serve a noticeable purpose within screenings, assessments, and diagnoses. Albudoor and Peña, Ijitona et al., and Švec et al. (2022) all demonstrate ASR used in detection of DLD, dysarthria, and Alzheimer's, respectively. In the case of DLD, and specifically DLD for bilingual speakers, Albudoor and Peña compared the performance of ASR to that of a human. After having bilinguals take both a Spanish and English assessment, the results were manually scored by a human and scored by an ASR system (based on a recorded sample of an assessment). The accuracy percentages were similar (human: 92%, ASR: 88%, with ASR increasing to 94% upon removal of certain testing items that were difficult for the system to process), indicating that ASR might be a feasible tool when assessing bilingual language. Ijitona et al. and Švec et al. also provide preliminary support for the use of ASR in dysarthria and Alzheimer's detection. From a corpus of standard and nonstandard speech samples within the work of Ijitona et al., the ASR feature extraction algorithm distinguished between the two with 75.6% accuracy. Švec et al. found their ASR algorithm to be around 70% accurate as well. In all three above studies, the ASR systems were not perfect, but neither are humans. ASR could be a comparable tool that saves speech-language pathologists time, and as the technology is more widely used, algorithms will become more accurate.

Vocal Biomarkers and Predictive Algorithms

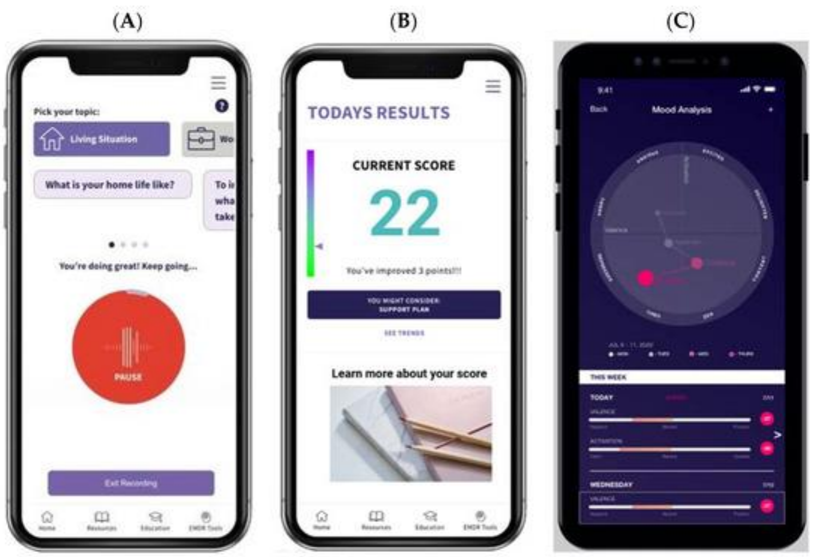
Predictive measures and vocal biomarkers are among the newest and most exciting applications of AI. Not only do predictive measures directly enhance the field of SLP, but vocal biomarkers indirectly enhance the broader healthcare field as well. Armstrong et al. (2018) and Franciscatto et al. (2019) each use AI to predict language development. Armstrong et al. used AI to analyze three-year-olds' communicative skills and predict communicative outcomes at 10 years old; the study provided preliminary support for the use of AI to predict communicative outcomes, with the understanding that future experiments would include a broader age range. Although more focused on short-term speech predictions, Franciscatto et al. also found their predictive measures to be accurate. Using similar technologies for different purposes, Chang et al. (2021) used information collected at hospital admission to predict a stroke patients' ADL at discharge. The study determined that three AI models are sufficient predictors of post-stroke outcomes when given information gathered at hospital admission for the stroke. Armstrong et al., Franciscatto et al., and Chang et al. share similarities in predictive AI technology, and all concluded with promising uses.

The preceding sources were examples of AI predicting associated speech-language outcomes, but the following sources use speech-language features (via vocal biomarkers) to predict more general health-related outcomes. Robin et al. (2020) and Fagherazzi et al. provide overviews of current literature regarding potential vocal biomarker applications and evaluations, respectively. The literature reviews mention some common populations of interest: Alzheimer's Disease, PD, cognitive impairments, and mental health disturbances. Robin et al. concluded that their research suggested a clear direction for vocal biomarkers in future health-care systems. Fagherazzi et al. also emphasized the utility of vocal biomarkers but stated that specific speech features and measurements must be further researched and identified.

A. Zhang et al.'s (2022) study is a highly specific example where vocal biomarkers were used to monitor the psychological state of adolescents and young adults undergoing cancer treatment. A. Zhang et al. created a speech-based screening app called "The Ellipsis Health Voice Tool" (EH Voice Tool) that patients spoke into (a 90-second conversation on various topics) each day. The app was equipped to analyze the speech in real-time and provide a depression and anxiety score that is charted over time.

Figure 2

EH Voice Tool mobile app user interface



Note: From: A. *Zhang et al. (2022)*

As shown in Figure 2, EH Voice Tool's Interface is an innovative tool for a tech-savvy generation. The app provides quantitative data that validates and supports patients undergoing psychological distress during treatment. By simply speaking into a device for 90 seconds, patients gain insight into their overall mood patterns and receive resources based on their results. Anxiety and depression are an unfortunate common factor that impacts patients' quality of life, and A.

Zhang et al.'s tool serves as an accessible and non-invasive way to monitor mental health throughout treatment.

In October 2022, The National Institutes of Health (NIH) launched a large research project to collect voice samples and develop an AI platform that makes diagnoses based on users' vocal biomarkers. Where EH Voice Tool was designed for a specific population and purpose, the NIH's app would be more encompassing and suggest broader diagnoses for a wider population. The National Public Radio (NPR) reported that a data collection of this magnitude is the first of its kind, despite previous applications of vocal biomarkers in healthcare. Over the span of four years, researchers hope to obtain data from 30,000 voices (NPR, 2022).

Currently, there are a handful of applications and platforms that have already executed or begun to execute smaller-scale versions of what NIH will accomplish in the future. Table 2 provides examples of current options that use vocal biomarkers to predict health conditions.

Table 2

Current Applications of Vocal Biomarkers

Application/Platform	Mode	Description
modality.ai *(hello.modality.ai)*	Online browser	A conversational AI system that monitors and provides indications on neurological and psychiatric conditions including ALS, PD, ASD, depression, and schizophrenia (Alzheimer's Disease, Laryngectomy, Long Covid, and post-stroke impairment are in development)
Aural Analytics *(auralanalytics.com)*	Smartphone and tablet app	Speech analytics are extracted from frequent, remote speech assessments to monitor and predict neurologic health
HEALTHYMIZE *(healthymize.com)*	Smartphone and tablet app *currently only for research participants	AI system monitors progression of voice-affecting diseases, namely asthma, pneumonia, and COPD and identifies flare ups
Beyond Verbal *(Beyondverbal on YouTube)*	Smartphone and tablet app	Continuously analyzes speech in real-time and reveals potential health conditions, specifically heart disease
Winterlight *(winterlightlabs.com)*	Smartphone and tablet app	Analyzes short snippets of speech to detect cognitive impairment associated with dementia and mental illness; can be used to track changes and identify treatment responses

Intervention

Populations

The following sections name populations that AI has assisted. The sections are structured with a definition of the disease or disorder and a reason AI might benefit both the population of interest and speech-language pathologist. Supporting sources will be introduced; however, more extensive information on the sources is given within the Applications of AI in Intervention.

Stroke

The CDC defines a stroke as an attack to the brain due to a blocked blood supply or burst blood vessel, causing serious and potentially fatal damage (CDC, 2022). Physiological effects vary depending upon the area of the brain affected by the stroke, but the damage will be serious nonetheless. In most cases, individuals who have suffered a stroke will need some combination of speech-language therapy, physical therapy, and occupational therapy.

In terms of speech-language therapy, recovery will look different depending on the type of stroke and its location within the brain. Issues post-stroke regarding speech, language, and executive functioning will fall under a speech-language pathologist's scope of practice. A common disorder that occurs after a stroke is aphasia (a disturbance in speech perception or production affecting one's ability to communicate); around one-third of individuals who have suffered from a stroke will experience an aphasia (Stroke Association, 2017). The *type* of aphasia will depend on the location of the brain damage, and subsequent therapy will depend on the *type* and *severity* of the aphasia.

Stroke is a major cause of disability in adults, and stroke recovery can be extensive. There is often insufficient time, healthcare personnel, or money to remediate all aspects of damage caused by a stroke, and effects of a stroke may last well beyond the timespan of therapy. Individuals are expected to independently return to activities of daily living (ADLs) before having the capacity or tools to do so. While not all stroke victims will be capable of making full recoveries, lasting effects should never be caused by inadequate access to care.

Artificial intelligence has opened up a world of possibility for individuals recovering from strokes, especially those with aphasias. Whether supplementing speech-language pathologists in real-time, extending care beyond sessions, or serving as a life-long tool, artificial intelligence can expand the effects of therapy in various ways to ensure a smoother transition back to an individual's ADLs. A handful of studies have examined this need for smarter, more adaptive therapy in stroke recovery.

Faria et al. (2018) recognize the benefits of cognitive-rehabilitation therapy while also acknowledging its limitations that hamper an individual's recovery trajectory. Much of stroke recovery follows a process-based approach, and physical or occupational therapy is often the initial focus. By the time an individual's speech-language needs are considered, gains have been lost. Furthermore, Faria et al. mention the high ratio of patients to therapists, which makes administering the proper frequency and intensity of necessary therapy for each patient challenging on a caseload. For these reasons and many others, Faria et al. propose a patient-personalized framework that takes some burden off healthcare workers and places greater emphasis on holistic recovery plans (see section *Future Directions* [p. 45.] for more detail).

Similarly, Egaji et al. (2019) propose technological advancements that take the burden off speech-language pathologists. When the article was written in 2019, speech-language therapy was experiencing budget cuts, which resulted in fewer available clinicians to serve the growing number of clients in need. This article emphasizes the need for innovative technology, namely immersive Virtual Reality (VR), that expands where and how clinicians may administer speech-language therapy to those recovering from aphasias. Both the workload of speech-language pathologists and the wait time of patients can be minimized. The AI-powered VR platform posed by Egaji et al. is elaborated on in section *VR* of *Applications of AI in Intervention (p. 35.)*. However, it is important to note that its integration may enhance the long-term recovery process for people with aphasia.

Another study used the framework put forward by Egaji et al. but added the importance of ease of acquisition. Bu et al. (2022) name one of the greatest limitations in effectiveness of treatment as lack of mechanical training for both aides and learners, since clinicians do not have time to learn the ins and outs of a complex platform then explain to a patient how to use it. Therefore, implementing a platform that is easy for the speech-language pathologist (the teacher) and the patient (the learner) to grasp would be ideal. The intelligent platform must be accessible on both ends for optimal efficiency and effectiveness.

One article introduces telerehabilitation (TR) for post-stroke patients amidst the COVID-19 pandemic. As the pandemic forced much of the healthcare world online, populations were forced to adapt. While the switch was a manageable hassle for minor healthcare needs such as check-ups or cold ailments, it was a major adjustment for severe healthcare needs such as stroke recovery. While not all TR includes a component of AI, Ciortea et al. (2021) talk about a scenario where AI is used in conjunction with TR. Interestingly, Ciortea et al. recognize the greatest challenge being patients' acceptance and engagement with such technologies. The TR world alone has been met with hesitation, so individuals are understandably unsure of a combined TR and AI approach.

Autism Spectrum Disorder (ASD)

For a definition of ASD, see ASD section within Screening, Assessment, and Diagnosis (p.10.). Just as AI can assist the screening, assessment, and diagnosis phase of ASD (e.g., via VR or serious games), AI aids the intervention as well. ASD intervention largely focuses on improvement of social skills. Speech-language pathologists ultimately want clients to feel more included socially and less isolated due to neurodivergent tendencies. Individuals with ASD must grow comfortable participating in and initiating conversation with peers. In order to do so, clients must practice conversational strategies and pragmatics that can be transferred to real-life situations.

While traditional therapy strategies used by the speech-language pathologist are effective, AI is believed to have the ability to further enhance and reaffirm principles instated by the therapist. Individuals with ASD can put skills to practice beyond therapy with the help of AI-generated technology and simulations.

Numerous articles address a limitation with traditional face-to-face therapy for people with ASD; ultimately, there is a lack of practice opportunity. A person with ASD learns how to interact with their therapist and then is thrown into, say, a classroom full of peers. There is no transitional experience between their comfortable therapist and real-time social interaction. All techniques and measured progress are evaluated solely upon the clinician's discretion, as explained by Zhang et al. (2020): "intervention in autism spectrum disorder (ASD) depends upon human raters, with limited generalizability to real world settings." (Zhang et al., Introduction). Many studies propose an AI platform or robot that presents a client with a controlled simulation, beyond the capability of a human clinician. Aresti-Bartolome and Garcia-Zapirain (2014) explain that there are benefits to such a controlled environment, one of them being decreased anxiety. An individual with ASD has the opportunity to practice their learned skills from therapy in a controlled, low-stakes environment that poses no real-world implications. Doing something wrong or awkward in the simulation does not change a real person's opinion.

M. Zhang et al., (2022) and Armstrong and Huh (2021) are in agreement with other studies' proposals of an AI-generated simulation or robot, but they share different motives than that of the previous studies. Both sources approach this from a more economical standpoint, claiming that AI can make ASD treatment more affordable and accessible for families. With ASD becoming more prevalent, M. Zhang et al. are driven to create an, "innovative and efficacious," solution and believes VR to be the affordable answer (M. Zhang et al., *Abstract*). Armstrong and Huh share a compelling case study of a family who struggled to find a private healthcare provider and school system that prioritized their needs. They felt limited, affordable sources were available; the family's problems were solved with the purchase of an AI robot designed to help children with ASD. One study has even gone so far to question who the better teacher is – the robot or the human clinician. The study of Lam (2018) is referenced in greater detail in section *Robots* within *Applications of AI in Intervention* (p.39.), but the exploration for effective and affordable artificially intelligent options for the treatment of ASD is noted.

Literacy Impairments

Literacy is the ability to read and write, and neither can happen without an established language. Most individuals cannot recall looking at a page and being unsure of what it says or how to decode it, despite it being in their native language. Unfortunately, that is the reality for many young children. Estimates show that 10 million children experience difficulty when learning how to read, but luckily, 90-95% are able to overcome these difficulties (Drummond, 2013). Overcoming literacy struggles is crucial for a child's education and quality of life.

Difficulty with reading and writing can occur for a variety of reasons, and knowing the root cause will shape the trajectory of intervention. For example, a child struggling with reading due to vision impairments can soon be back on track with proper corrective glasses. A child experiencing hearing loss is missing many crucial sounds for literacy acquisition, so they first need hearing aids before refining reading and writing skills. A child diagnosed with a learning disability such as dyslexia, on the other hand, needs their literacy skills addressed directly because there are no underlying physical impairments. In order to best address any issues, first understanding the general process of how children learn how to read is crucial.

Although it seems to be natural, children do not naturally learn how to read. Reading is not a second-nature skill that humans are born with and do not need to be taught. In reality, reading is a systematic process that depends on the language being taught. Lyon (2013) explains that in an alphabetic language (e.g., English and French), children have to learn which sounds are represented by which letters to make words that convey meaning. This ultimately comes down to phonics instruction and phonemic awareness (the ability to notice, think about, and manipulate sounds/phonemes in words). Reading and writing are learned skills that some individuals need extra support to successfully acquire.

Numerous resources and programs are established to support children's literacy, and adding AI-driven tools increases the breadth of options available to meet students' needs. The surrounding world is technologically advancing, and education must follow in stride so that every student may advance in the world around them. Traditional literacy models are tried-and-true, but supplementing with technology might enhance delivery methods. Literature acknowledges the constant presence of literacy impairments in schools, and many sources want to apply more innovative solutions that capture students' attention.

Neumann (2020) truly emphasizes this idea of capturing children's attention. The researcher has supported the idea of a social robot that promotes early literacy learning via social interaction. The idea is that child-robot interactions will feel engaging, and children will learn more when presented through a fun platform. Similarly, PR Newswire (2021) reports on Amplio's interactive AI-driven platform, *Esperanza*, for Spanish-speaking students with dyslexia. The platform, designed to help students gain native-language literacy, serves as an extension of therapy. *Esperanza* supports lessons provided by the speech-language therapist, giving students the best of both worlds. In comparing the two, the demographics of Neumann's and Amplio's technology may slightly differ by the amount of support necessary.

Groves Learning Organization (GLO) is a nonprofit organization that supports students with learning disabilities. With the use of assistive technology (AT), the organization desires to increase accessibility and autonomy for students with learning difficulties, particularly dyslexia (GLO, n.d.). Students with learning disabilities are often provided with additional support and human resources and subsequently grow dependent upon other humans. A more productive alternative is equipping a student with personalized AT, which allows them to be self-sufficient. GLO's focus on independence is not widely shared, and introducing the use of assistive AI technology advocates for students' autonomy. Nonetheless, Neumann, Amplio, and GLO seem to share the motive of wanting to implement an innovative and engaging technology that supports literacy acquisition to students in need.

Dysarthria

For a definition of dysarthria, see section Dysarthria within Screening, Assessment, and Diagnosis (p.12.). Speech-language therapy can be helpful to a person with dysarthria to strengthen facial muscles and practice speech technique. As described by the Cleveland Clinic, someone with dysarthria may sound as if they are mumbling or speaking too softly; speech can also sound slurred, or robotic and choppy (Cleveland Clinic, 2017). Given that the speech muscles are too weak, an individual does not necessarily have control over their voice. People with dysarthria might have a hard time being understood by others, so additional support to convey their message is ideal. In cases where one's dysarthria will not improve, a compensatory approach is best. While compensatory strategies could include gesturing, writing, or typing, technology is becoming an increasingly popular option.

However, several barriers must be overcome for AI to be effective. Just as the human ear might have a difficult time understanding a person with dysarthria, most technology (i.e. automatic speech recognition) does as well. Rudzicz et al. (2012) structure their work on overcoming this hurdle. They explored ways to improve AI's (specifically, ASR's) ability to understand nonstandard speech, which is the main limitation holding advancements back. This limitation might contribute to the paucity in literature on AI's benefit to people with dysarthria.

Once refined, AI technology can open up doors to more communication opportunities for someone with dysarthria. For starters, AI increases intelligibility and takes a burden off both the speaker and listener. Increased intelligibility aside, there is also an aspect of energy expenditure. People with dysarthria often experience fatigue due to how much energy is spent trying to communicate. Now, people with dysarthria can say more and feel less fatigued. Overall, one's communication experience improves, and quality of life is thereby enhanced. AI can give people a voice, both physically and metaphorically.

Parkinson's Disease (PD)

For a definition of PD, see section Parkinson's Disease within Screening, Assessment, and Diagnosis (p.15.). Parkinson's Disease is a progressive disease; therefore, speech-language therapy is focused more on compensation than remediation. Individuals with PD are taught coping skills and compensatory strategies to learn how to function with their disease.

Progressive disorders, like PD, benefit most from frequent and intense therapy sessions; however, funding is often insufficient, as greater attention is placed on treatable disorders.

Insurances prefer to cover treatment with good prognoses as opposed to static and degenerative ones, because the money is yielding a more tangible effect. As Ritterfeld et al. (2016) explain, “In many countries, a limited set of treatment units is funded by the health insurer with the consequence that many patients have only one appointment per week in speech therapy…Unfortunately, increase of frequency often fails due to a lack in human resources. This is where technology comes into play,” (Ritterfeld et al., *Introduction*). Traditional, face-to-face speech-language therapy can be supplemented with technology-based intervention, thereby increasing the frequency of intervention in an individualized and tailored way. Ritterfeld et al. share information on their project, *ISi-Speech,* which integrates automatic speech recognition and speech-language pathology tools in an autonomous way, guided by the therapist. *ISi-Speech* serves as a solution to the lack of human resources demands for treatment of PD. See section *ASR* within *Applications of AI in Intervention* (p. 32.) for more studies that incorporate ASR into their platforms and represent the significance of ASR in technologically-driven intervention approaches.

Hearing Loss

Hearing loss is a partial or total inability to hear, and it can occur at any level of the auditory pathway. The ear is composed of an outer ear, middle ear, and inner ear, and disease or injury in any part of this anatomy can contribute to hearing loss. The part of the ear the hearing loss occurs in will determine the *type* (sensorineural, conductive, or mixed) of hearing loss and potential treatment options (CDC, 2019). People who experience hearing loss may choose to use hearing aids, a bone-anchored hearing aid (BAHA), or cochlear implants. In addition, there are amplification systems, such as a frequency modulated (FM) system, that can be used in more public environments to help a person hear better beyond their personal devices.

Many of the assistive technology options available for hearing loss are beginning to incorporate aspects of AI into their algorithms to improve listening experiences for users. Evergreen Speech and Hearing Clinic (ESHC) uses a subtype of AI known as a deep neural network (DNN) in their hearing aids to amplify speech in background noise (ESHC, 2021). ESHC explains that the DNN in their hearing aids can select certain sounds, like speech, to amplify and suppress other sounds, like background noise. This is potentially useful in noisy environments with multiple speakers and increased background noise. Similarly, Horner (2021) introduces an app that uses AI to eliminate extraneous babble and background noise to help people with hearing loss. Hearing aids and assistive technology can be expensive, but a smart phone app is affordable and accessible. Hearing loss is becoming increasingly common, spanning across generations. As the World Health Organization (WHO) reports, 430 million people are currently affected by hearing loss, and this number is expected to increase to 700 million people by 2050 (WHO, 2023). As a greater percent of the population begins to experience hearing loss, more individuals will seek amplification. Everyone deserves a pleasant listening experience, and enhancing the technology of amplification via AI might serve as an effective way of doing so.

Applications of AI in Intervention

Automatic Speech Recognition and Voice Assistant

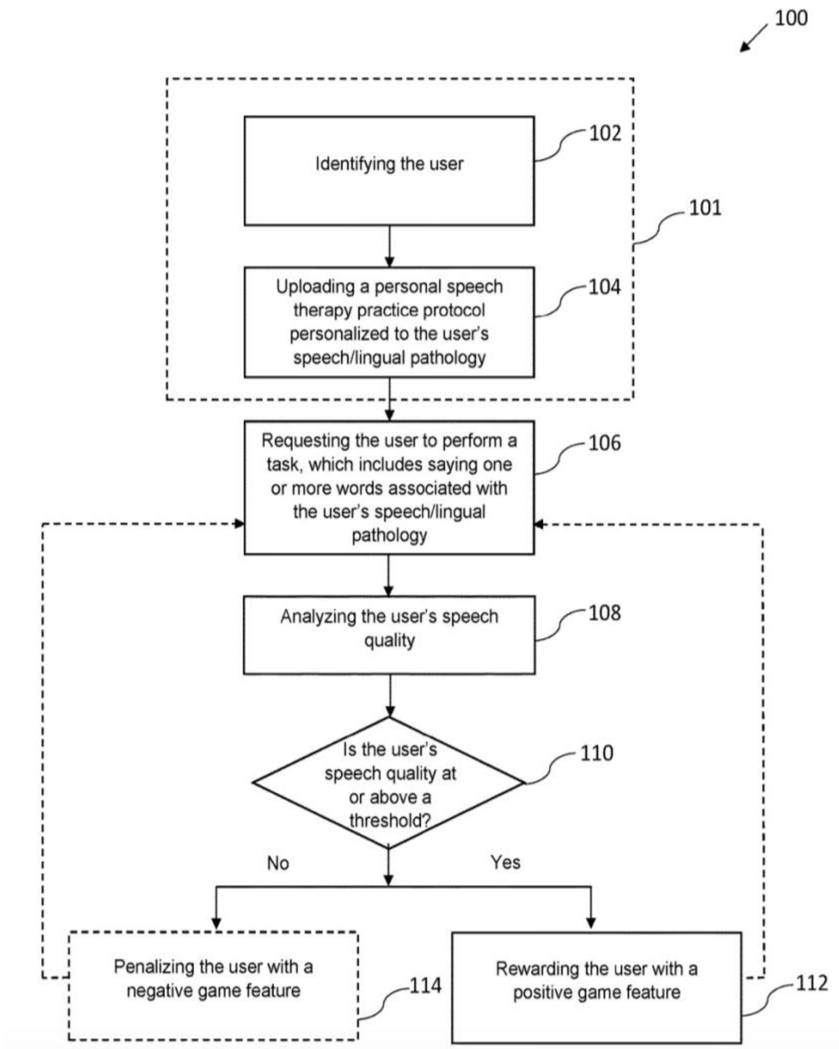
As explained in depth in the work of Rudzicz et al. (2012), the general goal of ASR is to determine the optimal phoneme sequence that describes acoustic input based on probability distributions. Probability distributions require large sets of realistic, representative samples, which is difficult to obtain for nonstandard speech. Rudzicz et al. estimate that ASR understands 85% of standard speech and only 3% of dysarthric speech. Current ASR has yet to learn the irregular sequence of dysarthric speech, and is limited largely by the lack of extensive representative data. The study of Rudzicz et al. addresses the high error rates and issues ASR faces when adapting to dysarthric speech. Researchers found that utilizing articulatory measurements, rather than just acoustic measurements, can improve the machine's ability to recognize dysarthric speech more accurately. A framework for a new type of ASR that incorporates more long-term dynamics was suggested for future research direction.

Rudzicz et al.'s study is based on the concept of improving ASR's algorithm as a whole, making the technology more accessible to nonstandard speakers. A company known as Voiceitt is also driven to improve ASR, but in a more personalized way. Voiceitt has designed a speech recognition app for individuals with nonstandard speech, such as dysarthria, that recognizes one's unique speech patterns (Voiceitt, n.d.). The system learns and adapts to one's speech over time by using data from distinctive speech, cadence, breath, and pauses. While Rudzicz et al.'s goal is to design an all-encompassing ASR algorithm that understands all nonstandard speech, Voiceitt is considering nonstandard speech from a case-by-case perspective. All nonstandard speech deviates from the norm in a different way, which is why designing a system that accounts for any possible irregular speech pattern is so challenging. Although training the ASR system takes time, Voiceitt's personalized protocol is currently a viable solution until a more comprehensive algorithm is created.

ASR is used more regularly on virtual or serious gaming platforms. Medan's (2021) work is an example of ASR embedded in a virtual platform, where ASR acts as the "voice assistant speech language pathologist" (VA SLP). Medan was motivated to create an interactive platform that encourages adherence to prescribed SLP protocol, given that many patients fall short on practice once they step outside of their face-to-face sessions. Medan has designed a VA platform personalized to individuals' speech-language needs that encourages positive practice through adaptive game feedback. The system is interactive and responsive to the user, promoting communication and conversation. The ASR system of the VA functions as a threshold, and the user must provide speech input above the threshold to earn positive feedback. Speech perceived to be below the given threshold penalizes the user with a negative game feature or withholds a positive feature.

Figure 3

VA System



Note. From: Medan (2021).

Medan's work is a good example of combined VA and ASR technology. As shown in Figure 3 the system is initially prompted by the user's specific voice: "identify the user". Unless the system becomes programmed to one person (in that case, VA would not have to continually identify the user's voice), the VA is prompted by a recognizable voice. From here, a client-specific profile is uploaded to the game, and the VA prompts the user with a task. At this point, ASR takes action to understand the input from the user and determine whether the input was above or below the acceptable threshold. The VA and ASR continuously work in tandem to assist the individual in the virtual game-like speech session.

Pompili et al.'s (2020) work serves as another example of an e-health platform, functioning with the help of ASR. Pompili et al.'s platform is known as VITHEA and is used in aphasia rehabilitation sessions. Users are prompted with semantic confrontation exercises (recalling content from presented photos or videos) by VITHEA, and ASR determines whether the individual was correct or incorrect. The platform serves as a complement to traditional face-to-face sessions, and speech-language pathologists rely on the validity of the ASR algorithm to further help their client.

Virtual Reality

M. Zhang et al. discuss current applications of VR for children with ASD in regards to ASD's core symptoms: social communication, emotional recognition, and speech and language skills. M. Zhang et al. highlight VR as an effective and inexpensive means of practicing social skills within and outside of therapy sessions in a less stressful way. Practicing therapy exercises alone is intimidating for a young child, and VR offers low-stakes practice opportunities for real-world applications; children with ASD do not need to fear mistakes or rejection in the simulated world of VR as they traditionally might in real-life encounters. Additionally, skills can be repeatedly and dynamically practiced, unlike real-life where social exchanges cannot be repeated until satisfactory performance. M. Zhang et al. explain the advantage of the customizability of VR in ASD, as therapists can craft a scenario tailored to the client's current needs and skills.

Bu et al. (2022), Egaji et al. (2019), and Beijer and Rietveld (2015) analyze the use of VR to support individuals recovering from aphasias. The sources recognize a need for the VR technology to supplement – but not replace – therapists' treatment. The most effective treatment for aphasia is an intensive rehabilitation program, which many therapists do not have time to accommodate. All three studies see VR as an effective way to increase therapeutic exposure without requiring more time from speech-language pathologists. Both Bu et al. and Egaji et al. mention a specific VR platform known as EVA Park. EVA Park is an online virtual world that contains numerous simulation locations (i.e. houses, cafes, restaurants, hair salons, etc.) for individuals with aphasias to practice successful communication with other users logged on at the same time. With only a microphone and headset, people with aphasias put skills to practice in a variety of environments from the comfort of their homes. While Bu et al. and Egaji et al. offer real conversations in simulated environments, Beijer and Rietveld focus on simulated interactions between a user's avatar and virtual therapist. All three studies found benefit in VR helping people recovering from aphasias practice every day social communication.

As demonstrated through recent studies, VR technology can be used to help specific populations of individuals undergoing rehabilitation or therapy. XRHealth serves as a more comprehensive VR option that assists a continuum of populations seeking therapy. XRHealth is a virtual clinic that administers weekly, personalized sessions through a VR headset (XRHealth, n.d.). XRHealth serves individuals seeking therapy for anxiety and stress, chronic pain, fibromyalgia, neurological conditions, and ASD. Subsequently, treatment plans are classified as occupational therapy, physical therapy, speech-language therapy, and mental health therapy. The steps are mapped out on XRHealth's website as follows: (1) choose your therapist, (2) receive your VR headset in the mail, and (3) begin therapy journey through scheduled online sessions. This innovative solution provides patients with all-in-one care without leaving home.

Apps

Perhaps the most accessible and affordable usage of AI is found within apps. Apps are versatile platforms that may serve as remote therapy supplements or daily communication aids for users. In a technologically-driven society, apps are tools that reach many demographics; generally, age, race, and SES do not hinder apps' usage. However, some apps are only compatible with certain software or devices. For example, Google's Project Relate is currently available only in beta (testing prototype) on Androids, and Apple users do not have access to this app (Google Research, n.d.). For those who do have access, Project Relate is intended to help individuals with nonstandard speech via personalized speech recognition, similarly to previously mentioned VoiceItt. Project Relate's app (currently accepting participant testers) initially records 500 phrases to understand a user's unique speech pattern. Once the algorithm has adapted to a user's personal speech model, the user can access a variety of features: keyboards, custom phrase cards, speech-to-text transcription, repeat (the system will repeat what the user said in a clearer, computerized voice), and Google Assistant. The hope is that Google will continue to obtain speech samples from the beta app and soon launch an app for anyone to download.

Novotalk is an app that anyone with internet connection and headphones can participate in; however, Novotalk is more expensive ($44/month) than some other apps on the market (Novotalk, n.d.). Mainly geared towards people who stutter, Novotalk personalizes a 10- to 12-week program that suits users' needs. An AI engine, referred to as the virtual therapist, "Emily", guides the user through the program and provides immediate feedback based upon analysis of their speech patterns. Novotalk is a convenient and effective solution that can be used anytime and anywhere. While AI uses discussed thus far have included a combination of AI and human intervention, Novotalk is completely AI-driven. This raises the question of whether a full AI approach is as effective as a human speech-language pathologist (see section *Future Direction* [p. 45.]. for more details).

InnerVoice and Amplio are additional examples of AI-driven apps that may be used independent of a speech-language pathologist; or in conjunction with human intervention. These apps are often used in the classroom under the supervision of a teacher to optimize a child's learning experience. InnerVoice utilizes AI to label and describe pictures taken with a camera to teach users about communicative relationships between objects (InnerVoice, n.d.). Amplio, on the other hand, is a platform designed specifically for special education (Amplio, n.d.). AI allows for adaptive learning on the platform, personalizing the curriculum to a student's needs. Although InnerVoice and Amplio serve different purposes, both are dynamic tools that can be used in the classroom to help children learn and communicate more effectively.

While AI-driven apps using ASR and real-time feedback are becoming increasingly popular, those intended for early intervention populations (in which speech has not yet emerged) are less common. Babbly is a virtual therapy platform intended to provide early intervention for babies and toddlers in need of speech-language treatment. Babbly has an app, "Babbly," that uses AI to initially determine if there is a need for early intervention based on an audio-babble sample prior to first words (Brunec, 2022). Parents submit recordings of babies' vocalizations: cooing (strings of vowels like "ooo"), single-syllable babbling (i.e., ba), duplicated babbling (i.e., baba), variegated babbling (i.e., bapoti), and turn-taking exchanges. The AI algorithm then detects the babble patterns and compares them to developmental norms for the infant's age. If the infant is behind norms, a plan for early intervention is put in place with Babbly. Babbly provides a way for caregivers to gain insight on children's speech and language development to address any potential delays as early as possible.

Similarly to how Babbly *predicts* a speech-language outcome based on an audio sample, several apps have been designed to analyze vocal biomarkers and provide insight into one's health. Apps like Beyond Verbal and Healthymize (see Table 2) utilize AI voice monitoring to monitor disease onset and progression. Apps such as these promote early intervention, which can potentially improve one's prognosis. For more details on these apps' impact on the screening, assessment, and diagnosis phases of therapy, see section *Vocal Biomarkers and Predictive Algorithms* within *Applications of AI in Screening, Assessment, and Diagnosis* (p. 18.).

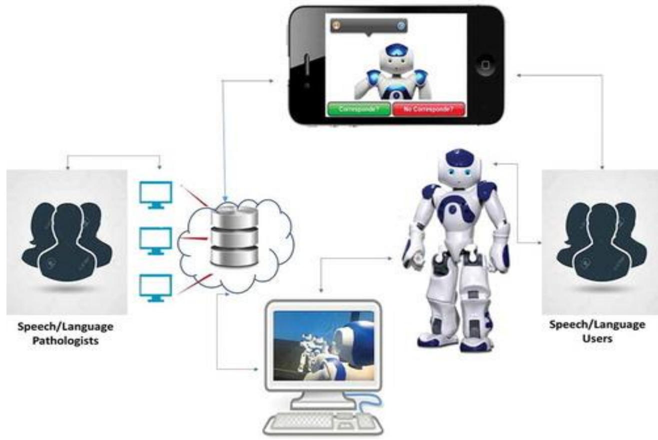
Robots

As of 2020, a sufficient number of sources explaining the use of social robots in education alone was available. Neumann (2020) reviews available literature regarding social robot usage and recognizes its limitations. From information gathered, the review concluded that social robots are effective assets for early language learning in classrooms; however, Neumann recognized a gap in research examining early literacy learning among young children. Additionally, Neumann acknowledged a need for research into the benefit that AI-equipped robots provide to teachers in the classroom. Since 2020, AI-equipped robots have only become more versatile.

Robots are intended to replicate human intelligence and movement, though the degree to which these standards of intelligence and physical semblance are met varies. Caldwell Marin et al. (2021) have designed a humanoid robot (linked to a computer platform) to assist speech-language pathologists, while Robles-Bykaev et al.'s (2017) model is more a non-physical robotic assistant embedded in a smart device or tablet. Figure 4, adapted from Caldwell Marin et al., demonstrates the physical, humanoid robot that is internally equipped with information.

Figure 4

Physical Humanoid Robot



Note: From: Caldwell Marin (2021)

Regardless of appearance (although human perception is important to consider), both sources are excellent examples of the innovative and intelligent features that robots introduce to the field of SLP. Individuals might find communicating with a robot unsettling, detracting from the intended therapeutic experience. However, the proceeding sources will support robots' ability to enhance therapy delivery.

Robles-Bykaev et al. designed their robot to be used for language intervention in the domains of semantics, phonology, pragmatics, and morphology. Onto-SPELTRA is the robotic assistance part of Robles-Bykaev et al.'s comprehensive platform. The platform as a whole provides decisions on planning therapy sessions, a robotic assistant that motivates children during therapy, and a module that groups patients of similar profiles together. As a whole, the AI-driven platform creates therapy plans (based on information in clients' profiles) to be carried out by the robot assistant, Onto-SPELTRA. Participants of the study felt comfortable with the robot and the educational information presented via the robot.

Caldwell Marin et al. designed a robot and integrated therapeutic exercises to treat speech sound disorders (articulation disorders). The exercises begin with the robot greeting the user, presenting a word on the screen, and then saying the word to the user. The user must then repeat the word back to the robot for the input to be perceived as correct or incorrect. The robot provides intermittent motivational feedback based on the user's performance. The study concluded that humans took to the therapeutic robot with ease, and speech-language pathologists found Caldwell Marin et al.'s robot's intervention in articulation treatment to be satisfactory. Lam (2018) compared humanoid robot-intervention (similar to that of Caldwell Marin et al.) to human-intervention in the treatment of ASD and determined that human and robot teaching agents were equally successful in highly-structured learning environments. Since students' learning outcomes were similar, the study further supports the potential therapeutic use of humanoid robots.

Each of these studies has contributed to the framework of real-world applications of robots. What felt like a distant concept five years ago is soon becoming reality for some classrooms. A team of researchers from the University of Central Florida (UCF) is implementing an AI robot and platform in classrooms and studying the effects on students with ASD (Shimalla, 2020). The project will be rolled out in phases, with an ultimate goal of implementing a national model. See *Future Directions* (p. 45) for greater detail on the cutting-edge technology being tested in Florida school districts.

Serious Games

In recent years, speech-language therapy has undergone a paradigm shift that has seen the incorporation of educational and engaging games – serious games – into therapy sessions. Serious games are fairly common nowadays, and serious games using AI are on the verge of advancement. Serious games using AI monitor users' performances in real-time, adapting to and providing feedback based on user performance. Given that serious games are built upon standard entertainment games, serious games may follow any theme and serve a variety of purposes or populations. The versatility of serious games makes them a useful tool for therapists covering diverse caseloads. From articulation or language therapy to stroke rehabilitation, a serious game has a place in healthcare. In fact, the article written by Ciortea et al. regarding stroke recovery via telerehabilitation, serious games are credited as the most common replacement of traditional therapy. The article explains that unlike humans, AI-powered serious games can be flawless, tireless, and instantly responsive; all that is required is a device and an internet connection.

Aguilar (2019) considers the utility of serious games to teach students with special education needs the communicative value of prosody (i.e., intonation, stress, rhythm). Researchers found that when incorporated in a pedagogical lesson plan, the serious game, "Pradia: Mystery in the City," was an effective tool for teaching both prosody and other soft skills (such as psychomotor, logic, and conceptual relationship skills). The success of serious games is due largely in part to the motivational features that keep children with special needs engaged. Of the participants in Anguilar's experiment, 8 out of every 10 felt motivated by the game and wanted to play again. However, children complained that they did not feel completely autonomous (given that the games were facilitated by the therapist) and wanted to play the game more independently. When the experiment allowed for more autonomy, the children experienced difficulty understanding the directions. For this reason, serious games were concluded to be useful under the guidance of therapists when part of a learning objective.

Emotional and Facial Recognition

Emotional and facial recognition is a cutting-edge form of AI that detects and responds to learned facial patterns. This form of AI is especially useful for nonverbal individuals that rely on alternate modes of communication. In fact, an individual with ALS – who communicates primarily via facial expression – prompted the development of Google's app, "Project Activate" (Seaver, 2023). The app is intended for people who cannot communicate with speech or motor movements (gestures); rather, they utilize the customized, preset communications via a facial expression like smiling or looking up. In addition to directly augmenting one's communication, emotional and facial recognition can be used within speech-language therapy.

Al-Nafjan et al. (2015) and Schipor (2014) use emotional and facial recognition to gain better insight into a client's feelings during a therapy session. Al-Nafjan et al. study brain activity (via an EEG) during a session and associates findings with affective states. Schipor, on the other hand, gathers visual, physiological, and auditory information to draw a conclusion on the client's emotions during the session. Both means of analysis lead to a discernment of the client's emotional state. With this information, the therapist – or, in the case of Schipor, the computer system – can better understand the emotional state of the client. An affective state says a lot about how an individual is retaining therapy practices. For example, sadness or fear might discourage a person and hinder performance; emotions of happiness or excitement might be a great opportunity to teach new skills. Schipor discusses an often-overlooked quality in human-therapists that computers lack: empathy. Undoubtedly, a human-therapist knows how to emotionally read their client in a way that computers currently cannot. As healthcare continues to move in the direction of VR, robots, and computer interfaces, the dearth of human-like characteristics (i.e., empathy) should be carefully considered.

Future Directions

This literature review has provided extensive information on advanced technology that is supported by different forms of AI. From initial keyword searches, a handful of articles appeared in results because of the mention of AI for future directions of their studies. This review has discussed different types of technology that are assumed to be equipped with AI; however, not *all* VR, apps, robots, and serious games include AI. Faria et al. (2018) have developed a framework that generates paper-and-pencil tasks for post-stroke patients, and the researchers wish to improve its AI capabilities in the future. Despite using advanced technology, their technology is not considered AI yet. Ijitona et al.'s (2017) experiment already utilizes AI, but further analysis of its utility via variations of AI technology is desired. A common theme among sources was an intention to employ AI in future instances where AI was not yet utilized, or intention to further improve and refine AI technology in current applications. An additional theme present across studies was the proposal of larger, more robust sample sizes for future work. Many studies referenced concluded with *preliminary* support for the respective AI mode of therapy but signified that greater research with larger sample sizes is necessary before certain AI uses may be deemed assuredly effective.

With rapidly advancing technology comes the inevitable feeling of hesitation among both therapists and users. However, in reviewing a large corpus of studies, I noticed a gap in the perceptions of the technological shift in therapy. The focus has been predominantly placed on the efficacy of AI in therapy, but effectiveness declines or is insignificant if the mode of therapy is poorly perceived by therapists and clients. Journalist Simon Creasey wrote an article, "Can we trust AI to teach children to read?," that tactfully illustrates the wonder and hesitation surrounding AI perceptions (Creasey, 2021). Creasey sets the scene by describing a classroom in which a student is reading to and conversing with an AI tablet – not another human. Creasey follows this description with a question for readers: "Is it too much of a stretch to see AI being used in this way - as a primary tool for teaching reading - in schools?" (Creasey, 2021). Overall, the tone of the article teeters between amazement toward and skepticism of AI technology. Such perceptions are missing from current literature on AI's involvement in the field.

A study by Huijnen et al. (2016) centered around gauging practitioner's expectations of an AI robot, KASPAR. A questionnaire was administered to collect therapists' opinions and which qualities they would value in the robot. This is a useful example of how clinical perceptions can improve the functionality of therapeutic AI methods. Armstrong and Huh presents a case of a child with ASD whose family dynamic significantly improved upon implementation of a social robot. The robot encouraged the child to communicate with caregivers more, and caregivers expressed that they began to feel greater love and affection from the child. I believe that future research should include qualitative aspects similar to those of these two studies. In an empathy-driven field, it is imperative that AI technology not diminish personal connections among therapists, clients, and families.

An interesting contribution of AI to the SLP field is introduced by Butina et al.'s (2013) study. Researchers have studied the benefits of VR learning environments to students in healthcare-related fields; VR has been found to train baseline skills in only a few fields thus far, including SLP, anesthesiology, dentistry, and psychology. Of the participants (all studying in healthcare-related fields) in Butina et al.'s study, 59.5% of students reported that they did not use VR in their learning environments; however, 84.6% of those students who did not use VR indicated that they would be interested in learning within a VR environment. The researchers of the study stated that minimal research on the concept is currently available, and I did not encounter any studies of VR-supported preservice education throughout my review. In the same way that AI is useful in the screening, assessment, diagnosis, and intervention phases of treatment, VR could serve as a tool for SLP students in their clinical training period. This is an area that deserves greater research in the near future. Likewise, under the assumption that AI technology continues to follow this trajectory of implementation, young clinicians should begin to receive training in the technology and devices; as AI becomes a staple in the field, clinicians must be well-versed in the uses and benefits of AI to comfortably and effectively serve clients.

An apparent gap in research focus exists with regards to types of service. The quantity of studies analyzing the use of AI for screening, assessment, and diagnosis phases is disproportionately lower when compared to intervention; 39 sources in the review support the use of AI in intervention, but only 24 support AI in screening, assessment, and diagnosis. AI in intervention is therefore 63% more documented than AI in screening, assessment, and diagnosis. The use of ASR in screenings and assessments was briefly discussed, as well as the potential of vocal biomarkers on the broader spectrum of healthcare. Of the 24 sources used within screening, assessment, and diagnosis, 13 are used in relation to vocal biomarkers and predictive measures, which suggests that AI's use in the screening, assessment, and diagnosis phase is not yet versatile. Other uses of AI within these phases of treatment are not yet determined. Future studies should place a greater emphasis on the benefit of AI to screening, assessment, and diagnosis.

CONCLUSION

Artificial intelligence is changing technology by the day. As I have written this review, new sources that challenged my literature corpus have continually emerged. I have learned that a technology-driven literature review cannot be nearly as extensive as intended due to the speed at which advancements are made. Within the field of speech-language pathology, a growing number of therapists are turning to AI technology to enhance the accuracy and efficiency of their practice. AI is undoubtedly revolutionizing the healthcare world, and speech-language pathologists are encouraged to adapt their practices accordingly.

AI is currently used to enhance the field of speech-language pathology within each phase of service delivery: screening, assessment, diagnosis, and intervention. Current applications of AI discussed in this review include ASR and VA, VR, apps, robots, serious games, emotional and facial recognition, and vocal biomarkers and predictive algorithms. Examples of these uses were discussed at length in relation to the disease and disorder populations of stroke, ASD, literacy impairments, dysarthria, DLD, PD, hearing loss, Alzheimer's, and dysphagia. The uses of AI span across all populations of interest and will continue to advance to suit countless individuals. Although gaps in clinical implementation and research of AI persist, the ultimate potential of AI is limitless. This review is a limited representation of AI's immense capability to aid people within and beyond the field of speech-language pathology.

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ACADEMIC VITA

Caitlin F. Grabowski

EDUCATION

Bachelor of Science in Communication Sciences and Disorders (MAY 2023)
*The Pennsylvania State University | Schreyer Honors College***,** University Park, PA
Thesis Title: *A Review of The Use of Artificial Intelligence to Enhance the Practice of Speech Language Pathology*
Relevant Coursework: American Sign Language I, II, III

WORK EXPERIENCE

JUNE 2022 - AUGUST 2022, JUNE 2021 - AUGUST 2021
Summer Remote Speech Intern
Abington Speech Pathology Services

- Created and organized materials to be used for online speech teletherapy sessions
- Compiled word lists for the common speech sounds mastered by school-aged children to be integrated into Abington Speech's online activity software
- Tailored resources to fit various age ranges, skill sets, and targeted speech and language goals as directed by licensed and certified SLP

JULY 2022 - AUGUST 2022
Personal Aide
Marie H. Katzenbach School for the Deaf

- Supported student one-on-one throughout Extended School Year (ESY)
- Implemented daily behavioral plan to encourage student's academic participation and cooperation
- Communicated with student primarily in American Sign Language, supplementing with English
- Collaborated with academic team and colleagues on how to best support students

AUGUST 2021 - MAY 2022
Teaching Assistant
Department of Sociology, Penn State University

- Thoroughly reviewed, commented on, and graded students' weekly discussion posts
- Moderated the students' questions and responses to ensure a scholarly standard
- Fostered diversity of thought and inclusive speech
- Provided resources to bolster understanding of class materials

JANUARY 2022 - MAY 2022
Teaching Assistant
American Sign Language, Penn State University

- Hosted weekly Office Hours to facilitate ASL use among students outside of the classroom
- Encouraged hard work and thoughtfulness among the class
- Administered guidance and support to students struggling with class concepts
- Aided professor in grading of weekly assignments

JUNE 2021 - AUGUST 2021

Culinary Support

Chandler Hall Health Services

- Prioritized residents by providing full meal service and meeting all requests
- Learned residents' diets and allergies to ensure delivery and consumption of healthy and balanced meals
- Fostered a cheerful and welcoming environment for residents to enjoy meals and social time

STUDENT OBSERVATIONAL EXPERIENCE

JULY 2022, AUGUST 2022

Marie H. Katzenbach School for the Deaf

- As student's one-on-one aide, attended speech therapy sessions with them three times a week
- Elected to observe additional sessions during scheduled work breaks
- Observed language-based sessions with a focus on vocabulary and reading comprehension
- Students communicated primarily in ASL but were encouraged to use speech as a means of enhancing language skills during therapy

JUNE 2022, MAY 2020, JUNE 2020

Abington Speech Pathology Services

- Shadowed Clinical Director/SLP in sessions remediating general expressive and receptive language deficits
- Observed implementation of AAC device "Lingraphica"
- Virtually shadowed school-based SLP and observed elementary-aged, group sessions

AWARDS AND RECOGNITION

Evan Pugh Scholar Award (2022, 2023)

Awarded to students who earn 4.0 GPA in 60+ consecutive credits at PSU; Top 0.5% of Junior, Senior classes

Academic Excellence Scholarship (2022, 2021, 2020, 2019)

Awarded to Schreyer Honors College scholars each semester

Jane B. Slep Honors Scholarship, College of Health and Human Development (2022, 2021, 2020, 2019)

Awarded to deserving students in the College of Health and Human Development at PSU

President Sparks Award (2021)

Awarded to students who received a 4.0 through their first 36 credits at PSU

President Freshman Award (2019)

Awarded to freshman who received a 4.0 through their first 15 credits at PSU

Smile Train Student Ambassador (2019)

One of 50 students nationally; attended Smile Train's Youth Summit in NYC in February 2019; hosted a local fundraiser at a venue with food, live music, and silent auction (February 2019)

EXTRACURRICULAR INVOLVEMENT

Sign Language Organization (SLO)

Center for Socially Responsible Artificial Intelligence (CSRAI) Student Affiliate

ServeState: *Students for Philanthropy*