

PAPER

The Role of CALL, MALL, and Assistive Technology in Supporting Dyslexic Learners: A Review and Analysis

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ABSTRACT

In recent years, computer-assisted language learning (CALL), mobile-assisted language learning (MALL), and assistive technologies (AT) have emerged as promising tools for supporting dyslexic learners in their educational journey, along with the traditional teaching methods. This systematic literature review explores the range of CALL, MALL, and AT's available to enhance the learning process of students with dyslexia. Also, the review examines recommendations for improving the learning experience through mobile applications and provides an overview of dyslexia's cognitive and neurological impact on language learning. The methodology involved reviewing ten journal articles and one thesis focused on interventions for dyslexic students. Findings (n = 11) indicate that CALL, MALL, and AT significantly improve reading, spelling, pronunciation, and engagement by offering personalized, multisensory, and accessible learning experiences. The effectiveness of these tools is maximized when they are interactive, teacher-supported, and continually optimized for individual and diverse needs. The review concludes that CALL, MALL, and AT offer effective, inclusive solutions that enhance literacy skills and learning engagement among students with dyslexia when appropriately designed and implemented.

KEYWORDS

dyslexia, mobile-assisted language learning (MALL), computer-assisted language learning (CALL), assistive technology (AT), reading fluency, dyslexic

1 INTRODUCTION

Dyslexia is a specific learning disability that is neurological in origin and characterized by persistent difficulties in word recognition, decoding, and spelling [1], [2]. The scientific community widely agrees that dyslexia has neurobiological and genetic origins that affect the brain's ability to process phonetic information [1]. Estimates of the prevalence of dyslexia range from 5% to 17% of the population among children [3]. Common dyslexic characteristics include letter inversion, omission of letters or words, difficulty in recalling letter sounds, and sequencing issues.

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Additional symptoms may involve challenges in spatial orientation, coordination, memory, oral expression, and written communication [3], [4]. These challenges can lead to difficulties in comprehension, slower reading speeds, and an overall sense of frustration when trying to engage with written materials [2]. The impact of dyslexia extends beyond the classroom, affecting self-worth and self-esteem. Children with dyslexia often feel isolated and stigmatized, which can hinder their social and emotional development [4].

According to Boder's classification, dyslexia is divided into three types [5], each with distinct symptoms namely: phonological dyslexia, surface dyslexia, and mixed dyslexia. Phonological dyslexia involve a deficit in the assembly pathway, leading to difficulties in reading non-words and a tendency to guess words rather than decipher them. Surface dyslexia results from a visuo-attentional disorder that affects the ability to automate reading from the visual form of words, with frequent confusion between phonetically similar words [6]. Mixed dyslexia combines difficulties in both pathways, resulting in laborious and often misunderstood reading, which can lead to a complete inability to read [5], [6].

From a cognitive perspective, individuals with dyslexia struggle with accurate and fluent word recognition, which in turn limits the cognitive resources available for comprehension [7]. Essentially, dyslexic individuals require specialized attention in their early years of life. The severity of dyslexia can persist throughout the life of an individual if no early and specialized intervention is done [8]. It is a myth that dyslexia have no cure, but with proper diagnosis, instruction, and support, individuals with dyslexia can be successful academically and professionally [6] [7]. Dyslexic is not low in intelligence; most individuals with dyslexia are highly capable and excelled in various fields [7].

Neurological studies show that dyslexia affects the functions of the brain responsible for phonetic processing, working memory, and rapid visual recognition of words [6], [9]. According to a report by Discovery ABA [10], mentioned, more than 780 million people worldwide are dyslexic; but the sad part is just two million of them are diagnosed. It hinders the individuals from expressing themselves clearly or understanding others. This underdiagnosis leads to lack of confidence and even school dropouts.

In the modern era, the explosion of technology across various sectors has opened new possibilities in educational inclusion [11]. The past two decades have seen an unprecedented proliferation of mobile technology, with smartphones and tablets becoming ubiquitous in our daily lives and the developments in computers and AT are of great help to students with dyslexia [8], [12]. The integration of digital tools in education is very important, especially as innovation and digitalization continue to advance to meet various needs, and it engages dyslexic students through technology that captures their attention and helps specialists better understand their behavior in learning and reading comprehension tasks [13]. The researchers are exploring interventions focusing on improving phonological awareness, minimizing confusion in spelling, and using legible fonts are effective learning strategies for children with dyslexia [14], [15].

Mobile apps such as *EasyLexia* [16], *Desembaralhando* [17], and *ALEXZA* [18] are proven with best results for dyslexic learners. Assistive tools such as the text-to-speech (TTS), speech-to-text (STT) software (which reads text aloud), and visual aids and the Orton-Gillingham multisensory approach would significantly ease the reading process for dyslexic learners' literacy skills [19].

Incorporating computer-assisted language learning (CALL), mobile-assisted language learning (MALL), and assistive technologies (AT) provides learning support 24/7, self-paced learning, promotes independence and allows students to revise the lessons as and when required [20], [21].

1.1 Research objective and questions

This paper aims to explore a comprehensive review of how CALL, MALL, and ATs can be used to support language learning among dyslexic learners. It also seeks to identify their effectiveness, common features, challenges, and best practices to inform future optimization.

Based on this background, the study raises the following core research questions:

RQ1: What is the role of CALL, MALL, and AT in supporting dyslexic in language learning?

RQ2: What does the existing literature suggest about the effectiveness of CALL, MALL, and AT in improving the learning outcomes of dyslexic students?

RQ3: What are the common features of CALL, MALL, and AT that aid dyslexic learners in reading, writing, and comprehension?

RQ4: How can future mobile and AT be optimized to better meet the needs of dyslexic learners?

2 METHODOLOGY

2.1 Identification

The study adopted the [22], [23] preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework for its systematic review. Three core steps were followed to identify relevant scholarly publications. In the first stage, keywords were identified through consultation of dictionaries and prior academic studies. Based on these terms, search strings were constructed and applied across major academic databases, including Scopus, Wiley, SAGE, and PubMed Central (refer to Table 1). A few of them were also considered by ResearchGate and Google Scholar. A total of 56 papers were successfully retrieved during this initial phase of the review process.

Table 1. Identification of keywords [24]

Scopus	TITLE-ABS-KEY "Mobile learning" OR "Mobile technology" OR "Mobile application" "Mobile apps," "MALL" OR "Assistive Technology," OR "Computer-Assisted Language Learning," "CALL"AND dyslexic* (Title) and Article (Document Types) AND ((LIMIT-TO (LANGUAGE , "English")) AND ((LIMIT-TO (PUB YEAR between 2006 -2024))
PubMed Central	TITLE-ABS-KEY "Mobile learning" OR "Mobile technology" OR "Mobile application" "Mobile apps," "MALL"OR "Assistive Technology," OR "Computer-Assisted Language Learning," "CALL" and "dyslexia") AND dyslexic* (Title) and Article (Document Types) AND ((LIMIT-TO (LANGUAGE , "English")) AND ((LIMIT-TO (PUB YEAR between 2006 -2024))
Wiley & SAGE	TITLE-ABS-KEY "Mobile learning" OR "Mobile technology" OR "Mobile application" "Mobile apps," "MALL" OR "Assistive Technology," OR "Computer-Assisted Language Learning," "CALL" AND dyslexic* (Title) and Article (Document Types) AND ((LIMIT-TO (LANGUAGE , "English")) AND ((LIMIT-TO (PUB YEAR between 2006 -2024))

2.2 Screening

In the second step, duplicate papers were removed during the initial screening phase. After identifying 56 publications, 29 were rejected in the study's initial phase.

In total, 27 papers were evaluated using scholarly inclusion and exclusion criteria (refer to Tables 2 and 3). The primary focus was on the literature, which included research publications. Additionally, the review only considered materials written in English. It is important to know that this strategy covered a period from 2006 to 2024. Only one paper was from 2006, and the others were taken from the last decade and a half.

2.3 Eligibility

In the third step 11 articles in all have been prepared for the eligibility phase. At this stage, each article’s titles and key points were closely scrutinized to ensure that the inclusion requirements were satisfied and that the articles aligned with the objectives of the current study. Fourteen papers were therefore rejected because they lacked empirical basis and were therefore not considered pure scientific publications. Finally, 11 articles were used for the study, according to Tables 2 and 3.

2.4 Inclusion criteria

A set of criteria were defined to include research articles for comprehensive review, which are explained in Table 2.

Table 2. Inclusion criteria

S.No	Inclusion Criteria
1	Studies published between 2006 and 2024 to focus on recent advancements.
2	Peer-reviewed journal articles and dissertations.
3	Research focusing on CALL, MALL, AT, or mobile applications related to dyslexia.
4	Studies published in English.
5	Research involving human participants (e.g., learners with dyslexia).
6	Articles that discuss technological interventions, effectiveness, or usability for dyslexic learners.

2.5 Exclusion criteria

This criterion excludes the irrelevant journals that were out of scope to the study which are explained in the Table 3.

Table 3. Exclusion criteria

S.No	Inclusion Criteria
1	Studies published before 2006 (unless foundational or highly relevant).
2	Publications that are not peer-reviewed (e.g., blog posts, opinion pieces, or editorials).
3	Research that does not involve computer or mobile assisted language learning or AT.
4	Studies not published in English.
5	Studies focusing on general learning disabilities without specific reference to dyslexia.
6	Studies centered on non-human subjects or non-educational contexts.

2.6 Data abstraction and analysis

The selection was focused on experimental studies on CALL, MALL, and AT for dyslexic learners, emphasizing their role in mitigating the effects of dyslexia. The researcher selected a set of selected peer-reviewed journal articles, and a dissertation was included as the key references for the literature review. During data analysis, records were maintained collaboratively with the co-author, considering factors such as participants, study purpose, research design, and findings. After filtering articles by publication year (2006–2024), a subset of results was further processed for review. Applying the full set of inclusion and exclusion criteria, eleven final papers were selected and then elaborated on each established subject, identifying associated themes, concepts, and ideas. A log was maintained throughout to document analyses, perspectives and insights relevant to interpretation. Comparative analysis was conducted to identify any inconsistencies in theme development, with discrepancies resolved through internal discussions among the authors. The resulting themes were refined for consistency.

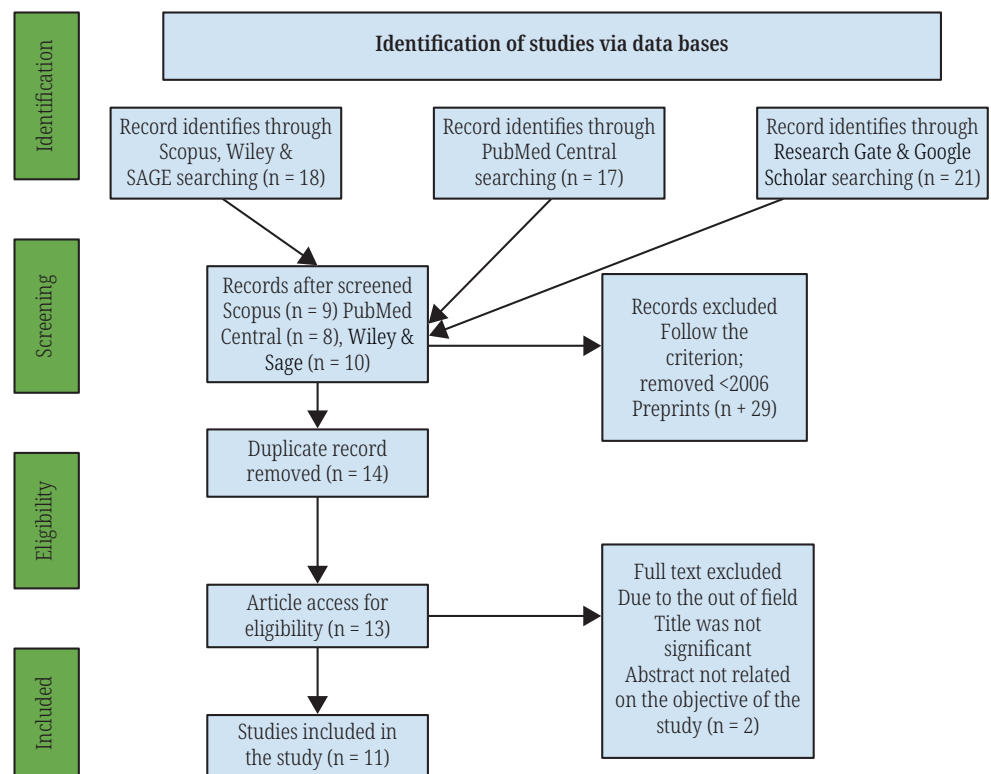


Fig. 1. PRISMA flow chart [22], [23]

3 FINDINGS

3.1 Purpose and study design

The researcher has categorized the studies into three main categories for dyslexic learners-CALL, MALL, and AT. The data gathered from these studies were organized into a table, categorizing them by tools, authors, participants, features, studies,

impact, results, findings, optimization area, and evidence. The table includes peer reviewed journal articles and a thesis.

3.2 CALL, MALL, and AT supporting dyslexic learners

Table 4 summarizes how CALL, MALL and AT support dyslexic learners and highlights the key findings, interventions, outcomes and tools that improve their reading, writing and comprehension skills.

Table 4. Support from CALL, MALL, and AT for dyslexic learners; findings for RQ1

Authors & Year of Study	Supporting Tools/Approach	Participants	Intervention/ Features	Main Findings
Skiada et al. (2022) [16]	EasyLexia (MALL)	Five dyslexic students	Gamified, interactive exercises	Enhanced engagement, reading accuracy, and spelling abilities among children with dyslexia. Participants showed noticeable improvement in literacy skills, demonstrating that mobile-assisted interventions can be effective in supporting dyslexic learners. All students preferred completing and practicing various tests on a mobile device rather than that of paper.
Rajapakse et al. (2023) [18]	ALEXZA (MALL, AI-based)	Individuals diagnosed with dyslexia.	AI-driven, personalized, gamified, AR-based learning	The prototype demonstrated tailored assistance motivating learning; fostered sustained use and learner autonomy
Cidrim et al. (2023) [17]	Desembaralhando (MALL)	Children aged 7 to 10 years diagnosed with dyslexia.	Targeted mirror writing, spelling errors, pre/post assessment	Provided an intuitive tool that facilitated the intervention process, helping to minimize difficulties related to letter mirroring in dyslexic children.
Greene (2006) [25]	CALL tools	Dyslexic teenagers in Irish secondary schools	Computer-assisted reading/spelling, multimedia, structured tasks	CALL has significant potential in supporting dyslexic students, but its success depends on the availability of appropriate resources and teacher preparedness. CALL tools, such as speech-to-text, text-to-speech, and spelling correction software, significantly improved reading comprehension and writing accuracy.
R. Werth (2022) [21]	CALL tools	28 dyslexic Children (ages ~ 9–7), two grades below expected level.	A structured literacy program using CALL tools designed specifically to improve reading, writing and phonological awareness.	Enhanced phonological awareness, spelling, and reading fluency among dyslexic children, which has reduced frustration and increased learner engagement. Copying words from the screen and writing them from memory both reduced spelling errors compared to reading alone, while all three methods equally enhanced reading accuracy and fluency.
Gunilla Almgren Backa et al. (2022) [15]	AT (TTS, STT, VR, etc.)	Nine dyslexic students (eight adolescents and one adult)	Consistent use of TTS, STT, audiobooks, VR, interviews and questionnaires	Improved dyslexic students' writing skills, boosted confidence, made them work in independence, and improved academic performance over five years. However, ongoing support and training were crucial for sustained benefits.

3.3 Effectiveness of mobile applications and digital tools for dyslexic learners

Table 5 summarizes study findings on the impact of MALL, CALL, and AT tools, highlighting improvements in reading, spelling, phonological awareness, and self-esteem among dyslexic learners.

Table 5. Effectiveness of mobile applications and digital tools for dyslexic learners; findings for RQ2

Tool/Approach	Study (Year)	Outcome Area	Effectiveness/Results
EasyLexia (MALL)	Skiada et al. (2022) [16]	Reading, spelling	Identified significant positive outcomes in reading and spelling through gamified exercises
Desembaralhando (MALL)	Cidrim et al. (2023) [17]	Spelling, mirror writing	Noted reduced errors, improved spelling via pre/post assessments
DysEggxia (MALL/AT)	Rello et al. (2022) [26]	Spelling	Notable identified reduction in spelling mistakes in the experimental settings
CALL tools	Greene (2006) [25]	Reading, spelling, comprehension	Improved outcomes, especially with teacher facilitation
CALL tools	R. Werth (2022) [21]	Reading, writing and phonological awareness	Enhanced phonological awareness, spelling, and reading fluency, reduced frustration and increased learner engagement.
AT (TTS, STT, audiobooks)	Gunilla Almgren Backa et al. (2022) [15]	Writing, self-esteem, academic achievement	Long-term use led to improved writing, self-esteem, and overall academic performance
Systematic Review	Politi-Georgousi & Drigas (2022) [27]	Screening, intervention	Mobile Apps delivered personalized learning; need for standardization

3.4 Common features of CALL, MALL, and AT for supporting dyslexic learners

Table 6 presents the core features of CALL, MALL, and AT such as gamification, personalization, multisensory input, and accessibility that supports dyslexic learners by engaging, motivating, and through other literacy outcomes.

Table 6. Common features of CALL, MALL, and AT for supporting dyslexic learners; findings for RQ3

Feature	Impact on Dyslexic Learners	Description/ Example Tools	Supporting Studies
Gamification	Increased motivation, and engaged the participants, and lead to a sustained use	Levels, rewards, challenges were part of it and all that motivated (EasyLexia, Desembaralhando)	Allafi (2023) [28], Skiada et al. (2022) [16], Cidrim et al. (2023) [17]
Independence	Fostered autonomy, reduces frustration, builds confidence	AT tools (reading pens, audiobooks, VR) were used	Gunilla Almgren Backa et al. (2022) [15]
Personalization/ Adaptivity	Tailored based learning strengths needs and prevented overload	ALEXZA, AI-driven customization	Rajapakse et al. (2023) [18]
Accessibility	Reduced cognitive load, increased inclusivity	Used dyslexia-friendly fonts, overlays, TTS/STT	Politi-Georgousi & Drigas (2022) [27]
Multisensory Input	Supported in memory retention, compensated for the phonological deficits	Was through visual, auditory, kinesthetic, AR (AR Apps)	Lazo-Amado & Andrade-Arenas (2023) [11]
Immediate Feedback	Promoted error correction, progress tracking was done effectively	Real-time correction and guidance was given	Cidrim et al. (2023) [17], Rello et al. (2022) [26]

3.5 Future directions for optimizing mobile and assistive technologies for dyslexic learners

Table 7 presents key recommendations for optimizing future MALL and AT tools, focusing on personalization, multisensory engagement, universal design, teacher support, and user-centered development to better support dyslexic learners.

Table 7. Future directions for optimizing mobile and assistive technologies for dyslexic learners; findings for RQ4

Supporting Studies	Evidence/Examples	Optimization Area	Recommendations for Future Tools
Lazo-Amado & Andrade-Arenas (2023) [11]	AR/VR, haptics, eye-tracking (Lazo-Amado & Andrade-Arenas, 2023)	Immersive/ Multisensory Learning	Integrate AR/VR, multisensory features for engagement and retention
Politi-Georgousi & Drigas (2022) [27]	Dyslexia-friendly fonts, overlays, TTS/STT	Universal Design & Accessibility	Standardize usability, offer adjustable text, intuitive navigation
Rajapakse et al. (2023) [18]	ALEXZA (Rajapakse et al., 2023)	Advanced Personalization & AI	Use AI and analytics for real-time, differentiated instruction
Gunilla Almgren Backa et al. (2022) [15]	Classroom integration, support modules	Teacher Training & Integration	Provide teacher training, lesson plans, and guides
Dawson et al. (2022) [12]	Co-design with dyslexic learners and educators	User-Centered Design	Involve users in development, focus on usability and evidence-based design
Gunilla Almgren Backa et al. (2022) [15]	Inclusive classroom culture	Reducing Stigma	Normalize AT as standard learning tools, not “special” accommodations
Gunilla Almgren Backa et al. (2022) [15]	Long-term, diverse studies needed	Longitudinal & Cross-Cultural Research	Conduct broader, long-term, and cross-cultural studies

Table 7 findings provide a foundation for the discussion, as how the identified features, effectiveness, outcomes align with current educational needs and future directions in supporting dyslexic learners.

4 DISCUSSION

The reviewed studies collectively deepen the understanding of CALL, MALL, and AT for learners with dyslexia, addressing various aspects of development and effectiveness. The tools used offered personalized, accessible, and multisensory experiences, provided their use is supported by the trained teachers.

RQ1: What is the role of CALL, MALL, and AT in supporting dyslexic in language learning?

The incorporation of CALL, MALL, and the AT has enhanced the overall learning experience of the dyslexic population. It has increased their comprehension, reading, and writing skills. In the domain of CALL, Green [25] and R. Werth [21] mentioned that CALL exercises have improved overall phonological awareness,

reading comprehension, and spellings. The features, such as structured activities and multimedia-supported exercises, benefited the learners of dyslexia specifically when facilitated by the trained teachers.

Considering the examples shown by Skiada et al. [16], the mobile app *EasyLexia*, that was created with gamified activities, interactive exercises are proven in increasing use of right spellings, better reading in dyslexic students. Such a positive outcome has resulted in increased student engagement and quantifiable literary gains. On the other hand, mobile app discussed study *ALEXZA* (AI-based & AR-driven) of Table 4 has also provided gamification and interactivity in its exercises, giving a personalized and motivating learning experience besides providing sustained use and learners autonomy. Cidrim et al. [17], have demonstrated that teaching through the app *Desembaralhando*, the dyslexic learners *have* reduced mirror writing errors and spelling errors and this was conducted through experimental pre- and post-testing.

Furthermore, Gunilla Almgren et al. [15], through their five-year longitudinal study, observed that the consistent use of AT, such as that of TTS, STT tools, audio books, and virtual reality has proven to improve the writing skills, confidence and contributed towards better academic outcomes.

The literature reviewed indicates that digital interventions such as CALL, MALL, and ATs engages, empowers, motivates dyslexic learners besides enhancing their literacy skills and provides a platform for them to participate actively and confidently in various classroom activities.

RQ2: What does the existing literature suggest about the effectiveness of CALL, MALL and AT in improving the learning outcomes of dyslexic students?

The reviewed literature strongly emphasizes the effectiveness of CALL, MALL, and ATs in enhancing the learning outcomes of dyslexia students. The digital interventions have been proven to improve phonological awareness, reading accuracy, proficiency in spelling, and comprehension skills provided when the tools are personalized, interactive and are facilitated by the trained teachers.

The interventions of CALL, by Greene [25] and R. Werth [21], mentioned that with its standardized, structured computer assisted language activities, multimedia content the learners improved the phonological awareness, spelling and reading skills. Moreover, the activities engaged the learners with increased motivation. Such an outcome was conducive to learning only when the teacher was a facilitator.

As mentioned by Cidrim et al. (2022) and MALL app *Desembaralhando*, were proven to be effective in reducing the mirror writing errors and spelling mistakes. According to Skiada et al. [16], *EasyLexis* another language App, has been proven in enhancing the dyslexic learners reading and writing skills through its gamified exercises and interactive activities. Rello et al. [26] opined that *DysEggxia*, an I-pad based educational game studied and analyzed also mentioned that it has reduced spelling errors of the students of dyslexia in an experimental setting. Besides these apps a systematic review conducted by Politi-Georgousi and Drogas [27] has emphasized the importance of mobile apps in intervention and screening of dyslexia. The findings emphasized standardized evaluation methods to ensure consistent outcomes.

The AT tools, such as STT, TTS, audiobooks and digital highlighters, enhanced the dyslexic students' reading, writing, spellings and decoding of letters. Gunilla Almgren Backa et al. [15], in their longitudinal study mentioned that the sustained use of these technologies for a period of five years, had a noticeable effect on academic performance, writing skills, and self-esteem amongst the dyslexic learners.

The studies indicate that the effectiveness of the results are dependent on various factors such as the design of the digital tools, quality of the digital tools, level of personalization, interactivity, usability and the role of a teacher as a facilitator. In conclusion, the integration of CALL, MALL, and AT is not just confined to the literary skills, it also enhances the learner's autonomy, independence, self-assurance, engagement, and confidence of the dyslexic learners.

RQ3: What are the common features of CALL, MALL, and AT that aid dyslexic learners in reading, writing, and comprehension?

Literature review reveals that CALL, MALL, and AT share several features that support the dyslexic learners in developing their reading, writing, and comprehension skills. The prominent features of these apps are *gamification and interactivity*, which enhance student motivation and engagement. Apps such as *EasyLexia* [16], *Desembaralhando* [17], and platforms studied by Allafi [28], integrate game-based elements that include the levels, rewards, and interactive challenges that transform traditional learning into a goal-oriented activity with involvement. Such involvement sustains attention and promotes regular use with concentration.

Another key component across CALL, MALL, and AT is *Multisensory input*. It strengthens language through a variety of sensory channels, including tools that utilize visual, auditory, and kinesthetic elements. Lazo-Amado & Andrade-Arenas mentioned that multimodal approach is much more effective for dyslexic learners, as it supports memory retention and improves phonological processing and comprehension skills.

One of the shared features is *adaptivity and personalization*, *ALEXZA* [18], an AI-driven tool that measures the performance of learners by offering customized exercises and immediate feedback, which are tailored to one's specific strengths and weaknesses. This kind of adaptive learning ensures the learners to be overwhelmed, thereby supporting their progress at a comfortable and productive pace.

Immediate feedback and interactivity are another best feature that have been emphasized in the works of Rello et al. [26] and Cidrim et al. [17], such features allow the learners to receive real-time corrections and guidance. This helps the students to identify their errors and track their progress. All this encourages learning by correcting the misconceptions as they appear, which is essential for improving phonological awareness and spelling accuracy.

In addition to the above, the *accessibility features* make digital tools more inclusive for dyslexic learners. As Politi-Georgousi & Drigas [27], highlight, most of these platforms include dyslexia-friendly fonts, color overlays, customizable text and size, and STT or TTS functions. These accessibility features help to reduce cognitive load and make the content more readable and less intimidating, thus fostering a more welcoming learning environment.

All these tools foster *independent learning*, which is most important in developing self-confidence among dyslexic learners. With the help of AT such as reading pens, audiobooks, digital highlighters, and virtual reality environments, the learners can access and process language content without being overly dependent on teachers or peer groups. Over time, this fosters autonomy, reduces frustration, and builds a sense of accomplishment. In summary, these features not only enhance literacy outcomes but also empower learners with the confidence and tools they need to succeed academically and beyond.

RQ4: How can future mobile and AT be optimized to better meet the needs of dyslexic learners?

The existing literature highlights avenues through which future digital tools can be optimized. The use of *AI and analytics for real-time* differentiated instruction. Rajapakse et al. [18] illustrate in their study of *ALEXZA*, an AI-powered app dynamically adapts to learners' performance levels and cognitive profiles. Using such a model, the future tools must leverage machine learning and real-time analytics to provide differentiated instruction, tailored content, adjusting pacing, content difficulty, and feedback based on user's progress.

Immersive and multisensory learning environments reinforce retention and comprehension by targeting multiple learning pathways. For example, Lazo-Amado et al. [11], demonstrated that by integrating AR, it has improved student engagement and their reading comprehension. Future technologies must incorporate AR/VR, haptic feedback, and even eye-tracking to deepen engagement and accommodate various learning styles. Multisensory apps with blended visual, auditory, and kinesthetic inputs offer varied supportive learning for dyslexic.

According to Politi-Georgousi and Drigas [27], *Universal design and accessibility* is a dire need for standardization in usability and accessibility. The future apps should be developed with a universal design, dyslexia-friendly fonts, adjustable text sizes, color overlays, ensuring intuitive navigation and TTS and STT compatibility tools. Gunilla Almgren Backa et al. [15], highlight in their study the importance of *classroom integration and teacher training*. Future tools should provide teacher training modules, user guides, and classroom ready lesson plans that pedagogically support dyslexic learners. Also, Dawson et al. [32] warn that many dyslexia apps lack evidence-based design. To address this the developers should co-design tools with dyslexic students, educators, and special education experts and then bring a user-centered design.

The success of tools depends on *social acceptance, longitudinal research and cross-cultural validity*. Hence tools must be normalized as everyday learning aids and should be integrated into inclusive classrooms to reduce stigma and boost confidence. Finally, there is a need for longer-term studies to evaluate the sustained impact of these tools. Research must go beyond short-term gains and examine how CALL, MALL, and AT influence learners' literacy skills, confidence, and academic outcomes over time.

These optimizations transform educational technologies into powerful, inclusive, and sustainable tools for improving the literacy outcomes and build confidence of dyslexic learners. Thus, by addressing these areas, educational technologies become more powerful, inclusive, and sustainable in enhancing the learning outcomes of students with dyslexia.

5 CONCLUSION

The incorporation of CALL, MALL, and AT has enhanced the overall learning experience of the dyslexic population. In the domain of CALL, Green [25] and R. Werth [21] mentioned that CALL exercises have improved the phonological awareness, read comprehension and spelling skills of dyslexic.

Mobile apps such as *EasyLexia*, *Desembaralhando*, and *ALEXZA* showed a significant improvement in spelling proficiency and reading accuracy, through its game-based elements (e.g., Allafi [28]), which have increased learners' motivation and engagement through its gamified exercises and interactive activities. Assistive tools such as dyslexia-friendly fonts, colour overlays, customizable text and size, and STT or TTS have proven effective under the guidance of trained facilitators.

Gunilla Almgren et al. [15] longitudinal study of five years also confirmed that if AT is used consistently the academic outcomes, writing skills and the confidence of the dyslexic learners will enhance.

Furthermore, the reviewed literature demonstrates that features such as gamification, (e.g., Cidrim et al. [17], Allafi [28], Skiada et al. [16]), the personalization feature as identified by Rajapakse et al. [18] multisensory input according to Lazo-Amado & Andrade-Arenas [11] accessibility feature as emphasized by Politi-Georgousi & Drigas [27] and real-time feedback by Cidrim et al. [17] and Rello et al. [26] contribute to measurable improvements. These features help in reducing the cognitive load, making content more readable and less intimidating, for the learners and foster a learner-friendly environment.

The studies highlight the need to prioritize inclusivity and accessibility in educational technology. Effective implementation not only needs thoughtfully designed digital tools but also needs systematic teacher training and ongoing support, thus ensuring that every child, regardless of their learning profile, gets an opportunity to thrive in a supportive and inclusive educational setting.

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