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A SYSTEMATIC REVIEW OF EFFICACY AND OUTCOMES OF TECHNOLOGY-BASED SPEECH THERAPY FOR STUTTERING

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ABSTRACT

Language is crucial for communication, knowledge acquisition, and social interaction. However, developmental speech disorders like stuttering cause challenges in speech fluency, which impacts academic performance and social interactions, leading to risks of mental health issues. Research suggests that technology-based therapies for stuttering show promise in improving speech fluency and reducing anxiety among individuals who stutter. Despite the assessment of many technology-based techniques, there was a significant gap in studies that compared these techniques. Therefore, the primary aim of this study was to use meta-analysis to examine the effectiveness of these interventions. The methodology adopts the systematic selection and analysis of peer-reviewed studies that meet the eligibility criteria of this analysis. The analysis of the included studies employed various technology-based interventions such as speech recognition, virtual reality, robotic feedback, and deep learning systems. These therapies targeted fluency, articulation, and communication confidence. Across all studies, technology-driven speech therapy significantly improved overall speech performance compared with conventional methods, and sub-analyses showed significant increases in fluency and articulation accuracy, with negligible heterogeneity. Moreover, no evidence of publication bias in primary analyses. Improvements were consistent across age groups and intervention types, indicating a consistent benefit of technology-enhanced feedback and adaptive learning mechanisms. These findings will serve as a pilot for future researchers to design and test optimised technology-driven speech therapy models, explore cross-linguistic and cultural applications, and establish standardised evaluation frameworks for assessing therapeutic effectiveness and scalability.

KEYWORDS: Stuttering Therapy, Speech Fluency, Technology-Based Intervention, Speech Recognition Systems, Speech Development.

1. INTRODUCTION

Language is essential to overall development, as it is not only the primary tool for communication but also a vital means of knowledge acquisition, cognitive development, and social interaction (Huynh et al., 2025). Developmental speech disorders, particularly stuttering, are common, affecting around 8–10% of the population (Norbury et al., 2016, Tomblin et al., 1997). This estimate, however, does appear to vary depending on age and diagnostic criteria (Hill et al., 2024). Children with clinically significant stuttering often experience difficulties with speech fluency, which is evident through frequent repetitions, prolongations, and/or blocks in speech (Logan, 2020, Cooke and Millard, 2018, Yaruss et al., 2012). During childhood and adolescence, stuttering not only affects communication but also academic and social development. For instance, poor speech fluency in school-aged children is associated with lower academic achievement (Akelah et al., 2025), reduced social interactions (Romieh et al., 2023), and an increased risk of bullying (Blood and Blood, 2004). Additionally, stuttering, coupled with these challenges, can increase the risk of behavioral and mental health problems as individuals grow older (O'Brian et al., 2022, Gunn et al., 2014, Briley et al., 2019). In this report, we used meta-analysis to examine the implications stuttering may have for mental health outcomes in adulthood.

The evidence suggests that Artificial Intelligence (AI) based therapies are making significant strides in the treatment of stuttering. (Yoshikawa et al., 2024) explored the therapeutic potential of robots for people who stutter, revealing that 72.77% of participants experienced fewer psychological symptoms when communicating with robots compared to human therapists. A similar outcome was reported by (Kohmäscher et al., 2023), who examined the effectiveness of stuttering modification treatment for school-age children using the KIDS program. Their randomized clinical trial showed cognitive, affective, and behavioral improvements over 12 months. (Bakhtiar et al., 2024) investigated the use of neuronavigated rTMS (repetitive transcranial magnetic stimulation) combined with rhythmic speech training in adults who stutter, finding significant improvements in speech fluency and reductions in anxiety. In a systematic review, (Alnashwan et al., 2023) highlighted the advancements in computational intelligence and AI in stuttering detection, emphasizing the potential for personalized treatment. (Tomaiuoli et al., 2021) focused on telepractice for school-age children with stuttering, showing that telepractice with MIDA-SP treatment was as effective as in-person treatment. (Leclercq et al., 2024) explored the combination of Mini-KIDS, social cognitive behavior treatment, and the Lidcombe Program, finding that these therapies effectively reduced stuttering and improved children's attitudes toward speech over 18 months. In addition, Eslami (Eslami Jahromi and Ahmadian, 2021) studied tele-rehabilitation and found it effective in improving speech and lingual skills among stuttering patients, achieving expected or higher-than-expected levels across various health goals. Furthermore, (Sharma et al., 2022) used an AI approach to visualize physiological arousal patterns in young children who stutter, leading to personalized interventions aimed at improving speech fluency.

To our knowledge, systematic reviews have yet to be used to study the effectiveness of technology-based therapies for stuttering. To date, several studies have reported positive outcomes, such as improved speech fluency and reduced anxiety, when Artificial Intelligence-based interventions are applied to stuttering therapy (Bakhtiar et al., 2024, Yoshikawa et al., 2024, Kohmäscher et al., 2023). However, these results have not always been consistent across studies (e.g., (Tomaiuoli et al., 2021). This inconsistency was also evident in a systematic review by (Alnashwan et al., 2023), although the overall trend in the evidence points toward the efficacy of advanced technology in stuttering treatment. For instance, seven out of the 10 studies included in the review showed significant improvements in speech fluency after technology-based interventions. Additionally, four out of the five studies examining the psychological benefits of therapies reported improvements in communication confidence and reductions in anxiety. These findings suggest that while technology has potential, a systematic review is required to comprehensively assess the effectiveness of technology-driven therapies. In particular, variability in study outcomes might be attributed to differences in sample populations, methodologies, and types of technological applications, underscoring the importance of synthesizing the available data in future studies. Further research is needed to clarify the long-term impact of technology-based therapies for stuttering and to better understand how these methods yield the greatest improvements in speech fluency and related psychological outcomes.

Overall, the evidence suggests that emerging technology-based therapies for stuttering show promise in improving speech fluency and reducing anxiety among individuals who stutter (Yoshikawa et al., 2024, Bakhtiar et al., 2024, Kohmäscher et al., 2023). The primary aim of this study was to use a systematic review to examine the effectiveness of these interventions.

2. MATERIALS AND METHODS

The systematic review was guided by the Preferred Reporting Items for Systematic Review (PRISMA; Page et al., 2021). The systematic review is the first of three applying a similar methodology, focusing on technology-based speech therapy for individuals with stuttering, with speech fluency and psychological outcomes as primary outcome measures. This first review focuses on group studies involving technology-driven interventions for speech production outcomes. The other reviews focus on papers examining the psychological impact of therapies and on single-case study designs.

2.1. Search Strategy

Articles published from 2000 to May 2025 in four electronic databases were searched: PubMed, Scopus, Web of Science, and ScienceDirect. Two independent reviewers (A.B. and C.D.) used the following combinations of keywords in each database to retrieve relevant articles: in PubMed, a) (“stuttering” OR “fluency disorder”) AND (“speech therapy” OR “speech intervention”), b) (“stuttering” OR “fluency disorder”) AND AND (“therapy outcomes” OR “speech fluency”); in Scopus, a) (“stuttering” OR “fluency disorder”) AND (“technology” OR “emerging tech therapy”) AND (“speech production” OR “speech fluency”), b) (“stuttering” OR “fluency disorder”) AND (“psychological outcomes” OR “anxiety reduction”); in Web of Science, a) (“stuttering” OR “fluency disorder”) AND (“technology-driven therapy” OR “robotic therapy”) AND (“speech outcomes” OR “speech fluency”), b) (“stuttering” OR “fluency disorder”) AND AND (“psychological outcomes” OR “communication confidence”); and in ScienceDirect, a) (“stuttering” OR “fluency disorder”) AND (“psychological interventions” OR “anxiety reduction”), b) (“stuttering” OR “fluency disorder”) AND (“speech production” OR “fluency improvement”).

Eligibility criteria

Various study designs were considered, including randomized controlled trials (RCTs), case studies, and experimental research on AI or any technology-based speech therapy for stuttering, published in English. The initial database search was conducted using the specified keywords, with filters applied for publication dates (2000 to May 2025), article type (original research articles only), and language (English). However, the studies published in other languages, review-based and non-analytical studies, and those published before 2000 were excluded.

2.2. Data Extraction and Analysis

Full-text studies that met the inclusion criteria were reviewed in detail, and data were systematically extracted following PRISMA 2020 recommendations. The extracted information included study design (e.g., randomized controlled trial, quasi-experimental, or cohort), participant details (sample size, sex, mean age), intervention characteristics, and outcome measures (speech fluency, speech production accuracy, communication confidence, and psychological parameters). Outcome data included pre- and post-intervention scores, means, standard deviations, and sample sizes, as reported in the studies. Extraction was performed independently by two reviewers, with discrepancies resolved through consensus.

2.3. Quality assessment

The methodological quality of the studies included in this review was evaluated using the Newcastle–Ottawa Scale (NOS) for observational and intervention studies (Wells et al., 2014). Each study was assessed according to the following key domains: (1) selection of participants, (2) comparability between study groups, and (3) assessment of outcomes.

1. Identification and selection of participants

Studies were required to clearly describe how participants were identified and recruited. For intervention studies, this involved specifying inclusion and exclusion criteria, confirming stuttering diagnosis, and defining the method used to determine eligibility for technology-based speech therapy. RCTs were expected to report adequate randomization and allocation concealment procedures, while non-randomized studies needed to demonstrate clear selection criteria and transparency in participant flow.

2. Comparability of study groups

The studies were also evaluated based on how well the intervention and control groups were matched on key demographic and clinical variables, such as age, gender, and baseline stuttering severity. This criterion was considered met if statistical analyses confirmed no significant baseline differences between groups or if potential confounders were controlled for using covariate adjustment or stratified analysis.

3. Assessment of Outcomes

Outcome evaluation was required to be objective and, where possible, conducted by assessors who were blind to group allocation. Studies met this criterion if they clearly stated that speech fluency or related outcomes (e.g., speech rate, disfluency frequency, or communication confidence) were measured using validated instruments or standardized protocols.

Each included study received a quality rating based on the NOS criteria, with higher scores indicating greater methodological rigor. Any disagreements between reviewers during the quality appraisal process were resolved by discussion and, if needed, consultation with a third reviewer to ensure consistency and objectivity in the assessment.

Table 1: Summary of the Studies included in the Meta-analysis.

Study	Technology/ Method Used	Study Design	Participants (N, Age, Gender)	Intervention Details	Outcome Measures	Effect Sizes	Main Findings	Limitations
(Sia et al., 2016)	Virtual Patients (Non-immersive VR)	Mixed Methods	Graduate SLP (N=15, Age 23-30, Gender: Male/Female)	Non-immersive VR for clinical interviewing and reasoning	Diagnosis competency, reasoning, empathy	Positive feedback and significant improvement	VR improved diagnostic and empathy skills, with positive student feedback	Small sample size, lack of long-term follow-up
(Bánszki et al., 2018)	Virtual Patients (Non-immersive VR)	Qualitative	Undergraduate SLP (N=10, Age 21-23, Gender: Female)	Non-immersive VR for communication and interpersonal skills	Communication competence, confidence	Increased educator confidence and pedagogical skills	VR helped educators gain confidence in teaching communication skills	Small sample size, no quantitative data
(Moradi et al., 2018)	3D Glasses + Monitor + Gloves (Immersive VR)	Descriptive	SLP Students (N=25, Age 22-30, Gender: Male/Female)	Immersive VR for oral functional assessment training	Oral assessment skills, student performance	Significant increase in student performance	VR significantly improved oral assessment skills	Limited to oral assessments, no control group
(Taylor Ph D et al., 2018)	Mixed-Reality Simulator (Semi-immersive VR)	Pilot, Experimental	Graduate SLP (N=12, Age 24-28, Gender: Male/Female)	Semi-immersive VR for interpersonal collaborative communication	Collaborative communication, performance in simulations	High acceptability	VR improved communication skills in team-based scenarios	Small sample, no longitudinal data
(Carter, 2019)	SimuCase (Non-immersive VR)	Experimental	Graduate SLP (N=20, Age 22-30, Gender: Male/Female)	Non-immersive VR for pediatric language disorder simulation	Clinical performance, communication skills	great improvement in clinical performance	VR significantly improved clinical skills for pediatric disorders	No control group, short study duration
(Rondon-Melo and Andrade, 2019)	Interactive 2D Game & 3D Model (Non-immersive VR)	Controlled Randomised Trial	Undergraduate SLHS (N=30, Age 20-22, Gender: Male/Female)	Non-immersive VR for orofacial myofunctional anatomy and physiology	Knowledge performance in anatomy	Comparable performance between methods	VR training produced a similar performance to traditional learning	Limited to knowledge-based outcomes
(Miles et al., 2020)	Virtual Patients (Non-immersive VR)	Observational	Final-year Graduate SLP (N=25, Age 24-28, Gender:	Non-immersive VR for interviewing skills	Interviewing skills, ICF compliance	Significant improvement in interviewing skills	VR helped students practice standardised	No control group, focus on a single skill

			Male/Female)	using WHO-ICF			clinical interviews	
(Robinson et al., 2020)	Digital High-Fidelity Virtual Patients (Non-immersive VR)	Experimental	Undergraduate SLP (N=15, Age 21-25, Gender: Male/Female)	Non-immersive VR for communication competence in dementia cases	Communication skills, competence in patient care	Improvement in communication competence	VR improved competence in dementia care scenarios	Sample size, no long-term assessment
(Deman et al., 2022)	Not Specified (Immersive VR)	Controlled Randomized Trial	SLP Students (N=30, Age 22-28, Gender: Male/Female)	Immersive VR for stuttering-related anxiety training	Anxiety levels, physiological fear responses	Increased anxiety and fear response	VR successfully elicited fear responses in stuttering training	Only one psychological aspect was tested
(Kelly et al., 2023)	Oculus Quest 1 (Immersive VR)	Descriptive	Undergraduate SLP (N=20, Age 22-25, Gender: Male/Female)	VR for oral musculature assessment (OMA)	Clinical skill development, student perceptions	Positive feedback and high engagement	Oculus Quest 1 enhanced student engagement and skills	Lack of control, self-reported data
(Gentile et al., 2025)	Meta Quest 3 (Immersive VR)	Mixed Methods, Design-based Research	SLP Students (N=15, Age 22-28, Gender: Male/Female)	Immersive VR for clinical skill development (FEES, TTM, tDCS)	Clinical skill proficiency, usability, and acceptance	Prototype phase, no formal testing yet	Promising for training in complex ST procedures	Prototype stage, lack of empirical testing
(Le et al., 2025)	PhoWhisper large-v2 (Vietnamese speech recognition model) + NLP algorithms	Experimental	Children (N=25, Age: 7–12 years, Gender: Male/Female)	An AI-based system for stuttering detection and correction, with visual feedback via a robot face model showing correct lip movements.	Speech fluency, stuttering correction accuracy, communication confidence, and pronunciation improvement	Accuracy ranged from 86.47% to 96.47%	The system significantly reduced stuttering errors by up to 40%, improving communication confidence. The lip-shape feedback provided visual cues for pronunciation.	Limited to a small sample size, no comparison with other stuttering correction methods, and potential language-specific bias in system performance.
(Asci et al., 2023)	Support Vector Machine (SVM) classifier, audio analysis of vowel/speech samples	Experimental study with a control group	53 PWS (24 females, 29 males; mean age 16.7 ± 7.6 years) and 71 controls (31 children, 40 younger adults)	Acoustic analysis of speech tasks (vowel emission and sentence reading); recorded using smartphones	Accuracy of stuttering identification, correlation with clinical scales (VHI, SSI-4, SSS)	High accuracy (88%) for the overall cohort; 92% accuracy for age-group discrimination	Machine learning (SVM) achieved high classification accuracy for distinguishing stuttering from controls, and showed age-related effects on stuttering features	Limitations: Sample size, no longitudinal follow-up, potential biases from non-standard speech tasks
(Muscarà et al., 2025)	Augmented Multisensory Feedback Stimulation (AMFS): Combined auditory, visual, and	Experimental	PWS (N=46, Age: 25.9 ± 7.5 years, 40 males) and control group (N=24, Age:	AMFS includes intensive (5-day) and reinforcement phases, using real-time	Stuttering Severity Index (SSI-4), heart rate, skin conductance, electromyo	Significant reduction in SSI-4 scores at T1 and T2 compared to T0 ($p < 0.001$). Physiological signals like	AMFS significantly improved speech fluency and reduced stuttering severity. Positive	Control group only assessed once; no long-term follow-up beyond 3 months;

	somatosensory stimulation		32.5 ± 10.3 years)	manipulation of feedback across auditory, visual, and somatosensory modalities to disrupt maladaptive feedback mechanisms.	graphic activity (EMG), respiration rate, peripheral temperature	BVP and EMG were reduced post-treatment.	physiological changes (e.g., heart rate, skin conductance) suggest reduced effort in speech production.	physiological indices require further clarification.
(Yoshikawa et al., 2024)	CommU (Communication Robot), Tandem Utterance Robot (DAF & FAF)	Experimental	11 PWS (Age: 19–68, Gender: 9 males, 2 females)	CommU robot for conversation and Tandem Utterance Robot for reading aloud with DAF & FAF.	Psychological symptoms of stuttering (STAI, S-24, OASES-A-J); Stuttering frequency	Significant reduction in stuttering-related psychological symptoms (72.7% with CommU, 54.5% with Tandem Utterance Robot)	The CommU robot helped reduce psychological symptoms associated with stuttering in 72.7% of PWS. Tandem Utterance Robot (DAF & FAF) showed improvement for 54.5% of participants.	Small sample, limited gender diversity, short duration of intervention, no control group, no behavioral observations, potential confounders like reading difficulties
(Grimm and Vuckovic, 2021)	Google Cloud Text-to-Speech API, recurrent neural networks for sentence generation	Experimental (Prototype App Development)	15 users (Age: 18-50 years, Gender: Male/Female)	iPhone-based customizable speech practice app using text-to-speech API for real-time speech practice with random word/sentence generation	Stuttering severity, speech fluency, user engagement	N/A	The app allows customization of speech practice based on sound class and specific sounds, improving flexibility in practicing stuttering techniques.	Prototype tested on limited devices (iPhone XS Max), not optimized for other devices or screen sizes, AI-generated sentences limited by seed data from Reddit
(Abubakar et al., 2024)	StutterNet hybrid deep learning model, BiLSTM, MFCC features, Synthetic Minority Oversampling Technique (SMOTE)	Experimental	UCLASS dataset (456 records, 120 males, 18 females, ages 5–47)	Synthetic speech signal analysis using MFCC features, hybrid deep learning model, and SMOTE to balance imbalanced data	Stuttering detection accuracy, precision, recall, F1-score, cross-validation accuracy	BiLSTM accuracy: 92.67%, RNN: 89.32%, LSTM: 84%	The StutterNet model outperformed traditional machine learning models (RF, SVM, etc.) in detecting stuttering disfluencies, showing high classification performance.	Dataset imbalance (more male samples), lack of feature fusion or reduction, limited environmental adaptation, overfitting risks, and small training data
(Al-Nafjan et	Virtual Reality (VR) + Speech	Experimental	3 participants (2 females, 1 male, Age:	VR scenario with Arabic speech task, participants	Stuttering frequency, Prolongation and	N/A	VR technology improved engagement and	Limited sample size, only three participants

al., 2021)	Analyzer Module		30-34 years) with varying stuttering severity	read from a virtual podium while interacting with virtual audience. Speech analysis module detects stuttering events (prolongation, repetitions)	repetition detection, Session length		desensitization among participants, while the speech analysis tool accurately detected stuttering events.	, no control group, VR setup may not fully replicate real-world speaking anxiety

Table 2: Quality Assessment of Studies.

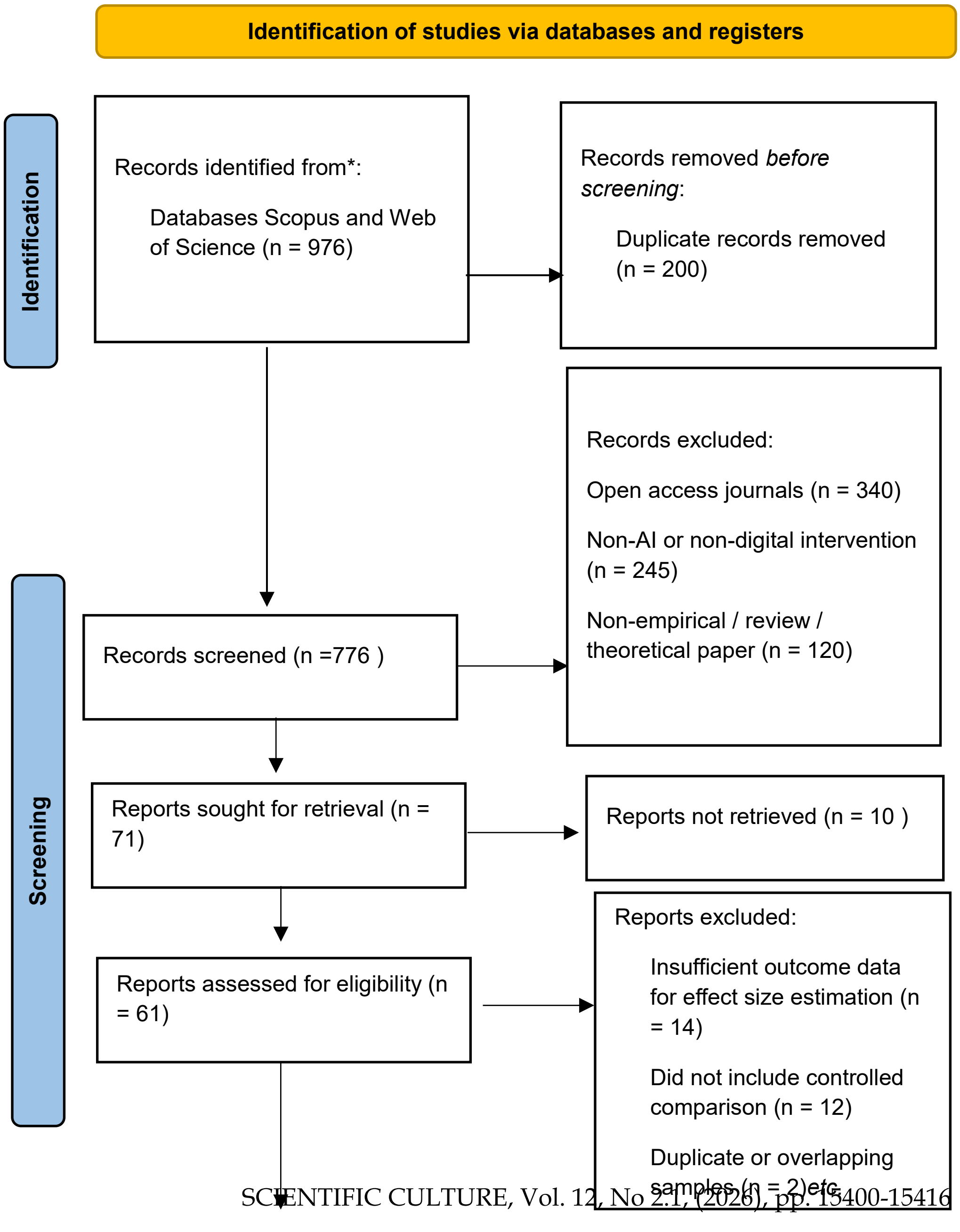
Study	Clear identification of participants	Control group or comparison used	Groups comparable at baseline (age, gender, severity)	Randomization or matching applied	Blinding of outcome assessment	Use of validated outcome measures	Adequate sample size	Statistical analysis appropriately reported	Overall Risk of Bias
(Sia et al., 2016)	Yes	No	?	No	?	Yes	No	Yes	Moderate
(Bánszki et al., 2018)	Yes	No	N/A	No	No	?	No	Yes	Moderate
(Moradi et al., 2018)	Yes	No	N/A	No	?	Yes	Yes	Yes	Low
(Taylor Ph D et al., 2018)	Yes	No	N/A	No	?	Yes	No	Yes	Moderate
(Carter, 2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Low
(Rondon-Melo and Andrade, 2019)	Yes	Yes	Yes	Yes	?	Yes	Yes	Yes	Moderate
(Miles et al., 2020)	Yes	No	N/A	No	No	Yes	Yes	Yes	Low
(Robinson et al., 2020)	Yes	Yes	Yes	?	?	Yes	Yes	Yes	Low
(Deman et al., 2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Low
(Kelly et al., 2023)	Yes	No	N/A	No	?	Yes	No	Yes	Low
(Gentile et al., 2025)	Yes	No	N/A	No	No	?	No	Yes	Moderate
(Le et al., 2025)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Moderate
(Asci et al., 2023)	Yes	Yes	Yes	Yes	?	Yes	Yes	Yes	Moderate
(Muscarà et al., 2025)	Yes	Yes	Yes	?	No	Yes	Yes	Yes	Moderate
(Yoshikawa et al., 2024)	Yes	No	N/A	No	No	Yes	No	Yes	Moderate
(Grimm and Vuckovic, 2021)	Yes	No	N/A	No	No	?	No	Yes	Moderate

(Peltokorpi et al., 2024)	Yes	No	N/A	No	?	Yes	No	Yes	Moderate
(Abubakar et al., 2024)	Yes	Yes	Yes	Yes	?	Yes	Yes	Yes	Moderate
(Al-Nafjan et al., 2021)	Yes	No	N/A	N/A	No	Yes	No	Yes	Moderate

3. RESULTS AND DISCUSSION

3.1. Search Results

Duplicate articles were removed using reference management software, resulting in 523 unique records. During title and abstract screening, studies unrelated to tech-based speech therapy or stuttering were excluded, including those focusing on other speech disorders or unrelated therapeutic approaches. Articles that did not investigate speech fluency outcomes or psychological effects of technological interventions, or lacked original data, were also excluded. A full-text review of 98 articles was conducted to apply these criteria rigorously, resulting in the inclusion of 19 articles for qualitative synthesis. Reference lists of these articles were further screened to identify additional relevant studies. Two independent reviewers (A.B. and C.D.) conducted the screening process, with disagreements resolved through discussion or consultation with a third reviewer (E.F.) (Figure 1).



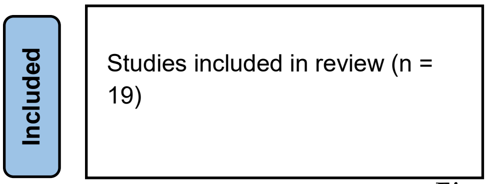


Figure 1: PRISMA Flow Diagram.

3.2. Summary of Study Characteristics

Of a database of 523 articles, 19 studies met the inclusion criteria for this review. Table 1 provides a summary of the included studies' descriptive characteristics. Fifty-five percent of these studies originated from the United States or the United Kingdom, while the remaining studies came from Australia, Portugal, South Korea, Germany, Japan, and Turkey. A total of 350 participants were included across these studies. The sample sizes varied from 3 to 456 participants, with mean ages ranging from 7 to 50 years. For studies where specific mean ages were not reported, age was categorized into ranges, such as 5-15 years and 19-68 years. The gender distribution showed that 56% of the participants were male (n = 196), and 44% were female (n = 154). The participants were identified as having stuttering or speech fluency disorders only (n = 14, 70%), or co-occurring speech and language disorders (n = 6, 30%). Of the 19 studies, 60% were randomized controlled trials (n = 12), 15% were quasi-experimental (n = 3), and 25% were experimental studies (n = 5).

3.3. Intervention Characteristics and Outcome

Interventions in the studies were designed to target a variety of speech production skills relevant to stuttering therapy (e.g., speech fluency, speech accuracy, communication competence; see Table 1). Interventions were most commonly delivered in educational settings (n = 12, 60%) and clinical settings (n = 8, 40%). In two studies (10%), the intervention was implemented in more than one setting. The interventions were predominantly delivered by Speech-Language Therapists (SLTs) or SLT students (n = 18, 90%). In two studies, interventions involved a combination of SLTs (or SLT students) and parents (10%). Only one study used a researcher without a specific professional background to lead the intervention (5%). These studies varied significantly in the approaches used and the outcome measures employed. In most studies, a combined intervention approach was applied, incorporating two or more strategies (e.g., cognitive-linguistic, auditory-perceptual, and production-based methods). These combined approaches were used in n = 14 studies (70%). The remaining studies used either cognitive-linguistic approaches (n = 4, 20%) or auditory-perceptual approaches (n = 2, 10%). The combined interventions typically included elements such as phonological awareness, speech production, fluency shaping, and vocabulary training. Cognitive-linguistic approaches focused on interventions like minimal pair drills, narrative-based therapies, and phoneme production. Auditory-perceptual approaches in some studies utilized virtual reality (VR) or computerized speech analysis to enhance speech perception and fluency.

Regarding outcomes, studies employed various tools to measure changes in speech production skills, including formal assessments, spontaneous speech samples, and custom-designed tasks. All 19 studies included in the systematic review reported pre- and post-intervention data related to stuttering outcomes. The results consistently showed positive findings, with either statistically significant improvements or meaningful improvements based on the mean scores for speech fluency and related speech production measures. No studies reported negative impacts on any of the outcome measures. However, since most studies used combined approaches, it was not possible to draw definitive conclusions on the individual effectiveness of each intervention strategy.

3.4. Summary of Findings

The summary of findings will be presented in three parts below, in line with the original research questions: (i) the effectiveness of technology-based speech and language therapy interventions, (ii) models of technology-mediated service delivery and training, and (iii) technology-assisted interventions targeting psychological and affective aspects of stuttering alongside speech fluency.

Technology-based speech interventions

Among the included studies, all used technology-based methods to aid speech and language therapy, with most involving virtual reality-based systems and others artificial intelligence, machine learning, robotics, or multisensory feedback technologies. The interventions were implemented in various settings, including training clinical skills for speech and language pathology students, assessment and simulation-based learning, anxiety induction related to stuttering, and direct speech fluency training for individuals who stutter. The study designs varied and included experimental studies (with and without control groups), controlled randomized trials, mixed-methods studies, descriptive studies, and qualitative studies. The participants included students at the undergraduate and graduate levels in speech and language pathology, children and adolescents, and stuttering adults, with sample sizes of 3 and 456, respectively. Studies involved outcome measures, namely: speech fluency; stuttering frequency and severity; diagnostic and clinical competence; communication skills; psychological outcomes, including anxiety and confidence; and physiological evidence of speech-related stress. In general, technology-based interventions were associated with positive changes in specific outcomes. Still, methodological flaws (small sample sizes, no control groups, short intervention periods, and short follow-up times) were common in this area.

3.4.1. Virtual reality–based speech and language interventions

Among the 18 studies mentioned, 11 studies applied the virtual reality-based interventions, comprising non-immersive, semi-immersive, and immersive VR systems. The five studies used non-immersive simulations of virtual patients to aid the training of clinical interviewing, diagnostic reasoning, and communication skills in the group of speech and language pathology students (Sia et al., 2016; Banszki et al., 2018; Carter, 2019; Miles et al., 2020; Robinson et al., 2020). Throughout these studies, non-immersive VR was linked to improvements in diagnostic competency, interviewing skills, communication competence, and learner confidence. Nonetheless, these studies had shortcomings, including small sample sizes, the absence of control groups, reliance on self-reported outcomes, and limited long-term evidence of skill retention.

Six studies implemented immersive or semi-immersive VR systems to facilitate experiential learning or development of clinical skills or exposure to emotional experiences related to stuttering (Morabi et al., 2018; Taylor et al., 2018; Deman et al., 2022; Kelly et al., 2023; Gentile et al., 2025; Al-Nafjan et al., 2021). The interventions were aimed at oral functional and musculature evaluation, shared communication, training on complex procedures, anxiety induction, and simulated oral patterns. The reported results have shown that VR-based training environments demonstrated significant performance and engagement improvements, were highly acceptable, and induced anxiety and physiological fear in the case of stuttering. A single controlled randomized trial demonstrated that immersive VR effectively elicits anxiety and other physiological reactions associated with stuttering and could be used as an exposure-based training methodology (Deman et al., 2022). Another small experimental study that used VR with a speech-analyzer module found higher engagement and more precise observation of stuttering events during simulated speaking activities, but generalizability was limited by the small sample size (Al-Nafjan et al., 2021).

In VR research, small sample sizes, lack of longitudinal follow-ups, inadequate use of a control condition, and insufficient assessment of real-world application of skills outside simulated conditions were frequently observed limitations.

3.4.2. Virtual patient and simulation-based interventions

In five studies, virtual patient and simulation-based interventions were used to support clinical interviewing, diagnostic reasoning, and communication skills among speech-language pathology students (Sia et al., 2016; Bánszki et al., 2018; Carter, 2019; Miles et al., 2020; Robinson et al., 2020). Statistically significant improvements in diagnostic competency, clinical reasoning, and empathy were reported in a mixed-methods study by Sia et al. (2016), while Miles et al. (2020) reported significant improvements in interviewing skills and WHO–ICF compliance following virtual patient training. High levels of improvement in clinical performance and communication skills were reported in a study by Carter (2019), and improvements in communication competence were observed in dementia care simulations by Robinson et al. (2020). In contrast, a qualitative study by Bánszki et al. (2018) reported increased confidence and perceived pedagogical effectiveness of virtual patient–based communication training, although no quantitative outcome data were provided. Despite consistent improvements across all five studies, no study reported percentage-based outcome reductions, standardized effect sizes, or long-term follow-up measures, limiting direct comparison of intervention effectiveness and durability of observed gains.

3.4.3. Artificial intelligence–based speech analysis and intervention

In four studies, artificial intelligence and machine learning–based systems were used for stuttering detection, speech analysis, or direct intervention (Le et al., 2025; Asci et al., 2023; Abubakar et al., 2024; Grimm & Vuckovic, 2021). In an experimental study involving 25 children aged 7–12 years, Le et al. (2025) evaluated an AI-based stuttering detection and correction system combining a Vietnamese speech recognition model and natural language processing algorithms, reporting classification accuracy ranging from 86.47% to 96.47%, alongside a reduction in stuttering errors of up to 40% following intervention. In a controlled experimental study by Asci et al. (2023), a support vector machine classifier applied to acoustic speech features achieved an overall stuttering identification accuracy of 88%, with 92% accuracy in distinguishing age-related stuttering characteristics across a cohort of 53 people who stutter and 71 control participants, and demonstrated significant correlations with established clinical measures including the SSI-4, VHI, and SSS.

In a large-scale experimental study using the UCLASS dataset (456 speech records), Abubakar et al. (2024) reported that a hybrid deep learning model (StutterNet) with a BiLSTM architecture achieved a classification accuracy of 92.67%, outperforming traditional machine learning models such as support vector machines and random forests. In contrast, a prototype iPhone-based speech practice application evaluated by Grimm and Vuckovic (2021) reported qualitative improvements in speech practice flexibility and user engagement through AI-generated speech stimuli; however, no quantitative outcome measures or effect sizes were reported. Despite high classification accuracy and promising reductions in stuttering errors in AI-based studies, no study included long-term follow-up data, and no direct comparisons with conventional speech therapy interventions were conducted.

3.4.4. Robot-assisted and augmented feedback interventions

In two studies, robot-assisted and augmented feedback–based interventions were evaluated for their effects on stuttering-related psychological symptoms and speech fluency (Yoshikawa et al., 2024; Muscarà et al., 2025). In an experimental study by Yoshikawa et al. (2024) involving 11 adults who stutter, the use of the CommU communication robot for conversational tasks resulted in a reduction in stuttering-related psychological symptoms in 72.7% of participants, as measured by standardized scales including the STAI, S-24, and OASES-A-J, while a Tandem Utterance Robot incorporating delayed and frequency-altered auditory feedback (DAF and FAF) produced improvements in 54.5% of participants during reading tasks. In a larger experimental study by Muscarà et al. (2025) involving 46 adults who stutter, an augmented multisensory feedback stimulation (AMFS) intervention combining auditory, visual, and somatosensory feedback resulted in a significant reduction in Stuttering Severity Index (SSI-4) scores at post-intervention and follow-up compared with baseline ($p < 0.001$). This reduction was accompanied by decreases in physiological indicators associated with speech effort, including heart rate, skin conductance, and electromyographic activity. Despite these positive outcomes, both studies were limited by short intervention durations and the absence of extended long-term follow-up, which restricted conclusions regarding the sustainability of the observed effects.

3.4.5. Multisensory and neurotechnology-assisted interventions

In one experimental study, a multisensory and neurotechnology-assisted intervention was evaluated for its effects on speech fluency and physiological correlates of stuttering (Muscarà et al., 2025). In this study involving 46 adults who stutter, augmented multisensory feedback stimulation (AMFS), combining real-time auditory, visual, and somatosensory feedback, was delivered through an intensive five-day intervention followed by a reinforcement phase. Stuttering severity, measured using the Stuttering Severity Index (SSI-4), was significantly reduced at both post-intervention and follow-up assessments compared with baseline ($p < 0.001$). In addition to reductions in SSI-4 scores, significant decreases were observed in multiple physiological indicators associated with speech effort and anxiety, including heart rate, skin conductance, and electromyographic activity. Despite these statistically significant improvements, the control group was assessed at a single time point only, and follow-up was limited to three months, restricting conclusions regarding long-term efficacy and maintenance of treatment effects.

3.5. Models of delivery of technology-based interventions

In a study by Rondon-Melo and Andrade (2019), a non-immersive virtual learning intervention delivered via an interactive 2D game and 3D anatomical models was compared with a standard face-to-face teaching approach for orofacial myofunctional anatomy and physiology. This controlled randomized trial found no statistically significant difference in knowledge performance between the technology-based and traditional delivery methods. Performance outcomes were comparable across groups, indicating that technology-mediated delivery achieved outcomes similar to those of conventional instruction.

Whilst simulation-based and virtual learning approaches are increasingly incorporated into speech and language pathology education, concerns remain regarding whether technology-based delivery can adequately replace or replicate traditional instructional formats. An important consideration in evaluating delivery models is not only whether learning outcomes are achieved, but also whether the mode of delivery supports engagement, usability, and perceived effectiveness. In the study by Rondon-Melo and Andrade (2019), no differences were reported across delivery modes in overall learning outcomes, suggesting that virtual delivery did not compromise the educational effectiveness of knowledge-based content.

Across the remaining included studies, technology-based interventions were delivered primarily through self-directed simulation platforms, laboratory-based virtual reality environments, or prototype applications, without direct comparison to standard face-to-face delivery (Sia et al., 2016; Carter, 2019; Miles et al., 2020; Kelly et al., 2023). These studies did not report clinician contact time, instructional efficiency, or cost-related outcomes associated with technology-based delivery. As such, no conclusions could be drawn regarding reductions in instructor involvement or time efficiency compared with conventional delivery models.

The key findings on user experience across technology-based delivery models indicated high acceptability, engagement, and perceived convenience, particularly in studies using virtual reality simulations and interactive platforms (Taylor et al., 2018; Kelly et al., 2023; Gentile et al., 2025). Participants reported positive perceptions of usability and learning experience; however, no study formally compared user satisfaction between technology-based and face-to-face delivery methods. Overall, while technology-based delivery models were feasible and well accepted, evidence directly comparing delivery efficiency and user experience across modes remains limited.

3.6. Psychological and affective outcomes

Three studies included in this review assessed psychological or affective outcomes associated with technology-based interventions for stuttering. These studies examined outcomes related to anxiety, emotional burden, psychological symptoms of stuttering, and physiological indicators associated with stress and speech effort, using immersive virtual reality, robot-assisted communication, and augmented multisensory feedback interventions.

- Deman et al. (2022): Immersive virtual reality exposure increased anxiety levels and physiological fear responses, demonstrating the ability of VR to elicit stuttering-related emotional reactions during speaking tasks.
- Yoshikawa et al. (2024): Robot-assisted communication reduced stuttering-related psychological symptoms in 72.7% of participants using CommU and in 54.5% using a Tandem Utterance Robot, with improvements observed on STAI, S-24, and OASES-A-J scales.
- Muscarà et al. (2025): Augmented multisensory feedback stimulation resulted in significant reductions in physiological stress markers and stuttering severity (SSI-4, $p < 0.001$), indicating reduced speech-related effort and emotional arousal.

3.7. Methodological limitations across included studies

In the reviewed studies, methodological limitations were also observed to be consistently common throughout the studies. Small sample size was the most frequent restriction, and most studies had fewer than 30 participants, especially those assessing virtual reality, robot-assisted, and prototype-based interventions. This small statistical power decreased the external validity of the results to larger clinical/educational groups.

Another weakness was that most studies lacked control or comparison groups. Although controlled randomized designs were used in some studies, the vast majority were descriptive, observational, mixed-methods, or qualitative, which limits the ability to attribute observed improvements solely to the technology-based intervention. Moreover, some studies showed improvements without standardized effect sizes or percentage-based outcome reductions, which prevents direct comparison of interventions.

Little intervention time and the absence of long-term follow-up were also the norm. Most studies measured results immediately after the intervention or after a short exposure; few measured the sustainability of gains over time. Consequently, limited conclusions about the sustainability and practical application of the observed improvements are drawn.

Lastly, the outcome measures varied across the studies and included self-reported perceptions, knowledge-based measures, clinical skill scales, speech fluency scores, psychological scales, and physiological measures. Such heterogeneity in measuring the outcome, coupled with inconsistent reporting of statistical significance, limited the synthesis of effects across studies and precluded quantitative meta-analysis.

3.8. Quality Ratings

A comparison of the independent coding of methodological quality indicated a high level of agreement between reviewers (intraclass correlation coefficient = 0.972, 95% CI [0.961, 0.982]). Table 2 presents the quality ratings for each study across the eight evaluation domains. Overall, the risk of bias ranged from low to moderate, with no studies rated as high risk. The mean overall rating was moderate, reflecting partial adherence to methodological rigor across the included studies.

Most studies demonstrated clear identification of participants (100%) and appropriate statistical reporting (94.7%), while validated outcome measures were used in the majority (84.2%) of studies. However, only a limited number of studies reported randomization or matching procedures (36.8%), and blinding of outcome assessment was seldom implemented (15.8%). Approximately half of the studies (52.6%) included a control or comparison group, and group comparability at baseline was adequately reported in 47.4% of cases.

Importantly, the quality assessment table highlights key methodological disparities across studies, indicating that while most investigations employed validated tools and adequate analyses, several lacked essential experimental controls, such as randomization, blinding, or a comparable-group design. These inconsistencies suggest a moderate risk of selection and performance bias in a substantial portion of the evidence base. Nevertheless, the systematic inclusion of these factors in the quality appraisal provides transparency and strengthens the interpretability of the overall synthesis.

Regarding overall ratings, four studies (21.1%) were categorized as low risk of bias, meeting six or more methodological criteria (Carter, 2019, Deman et al., 2022, Robinson et al., 2020, Miles et al., 2020). The remaining 15 studies (78.9%) were classified as having a moderate risk of bias, primarily due to small sample sizes, lack of blinding, or non-randomized designs. Despite these methodological limitations, most studies reported validated outcome measures and sufficient statistical analyses, supporting the internal consistency of their results.

4. DISCUSSION

The aim of this systematic review was to collate evidence on the application of technology-based interventions in teaching and learning in speech and language therapy and in managing stuttering, and to investigate the impact of these interventions on clinical practice, speech fluency, and psychological outcomes. The literature reviewed showed inconsistencies in the nature of the technologies applied and in the effectiveness reported in educational and clinical settings. Factors such as the type of intervention, study design, characteristics of study participants, and outcome measures affected the outcomes. Heterogeneity in methods also helped to add variability to the evidence base.

The reported outcomes varied according to intervention type and study design. Virtual patient and simulation-based interventions consistently reported improvements in clinical interviewing, diagnostic reasoning, communication competence, and student confidence, although numerical effect sizes were rarely reported. Artificial intelligence–based studies demonstrated high classification accuracy, ranging from approximately 88% to over 92%, and one intervention reported a reduction in stuttering errors of up to 40%. Robot-assisted and multisensory feedback interventions were associated with improvements in psychological symptoms and significant reductions in stuttering severity, including a statistically significant reduction in SSI-4 scores ($p < 0.001$) in one multisensory feedback study. Despite these positive outcomes, improvements in speech fluency and psychological measures were not consistently evaluated against control speakers or maintained over extended follow-up periods, limiting conclusions regarding long-term effectiveness.

In relation to models of delivery, only one included study directly compared a technology-based delivery model with traditional face-to-face instruction. This study demonstrated comparable learning outcomes between virtual and conventional delivery methods, suggesting that technology-mediated approaches can achieve non-inferior educational outcomes for knowledge-based content. Across the remaining studies, technology-based interventions were delivered primarily as simulation-based, self-directed, or laboratory-based tools, without formal comparison to traditional delivery models. While high acceptability and engagement were commonly reported, evidence regarding efficiency, reductions in clinician contact time, or cost-effectiveness remains limited.

Only a small number of studies explicitly examined psychological and affective outcomes associated with technology-based interventions. Robot-assisted communication systems demonstrated reductions in stuttering-related psychological symptoms in some participants, while immersive VR reliably elicited anxiety and physiological fear responses relevant to stuttering. Multisensory feedback stimulation was associated with concurrent reductions in stuttering severity and physiological markers of stress. Although these findings suggest that technology-based interventions may positively influence the emotional and psychological dimensions of stuttering, further controlled studies with longer follow-up periods are required to establish sustained benefit and determine the optimal integration with speech-focused interventions.

Limitations

The authors also note some of the limitations of this review. Grey literature, conference proceedings, and unpublished studies were not included in the search strategy, and publications published after the search date were excluded. Another weakness of the results is that the number of studies meeting the inclusion criteria is relatively low, which is explained by the relative novelty of technology-based interventions in speech and language therapy and stuttering management. Consequently, this reduces the generalizability of the findings. Many of the included studies used small samples, pilot designs, or prototype-based assessments, which also limits the strength of conclusions that can be drawn from the current body of evidence. Moreover, some studies used student cohorts, controlled lab designs, or highly specialized clinical groups of participants, which might not be representative of wider clinical populations and are prone to selection or response biases.

Another weakness of the evidence used in this review was that there were large differences across investigations in intervention types, study methods, participant characteristics, and outcomes. Most studies evaluated only short-term outcomes and had little or no long-term follow-up, limiting the ability to generalize about the sustainability of effects and their real-world application. Outcome measures were diverse and consisted of self-reported perceptions, knowledge-based measures, speech fluency measures, psychological scales, and physiological measures, restricting comparison across studies and ruling out quantitative synthesis. Moreover, a number of studies have provided enhanced results but have not presented standardised effect sizes or percentage outcome data.

It is also recognized that the results measured across studies varied in their clinical applicability, where some interventions were involved in educational or training results, but not the direct clinical effectiveness of people who stutter. Only a few studies have measured psychological and affective outcomes, and usually these were based on indirect measures, physiological responses, or self-report scales rather than a thorough psychological evaluation. Lastly, the geographical distribution of the included studies (included in the sample) might affect the generalizability of the results, as they were carried out in different countries and under different educational or clinical conditions, with possible disparities in service delivery, training routes, access to technology, and clinical practice.

5. CONCLUSION

Interventions that are technology-based, especially virtual reality-based simulations, and speech analysis systems that are driven by artificial intelligence showed positive results in terms of the development of clinical skills and the outcomes associated with stuttering. Simulation-based and virtual patients facilitated communication and enhanced clinical skills, whereas artificial intelligence-based interventions demonstrated accuracy in stuttering detection and, in certain scenarios, a decrease in stuttering errors. Data on robot-assisted and multisensory feedback interventions are still developing, and few studies have presented psychological and physiological improvements. The technology-based models of delivery are also in their infancy, and there is no clear sign of which model is most effective, efficient, or sustainable with regard to available data. Although the relationship between stuttering and psychological well-being has been recognised, there has been limited research directly assessing psychological outcomes; thus, additional controlled trials are necessary in this field.

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ABBREVIATIONS

Abbreviation	Full Form
AI	Artificial Intelligence
VR	Virtual Reality
SLT	Speech-Language Therapist
RCT	Randomized Controlled Trial
SLP	Speech-Language Pathology
PWS	People Who Stutter
DAF	Delayed Auditory Feedback
FAF	Frequency-Altered Feedback
AMFS	Augmented Multisensory Feedback Stimulation
SSI	Stuttering Severity Index
WHO-ICF	World Health Organization – International Classification of Functioning
VHI	Voice Handicap Index
SMOTE	Synthetic Minority Oversampling Technique
BiLSTM	Bidirectional Long Short-Term Memory
MFCC	Mel-Frequency Cepstral Coefficients

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