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Enhancing teaching and learning for pupils with dyslexia: A comprehensive review of technological and non-technological interventions

Salman Javed[1] · **Manoranjitham Muniandy**[1] · **Chen Kang Lee**[1] · **Husniza Husni**[2]

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Abstract
Dyslexia is the most prevalent disorder in the world that causes difficulties with reading, writing, and spelling. Pupils with dyslexia show trouble with their cognitive skills. Various interventions were already introduced for their treatment but dyslexia is still a trending disorder. The available interventions utilized for these pupils' learning open the research area for the current state-of-art of learning interventions for pupils with dyslexia. The results of this Systematic Literature Review show the trending interventions, sensory approaches utilized, and difficulties for pupils with dyslexia learning. Papers published over a period of 5 years were reviewed and their data was collected using a rigid systematic process. Based on the gathered data, several analyses were conducted. The search shows that nowadays, technological-based interventions are trending specifically apps and games, in parallel haptics technology is in its very initial stage. The most predominant sensory approaches were visual and auditory, followed by kinesthetic and tactile, mainly intervening with non-technological and technological interventions. There are still many open issues and research opportunities in the field of learning interventions for pupils with dyslexia, as most researchers utilized the visual and auditory approaches for the feedback and guidance of these pupils, while they lack to utilize the kinesthetic and tactile.

Keywords Dyslexia · Haptics · Sensory approaches · Cognitive skills

✉ Manoranjitham Muniandy
manoranm@utar.edu.my

[1] Faculty of Information and Communication Technology (FICT), Universiti Tunku Abdul Rahman (UTAR), Kampar, Malaysia

[2] School of Computing, Universiti Utara Malaysia, Sintok, Malaysia

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1 Introduction

Dyslexia is a neurodevelopmental disorder and type of learning disorder (Novembli & Azizah, 2019) as shown in Fig. 1, manifested as a result of challenges with word-accurate identification and weak reading and writing skills (Yuzaidey et al., 2018). According to the International Dyslexia Association, dyslexia affects 10% to 15% of the world's population ((IDA), 2020). Dyslexia is not a physical condition like a visual problem; rather, it refers to how the brain processes information. Dyslexia is a brain processing condition that affects a person's ability to break down words into their component parts when reading, speaking, or writing (Mills, 2018). A person's literacy abilities, or their capacity to read, write, speak, and listen in a way that allows them to effectively communicate, are impacted by dyslexia. Reading is the process of understanding text which is crucially affected by dyslexia. Pupils with dyslexia show trouble with vocabulary, fluency, the blending of words, recognition of words, memorization of words, and pronunciation all are necessary for reading (Novembli & Azizah, 2019). Reading and writing are both dependent and underlying processes that are connected (Hebert et al., 2018). Before writing any content, writers usually need to examine source materials. They also have to read their work to detect text issues such as spelling and grammatical faults and disorganization with the use of their cognitive skills.

Pupils with dyslexia show trouble with their cognitive skills as shown in Fig. 1; which affects them in the learning process (Hanif et al., 2019). The term "cognitive skills" refers to the fundamental mental processes that go into knowledge acquisition, information manipulation, and higher-order reasoning (Behrman et al., 2022). In developing one's intelligence, cognitive skills are made up of a variety of abilities like understanding, judgment, assessment, thinking, memorizing, paying attention, and remembering that interact and complement one another (Gong & Zhu, 2019). These abilities gather and process information together, and they support various cognitive skills like think, read, learn, remember, reason, and pay attention (Gong & Zhu, 2019). Cognitive abilities affect learning capacity and effectiveness since they



Fig. 1 Dyslexia learning process: (Hanif et al., 2019; Novembli & Azizah, 2019; Russell-Chapin et al., 2020; Romero, 2020; Saputra et al., 2018)

are closely linked to information processing (Islam et al., 2022). Processing different types of sensory information requires strong cognitive abilities (Islam et al., 2022).

A person's ability to coordinate sensory inputs with motor outputs and maintain a sensorimotor rhythm depends on their brain function. Sensory systems such as VAKT (visual, auditory, kinesthetic, and tactile) are responsible for receiving information, while sensory processing performs perception, organization, and interpretation of this information (Kilroy et al., 2019). Sensory integration is the ability to respond to stimuli with suitable motor and behavioral responses. The term "motor responses" refers to the body's muscles' movement to perform certain tasks (Dias da Silva & Postma, 2022). A person will be able to strengthen the control of their brainwaves by making use of their abilities to carry out motor movements and enhance sensorimotor rhythm (Russell-Chapin et al., 2020). Training interventions typically include exercises involving both motor and sensory activities, despite being intended to increase sensory functions (Zemková, 2022). It may be more efficient to do motor training activities and sensory stimulation simultaneously (Mollajani et al., 2019). All children, even those with dyslexia, benefit from using a multisensory approach since it combines visual, auditory, tactile, and kinesthetic learning components which activate multiple regions of the brain (Johnston, 2019). Due to their increased creativity and robust sensory receptors, a multi-sensory approach is seen to be the most effective for pupils with dyslexia learning (Saputra et al., 2018).

Using a multi-sensory approach as shown in Fig. 1, pupils with learning difficulties can learn more effectively (Romero, 2020; Saputra et al., 2018). Effective interventions for pupils with dyslexia follow a methodical and hierarchical approach, teaching simpler skills before more difficult ones, employing a variety of response modalities to enhance learning, and using different assessment methods (Denton et al., 2021). If the right interventions will be provided, pupils with dyslexia can learn to read and write successfully. During instruction, the student should gradually take on more responsibility as the teacher serves as a model, offloading the teacher's cognitive load (Johnston, 2019). This process begins with the teacher providing guided teaching, followed by cooperative learning and ultimately independent learning. Various non-technological and technological teaching and learning approaches were introduced for pupils with dyslexia. Non-technological approaches have ordinary teaching and learning modules that help pupils with dyslexia but not in an optimal way. In this digital era, the advancement of technology plays a vital role. The rise in literacy, combined with the rapid evolution of technology, has resulted in the growth of technology in education. Introduces new approaches for teaching and learning of pupils with dyslexia. These technological approaches make teaching and learning easier and more convenient by introducing different apps and games and some assistive technology. Technological advancement mainly improves teaching and learning interventions for pupils with dyslexia. Direct, explicit, and integrated instruction is among the most efficient interventions for these pupils with dyslexia (Denton et al., 2021).

The infrastructure of intervention programs meant for pupils with dyslexia is not optimal. In this respect, this article details the methodology and findings of a systematic review of interventions based on sensory approaches for the learning of pupils with dyslexia. This article followed the guidelines provided

by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009; Moher et al., 2009). Based on these guidelines, Research Questions (RQs) are developed, and the following RQs are the primary focus of this work:

- RQ1: What interventions are currently employed to facilitate the learning of pupils with dyslexia and what are the key characteristics of these interventions?
- RQ2: What primary approaches serve as the foundation for the pupils with dyslexia learning interventions, and what factors contribute to the prevalence of specific approaches?
- RQ3: What research gaps exist in the current understanding of dyslexia learning interventions, and what improvements to the learning process can be made for pupils with dyslexia by addressing these gaps?

The main contribution of this systematic literature review (SLR) is to show the current state-of-art of interventions for the learning of pupils with dyslexia, and the objective is to achieve a critical and comprehensive systematic review. A detailed description of research from the past five years in the field, and also identifying the research gap that helps the researchers to improve the interventions and make easy the learning process of pupils with dyslexia. The objective of this study is achieved through the SLR.

2 Background study

The multi-sensory learning approach involves the most senses possible and utilizing several senses also increases the brain's connections and associations, facilitating memory and learning by facilitating knowledge retrieval in the future (Newman, 2019). The sensory memory system enables people to remember sensory data even after the initial stimulus has ended. The conscious cognitive system known as working memory, which has a constrained capacity, is in charge of temporarily storing, processing, and manipulating information (Bonetti et al., 2018). They collectively agree on how the information is processed. It is essential to cognitive functions including reasoning and decision-making. The more we engage our senses, the more opportunity we give the brain to process information in our preferred way. Utilizing many senses helps all students, including those with dyslexia, to maximize their potential by bridging traditional teaching strategies with these abilities (Mills, 2018). When dyslexic children are taught utilizing multisensory approaches like visual, auditory, tactile, and kinesthetic they learn more quickly, retain information better, and can apply concepts to new learning more readily (Fazmina et al., 2020). Multisensory approaches are associated with vision, sound, movement, and touch-based learning as shown in Fig. 2. Multisensory approaches are found to be most effective with dyslexia.



Fig. 2 Multi-sensory techniques and associated learning

2.1 Visual

The brain area visual cortex is responsible for the sensory-motor function as shown in Fig. 3. The visual activities are controlled by the visual cortex which is present in the Occipital lobe area of the brain (Nguyen et al., 2021). The signal that directs the body to react and conveys information is vision. The vision encompasses more than just being able to see clearly; it also includes related visual skills that have an impact on performance (Millard et al., n.d.). Inaccurate or slow message reception by the visual system may have an adverse effect on performance. Dyslexia pupils have difficulties in visual memory and perception, which is caused by a problem with brain function (Hanif et al., 2019). The main element in processing and remembering the activity's action is visual memory. Being able to read visually is one of the most demanding systems, thus it's crucial for the visual system to perform at its best.

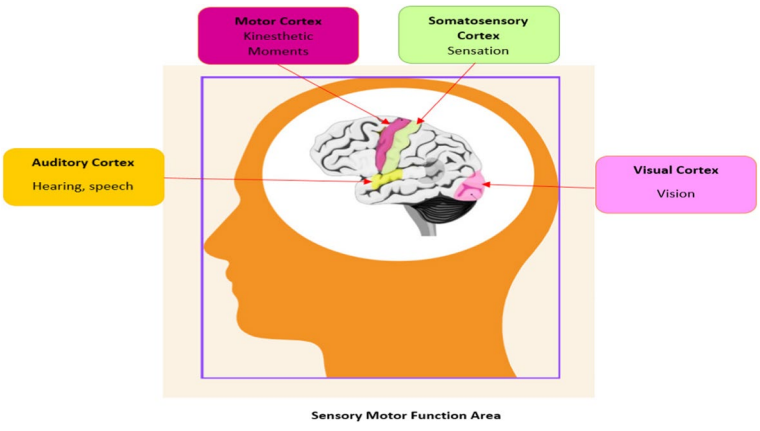


Fig. 3 Sensory motor function areas

2.2 Auditory

The sensory-motor function area of the sound is the auditory cortex as shown in Fig. 3; which is present in the temporal lobe area of the brain (Kell et al., 2018). Sound provides us with a great variety of information about the outside environment. These skills are made possible by neural processing, which converts the sound waveform that enters the ear into cortical representations that are hypothesized to make sound qualities that are crucial for action explicit (Kell et al., 2018). The sound signal directs the body to react and conveys information.

2.3 Kinesthetic

The sensory-motor function area of the movement is the motor cortex in the brain as shown in Fig. 3. The term kinesthetic refers to the body movement that a learner uses to interact with their environment. The human kinesthetic system has the ability of processing, integrating, and remembering information, and the system is based on the immediate perception of motion impulses (Shan et al., 2021). Nevertheless, it is important to remember that our human kinesthetic system not only carries out sensory tasks, such as processing motor impulses but also interprets and retains motor nerve signals. Learning is most effective kinesthetically when learner use their large or gross motor muscles (Ngong, 2019).

2.4 Tactile

The sensory-motor function area of the touch is the somatosensory cortex in the brain as shown in Fig. 3. The most complex and oldest-formed sensory system is the tactile sensation, which has the ability to translate information from the outside physical world into interior feelings (Yu et al., 2020). In the human, touch stimulates a brain network that processes stimuli, having a central node in the superior temporal sulcus (STS). It is well recognized that the STS is a region that is very vulnerable to individual variation, especially for the processing of tactile inputs.

3 Methodology

SLR was used to acquire data for the current study that was pertinent to the study's issue. The systematic review was organized and carried out in accordance with established procedures. PRISMA (Liberati et al., 2009; Moher et al., 2009) was adopted because it gives systematic reviews and meta-analyses reporting a clear direction. The PRISMA specifies three primary phases for doing an SLR: literature review, choosing eligible publications, and data extraction and summarizing.

To ensure that the most recent trend is represented, publications from the past five years were selected as the appropriate time frame for review.

3.1 Eligibility criteria

The eligibility criteria adopted in this SLR are focused on interventions for dyslexia that use sensory activities as a learning approach. The search includes comorbid cases. In other words, research on dyslexia alongside other disorders in relation to intervention in teaching and learning is included. Keep in mind that the criteria do not exclude works that utilized multi-sensory activities.

3.2 Database sources

The search was conducted entirely using the Google Scholar and Scopus search engine. In the target field, these search engines search pertinent digital libraries and/or publishers including Elsevier, Springer, IEEE Xplore, and Taylor & Francis. Journal and conference publications that have undergone peer review that may be pertinent to the objectives of this study are offered by these digital libraries. The relevant papers included in the above-mentioned databases were found using these two search engines Google Scholar and Scopus.

3.3 Keyword search

Keywords pertaining to dyslexia, well-known multisensory approaches, and interventions were used to establish the search terms**.** A set of different related words are used for the search.

> The search string is divided into two groups and each group is connected with the OR operator, and then both groups are connected through the AND operator. Below is the search string:(“Dyslexia”) AND (“intervention” OR “multisensory approach” OR “learning approach” OR “learning technique”) AND (“mobile application” OR “computer application” OR “Information and Communications Technology (ICT)” OR “technological approach” OR “touch device” OR “visual” OR “auditory” OR “kinesthetic” OR “tactile” OR “non-technological” OR “app” OR “game” OR “haptic” OR “compliance control” OR “force feedback”)

The above search string is used to search articles in google scholar and SCOPUS. Using the advanced search of both search engines, Google Scholar returned over 3000 results, so we only considered the entries from the first 100 pages, each of which had 10 articles. Scopus also returned results over 4000, so we only considered the first 50 pages, each of which contained 20 articles. The search was taken into consideration from 2018 to 2022. The second appearance of the exact article in these two search engines was regarded as a duplication and was omitted in the Removed Duplicates stage. As a result, just one occurrence of each article was examined for inclusion.

Table 1 Selection criteria

Sr.No	Description	Criteria
1	Publication year	Articles must be published between 2018 to 2022
2	Publication language	Articles must be written in English
3	Publication focus	Articles must be mainly focused on the learning of dyslexia pupils in the title or abstract
4	Publication type	Articles must be peer-reviewed journals or conferences proceeding

Table 2 Exclusion criteria

Sr.No	Description	Criteria
1	Target of Intervention	The main target of the article is not learning intervention for pupils with dyslexia
2	Use of Intervention	Used the intervention for the diagnosis of pupils with dyslexia

3.4 Study selection

A set of criteria has been employed to limit the findings to a set addressing the RQs, and pertinent publications in the field. Selection criteria serve as the initial filter for collecting pertinent works. The selection criteria are shown in Table 1.

To gather pertinent works, the Selection Criteria were developed as a preliminary filter. Selection criterion 1 calls for a review of the most recent research findings and assistance in identifying trends in the field. Selection criterion 2 is required to make all review readers able to access and read any analytical work outlining the interventions assessments. Selection criterion 3 primarily focuses on the review's area of interest. Selection criterion 4 is to select worthy data from the selected articles which will help in the analysis.

3.5 Exclusion criteria

A set of criteria were employed, if the research focus was poorly described in the abstract, the article was completely retained for a second look. The article's quality was not addressed in the initial stage. The content of the chosen articles was then assessed in accordance with the exclusion criteria as shown in Table 2.

The article was taken out of the results if any of the exclusion criteria were satisfied.

Table 3 Inclusion criteria

Sr.No	Description	Criteria
1	Article objective	The main objective of the article must be related to learning intervention of pupils with dyslexia
2	Intervention approach	Any visual, auditory, kinesthetic, or tactile approach was used to facilitate the learning of pupils with dyslexia in any aspect

3.6 Inclusion criteria

A set of criteria were employed, if the articles pass the exclusion criteria. At this stage the remaining articles are being carefully further analyzed for their context, in accordance with the inclusion criteria as shown in Table 3.

The articles were taken out of the results if any of the inclusion criteria were not satisfied.

3.7 Quality criteria

A set of criteria were employed, if the articles meet any of the inclusion criteria. At this stage now the selected articles process through quality screening, in accordance with the quality criteria as shown in Table 4.

The use of the quality criteria helped to confirm that each article assessed could contribute to resolving the RQs. Each paper that was included would then have access to enough data and details to describe the intervention, how the multisensory approaches worked, and clearly outline the study's goals.

3.8 Data classification

Each of the data points was gathered in relation to the interventions. The classification of the interventions was performed according to elements and gadgets used in activities for the learning interventions of pupils with dyslexia. The

Table 4 Quality criteria

Sr.No	Description	Criteria
1	Objective clarity	Are the research objectives described in clear terms?
2	Analysis of the presented intervention	Are the developed or presented interventions the primary focus of the research?
3	Details of approaches	Are the multisensory approaches and activities clearly described?
4	Detail findings	Are there any definitive findings pertaining to the application of the chosen technologies/approaches/activities? Are the key findings discussed in detail?

learning intervention activities performed, tools employed, participant strengths, and analytic technique were characterized subjectively based on the intervention's description, while the sensory approaches, impact of approaches on learning, and study approach were all gathered objectively from the studies. It is crucial to remember that a single intervention might feature elements from several different activities, tools, strengths, and sensory approaches which can serve one or more purposes.

The classification of the sensory approaches was performed according to which sensory approach is used if an instructor uses both visual and auditory for the learning then both the sensory approaches will be selected. All the approaches which were used will be added and classified as visual, auditory, kinaesthetic, and tactile. The classification of the effects by approaches on learning also added that if the learning intervention is impacted by one or more learning factors then all the factors will be added to this section.

4 Results

4.1 Study selection

After the search in Google Scholar and Scopus, a total of 2000 articles were first found to be pertinent. Before the implementation of the selection criteria, a total of 202 duplicate results were eliminated, producing 1798 results. 625 articles were eliminated after the first step of the selection criteria's title and abstract assessment of the remaining articles, bringing the final number down to 1173. For the second stage, the exclusion criteria, the entire texts of the remaining articles were reviewed, and 547 articles—251 for exclusion criteria 1, and 296 for exclusion criteria 2—were eliminated as shown in Table 5. The 626 articles that were left underwent the inclusion criteria, and 376 more were eliminated. The surviving 250 were subjected to the quality criteria stage, where 216 additional articles were eliminated, resulting in a total of 34 articles being processed in the data extraction phase. Consequently, 34 articles in all were part of this study which were divided into non-technological and technological intervention categories on the base utilized tools for interventions. The PRISMA flow diagram shown in Fig. 4 depicts an overview of this procedure.

Table 5 Number of eliminated articles by each criterion

Criteria description	Criteria 1	Criteria 2	Criteria 3	Criteria 4
Duplication	202	N/A	N/A	N/A
Selection criteria	0	108	239	278
Exclusion criteria	251	296	N/A	N/A
Inclusion criteria	160	216	N/A	N/A
Quality criteria	33	61	48	74

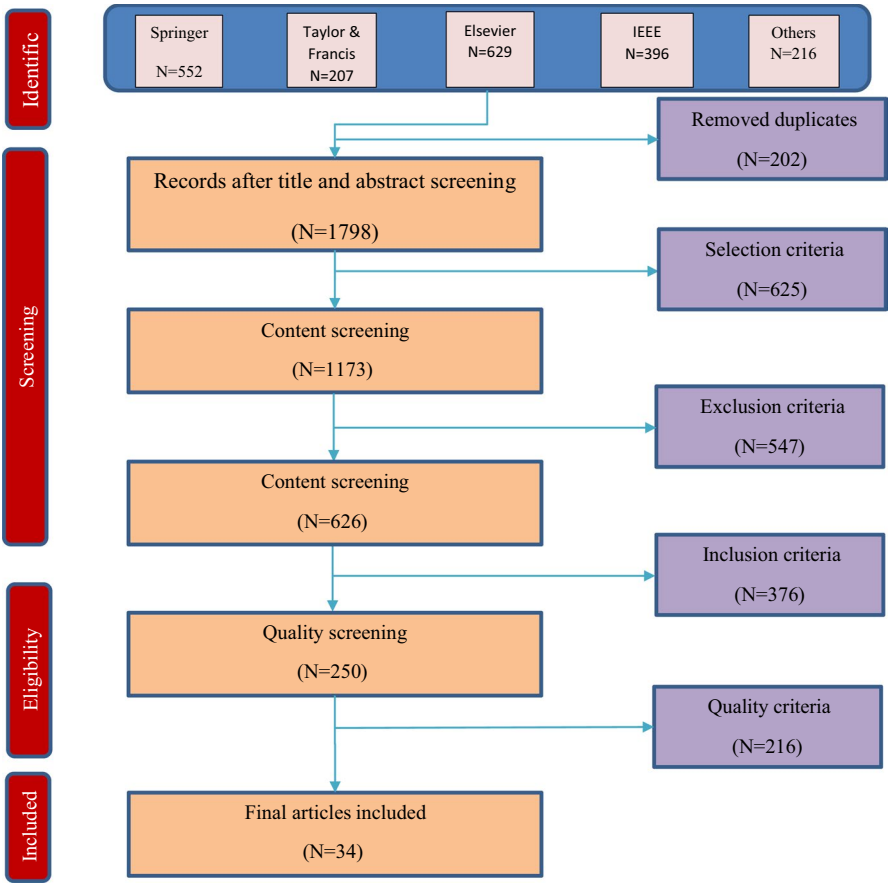


Fig. 4 Flow diagram of PRISMA

4.2 Study characteristics

The selected studies and their respective interventions were classified according to a few criteria such as (1) types of sensory modalities employed, (2) usage of activities as a learning approach. Regarding the employed sensory modalities, all these 34 studies used multi-sensory modalities. All the non-technological studies used the

Table 6 Utilized modalities percentage in each intervention

Interventions	Modalities used			
	Visual	Auditory	Kinesthetic	Tactile
Non-technological	100%	84.6%	38.4%	15.3%
App/Game	100%	93.3%	0%	0%
Haptic	100%	40%	100%	100%

visual (100%), 11 used the auditory (84.6%), 5 used the kinesthetic (38.4%), and 2 used the tactile (15.3%) modalities as shown in Table 6. On the other hand, technological interventions were divided into apps/games and haptics technology. In apps/games, the visual modality is utilized by 100% and the auditory modality is utilized by 93.3% of interventions the tactile and kinesthetic are utilized by 0% as shown

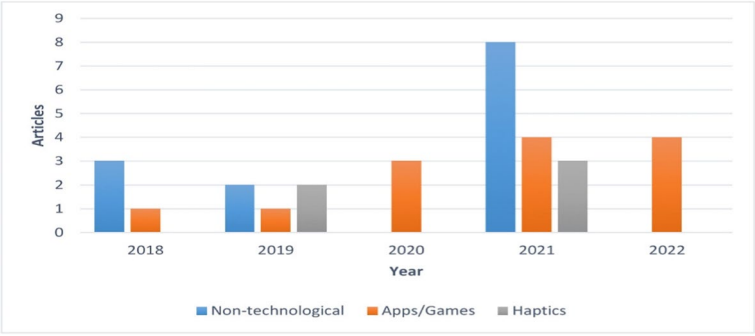


Fig. 5 Number of articles published by year

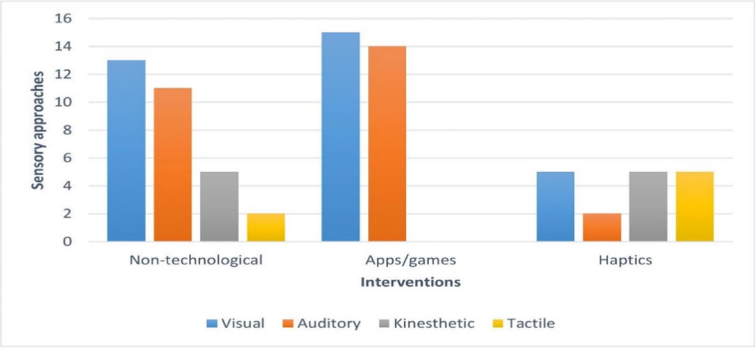


Fig. 6 Number of articles using sensory approaches per intervention

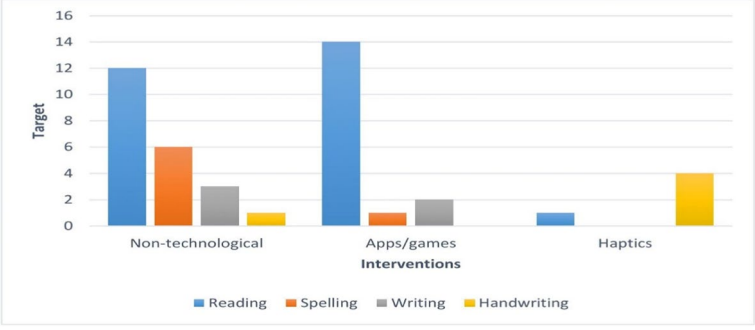


Fig. 7 Number of articles targeting learning skills per intervention

in Table 6. Tactile is just used for data entry not utilized the functions of tactile for learning. In the haptics-based approaches the visual, tactile, and kinesthetic modalities are utilized by 100% of studies in this review, and 40% used the auditory.

Figure 5 shows the intervention published by year and Fig. 6 gives the chart of each sensory approach. Figure 7 shows the number of articles targeting learning skills per intervention. Most of the interventions target reading difficulties but in haptics most of the articles target handwriting.

4.3 Individual studies

Following that, interventions are listed according to their unique qualities and then categorized according to the elements and gadgets they have used for activities. Various interventions are available, and different approaches and components are employed to implement them as shown in Fig. 8.

4.3.1 Non-technological

There are numerous non-technological approaches available for the learning process of dyslexic children. These traditional practices show a positive effect on the learning process of dyslexic children. Mainly these practices focus on reading, writing, handwriting, and spelling. Using various combinations of the VAKT approaches were performed in these practices as shown in Table 7. These are the sensory-motor techniques that take information through the senses and develop responses to that

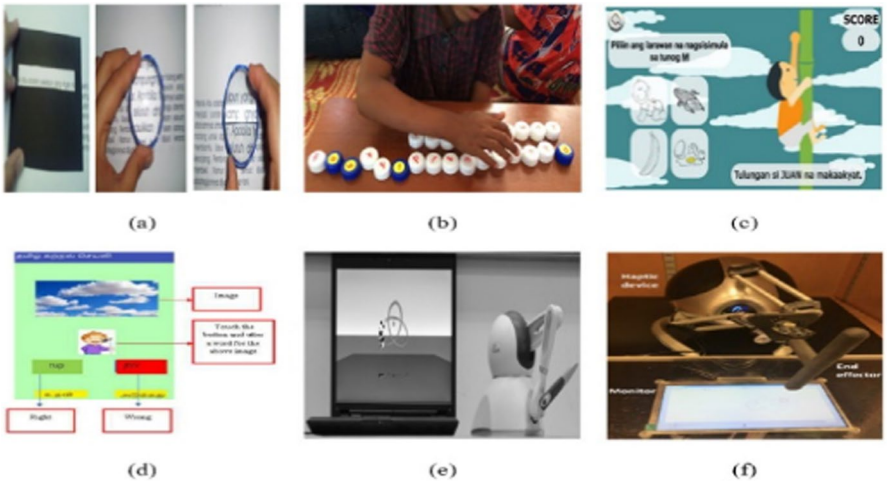


Fig. 8 Components used: **a** Reading Tasks with Typoscope, Visual Tracking Magnifier(VTM), and Magnifier; **b** Alphabet Learning with Plastic Bottle Cap; **c** Story Learning Game; **d** Reading and Vocabulary App; **e** Tracing Wire through Haptic Device; **f** Handwriting on Touch Monitor using Haptic Device From: (Omar et al., 2021; Liu et al., 2021; Bigueras et al., 2020; Karpagavalli et al., 2021; Bingham & Snapp-Childs, 2019; Park et al., 2019)

Table 7 Summary of non-technological interventions

Sr.No	Ref	Modalities used				Effects of approaches	Study approach
		Visual	Auditory	Kinesthetic	Tactile		
1	(Ziadat, 2021)	✓	✓	✓	✓	Oral reading and reading comprehension	Quasi-experimental
2	(Van Reybroeck & Michiels, 2018)	✓	✗	✓	✗	Reading, spelling, and handwriting	Single-case intervention study
3	(Omar et al., 2021)	✓	✗	✗	✗	Reading	Case–control study
4	(Liu et al., 2021)	✓	✓	✓	✓	Reading, writing, and spelling	Quasi-experimental
5	(Wan Norudin & Baba, 2018)	✓	✓	✗	✗	Reading	Qualitative case study
6	(Lee, 2021)	✓	✓	✗	✗	Reading and spelling	Correlational study
7	(Martínez-García et al., 2021)	✓	✓	✓	✗	Reading, writing, and spelling	Experimental study
8	(Van Rijthoven et al., 2021a)	✓	✓	✗	✗	Reading and spelling	Qualitative and Quantitative study
9	(van Rijthoven et al., 2021b)	✓	✓	✗	✗	Spelling	Qualitative study
10	(Ferraz et al., 2018)	✓	✓	✓	✗	Reading and writing	Experimental study
11	(Van der Kleij et al., 2019)	✓	✓	✗	✗	Reading	Longitudinally study
12	(Leloup et al., 2021)	✓	✓	✗	✗	Reading	Longitudinal study
13	(Wang et al., 2019)	✓	✓	✗	✗	Reading	Experimental study

information which encourages cognitive ability. There are numerous tasks and activities like word tracing, skywriting, writing on the wrist, identification of the phoneme, repetition of the rhyme, and drawing the shape of grapheme with a finger involved in the implementation of the VAKT approach.

In this study (Ziadat, 2021), a researcher from Jordan used to examine the VAKT approach effect on the oral reading and reading comprehension of dyslexic children. The study follows a Quasi-experimental approach which has pre and post-test measurement phases. In their study, 39 dyslexic children were divided into a control ($N=19$) and an experimental group ($N=20$). The experimental group deals with specific instructional activities, such as word tracing, skywriting, writing on the wrist, utilizing the word in passages, visual modulation of terms, and instructional materials, such as word cards, highlighted and colored pens, mirrors, sand, and whiteboard. The control group used the normal routine classes in the dyslexic center. This study showed that the experimental group showed more improvement than the control group in oral and comprehension reading. The study's data was restricted to categorical data so the recommendation is to adopt continuous scale measurement. Further study is needed to determine the applicability of the VAKT approach in schools and at home.

Another research from Belgium in his study (Van Reybroeck & Michiels, 2018), shows that finger-writing intervention showed a more positive effect on reading, spelling, and handwriting performance as compared to visual discrimination intervention. This study follows the single-case intervention approach which has pre and post-test measurement phases. In their study, five Developmental Language Disorder children were selected and divided into 2 intervention groups they received finger-writing intervention individually for 2 months. The finger-writing intervention contains different tasks like identifying the shape of the graphemes and letters with their finger and including the phoneme in the syllable of the word. The same intervention exercises were performed except the two finger-writing tasks were replaced by two visual discrimination tasks. Children's performance was compared before and after the treatment based on reading, spelling, handwriting, and phonological awareness. The study has minimal participants and limited items in the grapheme reading task and handwriting instruction which show the worst effect on the precision of results.

Another team of researchers from Malaysia in his study (Omar et al., 2021), determines the effectiveness of simple visual devices in the reading performance of children with dyslexia as shown in Fig. 8(a). A case–control study was conducted in which reading performance was assessed at baseline, week 2nd,6th, and 12th. In their study, 80 dyslexic children aged 8–11 years were selected and divided into four groups: one control group and three groups assigned with the typoscope, VTM, and magnifier. The analysis is done based on the time taken to complete the reading of the text and the reading error rate. The reading performance of magnifiers and the VTM group is significantly increased with 2.5 times faster-reading speed than the typoscope and control group.

In this study (Liu et al., 2021), a Malaysian research team created multi-sensorial-based two programs using phonics that enhance the reading, writing, and spelling skills of children with reading difficulties. One is SMARTER*phonics which is for the English language and another is foniks*PINTAR which is for the Malay

language. This study follows the quasi-experimental approach which has pre and post-test. In this study total of 28 participants are involved who have reading difficulties 16 participants tested in the English language and 12 in the Malay language. The children intervene with multisensory approaches which contain different tasks like; recognizing the letters using bottle caps as shown in Fig. 8(b), visualizing the letters using sky-writing, and also using the tactile mat to trigger fingers nerves during writing. The analysis was done based on task time. These practices facilitate the teaching methodology of teachers who teach language to children with reading difficulties.

Another Spanish group of researchers in his study (Martínez-García et al., 2021), investigates the interaction between spelling and handwriting difficulties in children with dyslexia using visual, auditory, and kinesthetic tasks. The study follows an experimental approach in which dyslexic children were compared with the same age group and same-level reading group. In this study total of 20 dyslexic children were involved who were tested with the spelling to dictation task, an alphabet writing task, and two graphic tasks. Statistical analysis is done and measures included writing latency, total writing duration, writing speed, and peaks of speed. The findings indicated that although children with dyslexia prepared and executed written responses less quickly and accurately than fellow students who were typically developing (TD), they displayed the level of spelling that was expected given their reading proficiency.

In this study(Van Rijthoven et al., 2021a), a group of researchers from the Netherlands examined children with dyslexia, they looked at how well they read words and pseudo words and how well they spelled words after receiving phonics through spelling intervention. They also looked at how consistently the intervention's response held up across various cognitive characteristics. The study follows the qualitative and also quantitative approaches. A total number of 54 Dutch children were chosen for this study. Their parents and teachers first completed questionnaires regarding the child's developmental and present issues and parents were interviewed to rule out other potential causes for reading and spelling difficulties. These children got a structured intervention that incorporated reading and spelling practice and teaching with phonics. From the pre-test to the post-test, there were positive impacts on word and pseudo-word reading speed and word spelling. This study leads to the conclusion that, regardless of the cognitive characteristics, the efficiency of word and pseudo-word reading as well as word spelling positively increases by combined reading and spelling intervention. Despite the encouraging findings, this study also demonstrated how reading and spelling difficulties among children with dyslexia persisted even after an intervention, with reading difficulties being considerably more persistent.

This time group of researchers from the Netherlands in his study (van Rijthoven et al., 2021b) assess the dyslexic children's responses by comparing the phonological, morphological, and orthographic spelling errors made by dyslexic children before and after receiving phonics via spelling intervention. Investigations were also conducted on whether semantics might play a compensatory influence in the intervention's outcomes. In this study, 52 dyslexic and 105 TD children were selected whose native language was Dutch. Results demonstrated that, before the

intervention, children with dyslexia and normally developing youngsters alike made more morphological errors than orthographic or phonological errors. Children with dyslexia committed more errors compared to children with average development in each area, with phonological errors showing the greatest discrepancies. Children with dyslexia who had more fully established semantic representations exhibited lower levels of phonological, morphological, and orthographic mistakes than those who had less fully developed semantic representations. This study indicates that children who are developing their spelling skills and are dyslexic or at risk may benefit from semantic stimulation.

A group of researchers from Brazil in his study (Ferraz et al., 2018) used behavioral and objective measures, to assess the effects of a phonological rehabilitation reading and writing program in dyslexic children. In this study, 20 dyslexic kids between the ages of 8 and 14 were enrolled. These children were divided into two groups; group 1, who participated in the program, and ten others made up group 2, who did not participate in the rehabilitation. Pre and post-testing assessed working memory, phonological awareness, quick naming, the ability to read and write words and non-words, thematic writing, and auditory evoked potential. The phonological reading and writing rehabilitation program were used in a total of 24 sessions, which were held twice a week and lasted 30 min each. There was a significant difference observed in pre and post-testing. The dyslexic kids' written language improved quickly as a result of the phonological remediation program, which is an effective therapeutic strategy.

4.3.2 Technological practices

In this digital era, there are a lot of technological practices for the learning of dyslexic children. Researchers introduced technology to the learning practices of dyslexic children which facilitates the teaching style as well as makes the student learning easy. During the COVID-19 pandemic when schools were closed, dyslexic school teachers widely used these applications in online classes. Mainly the technological practices are divided into two categories Apps/Games and Haptics.

Apps and games The widespread usage of mobile and laptop devices offers a potential tool for developing structural approaches to aiding special-needs children. Apps and Games are easy and interesting ways of learning for students. Most apps and games provided visual and auditory methods as shown in Table 8. Apps and games help dyslexic children in their phonological awareness and grapheme-phonemes. This method also builds the interest of dyslexic children. According to the teacher's point of view apps and games minimize the practicing activities time spent and also provided the opportunity of performing activities individually (Larco et al., 2021). Quality of research done throughout the world shows that Apps and Games play a vital role in the learning process of dyslexic children.

In this study (Mehringer et al., 2020) a group of researchers from Switzerland designed a computer game based on grapheme-phoneme to support the reading of dyslexic children. In this longitudinal study total of 34 dyslexic children were selected and divided into two groups the control group ($N=16$), and the training

Table 8 Summary of apps and games interventions

Sr.No	Ref	Modalities used				Effects of approaches	Study approach
		Visual	Auditory	Kinesthetic	Tactile		
1	(Mehringer et al., 2020)	✓	✓	✗	✗	Reading	Longitudinal study
2	(Minoofam et al., 2022)	✓	✓	✗	✗	Reading	Case-study
3	(Rahim, 2021)	✓	✓	✗	✗	Spelling and Speech	Qualitative and Quantitative study
4	(Bigueras et al., 2020)	✓	✓	✗	✗	Reading	Experimental study
5	(Helland et al., 2018)	✓	✓	✗	✗	Reading	Experimental study
6	(Ansari et al., 2020)	✓	✓	✗	✗	Reading	Pilot study
7	(Karpagavalli et al., 2021)	✓	✓	✗	✗	Reading and writing	Case study
8	(Brennan et al., 2022)	✓	✓	✗	✗	Reading, writing, and pronunciation	A Pilot study with a case study approach
9	(Cancer et al., 2021)	✓	✓	✗	✗	Reading	Clinical trials
10	(Cavalli et al., 2019)	✓	✓	✗	✗	Reading	Exploratory study
11	(Łuniewska et al., 2022)	✓	✗	✗	✗	Reading	Experimental study
12	(Bertoni et al., 2021)	✓	✓	✗	✗	Reading, Phonological decoding & attention control	Experimental study
13	(Maculada et al., 2023)	✓	✓	✗	✗	Reading, phonological awareness	Case study
14	(Eroğlu et al., 2022)	✓	✓	✗	✗	Reading comprehension	Clinical study
15	(Franceschini & Bertoni, 2019)	✓	✓	✗	✗	Reading and visual attention	Clinical study

group ($N=18$). In this game, different tasks were introduced like rhyming tasks, word building, and sentence building. The GraphoLearn game facilitates the reading abilities and teaching instruction with the help of phonological decoding and phoneme awareness of dyslexic children.

Another group of researchers from the Philippines (Bigueras et al., 2020) develop a game to identify the specific game elements based on the learning needs of dyslexic children, which need to be integrated into the Larolexia application presented in Fig. 8(c). The game is based on auditory and visual methods. The study aims to identify the improvement in the reading performance of dyslexic children. This study follows an experimental approach in which there is pre and post-training test. For the improvement of reading performance, different game elements are used like story, goal, rewards, points, achievements feedback, and levels. The T-test is used for the analysis of pre and post-test. This game is considered the intervention to enhance the reading performance of dyslexic children.

Another group of researchers from Norway (Helland et al., 2018) works on the dichotic listening app to show the auditory training effect in dyslexic children. In this experimental study, 8-year-old 47 children were selected. 31 children were selected with no identified learning disabilities and divided into two groups the control group ($N=16$) with no training, and the control group ($N=15$) receiving training. The 16 participants were selected with reading and writing learning difficulties and this group received the training. In this app different auditory tasks were introduced like 36 stimuli combinations, homonym pairs, syllables played to the ear through earphones, and finding correct syllables. In summary, this study revealed that high language processing and verbal working memory skills are associated with good focus and attention-shifting abilities.

In this study (Ansari et al., 2020) a group of researchers from India proposed a game-based intervention that aims to reduce expert reliance by offering a uniform platform to benefit both dyslexic experts and children. In this pilot study there are different training and testing activities used like word-sound relationship tasks, letter-word-sound relationship tasks, simple word recognition tests, making a sight word from scattered characters, and for correct pronunciation need to speak the word. The proposed game-based intervention received satisfactory evaluation results and can be used as a learning tool for dyslexic children.

In this study (Karpagavalli et al., 2021) another group of researchers from India designed and develop a mobile application as shown in Fig. 8(d); to improve and support the reading and writing of learning-disabled children. This research follows a case study approach in which two different learning groups are selected ages 9–12 and 13–15. This application introduces the feature voice-enabled interface for reading disabled children which repeatedly reads as much as a child required. Another feature is voice recognition for writing-disabled children which takes input speech from the child and converts the process speech into text. Pre and post-assessment of children in learning Tamil words are done using various parameters like; reading words, recalling words, reading fluency, and rapid naming. The proposed mobile application helps the learning-disabled child in reading, writing, and motivating them.

In this study (Brennan et al., 2022) a group of researchers develops a game with the toolkit Cosmic Sounds, to boost the learning process of dyslexic children. This research follows the case study approach which aims to facilitate the phonological awareness skills of dyslexic children age group 9 to 12 years by supporting teaching techniques. To support the phonological awareness skills of dyslexic children there are different techniques used like combining words using blocks, a word with missing consonant digraph, identifying sounds and symbols, letter blends, decomposing words, and open and closed vowels. The cosmic sounds game facilitates the teachers and shows improvement in the dyslexic children's phonological awareness skills and also engagement in learning.

A group of researchers from Italy (Cancer et al., 2021) reorganized the rehabilitation procedures for learning disorders (LDs) during COVID-19. Tele-rehabilitation provided a way to carry on with training treatments while allowing for social isolation during the lockdown period. A rhythm-based reading intervention was put to the test in a small-scale clinical experiment during the lockdown phase of the COVID-19 pandemic to assess the efficacy of tele-rehabilitation and in-presence dyslexia rehabilitation. Assigned to either an in-presence or tele-rehabilitation setting, thirty children with a diagnosis of developmental dyslexia between the ages of 8 and 13 received rhythm-based reading intervention called Rhythmic Reading Training (RRT) for ten sessions of 45 min each, held every two weeks, under the supervision of a qualified professional. The findings demonstrated that both tele-rehabilitation and in-presence rehabilitation was helpful to enhance reading and quick automated naming in children with dyslexia. In light of this, RRT was proven to be efficacious regardless of the method of administration (remote or in-presence). The efficacy of telemedicine for the treatment of LDs is supported by these findings.

Haptics Digitalization and rapid advancements in technology have significantly transformed the field of education, revolutionizing the way we teach and learn. A remarkable and promising technology called "Haptic" has emerged among these profound shifts. Haptic is the sensing and manipulation of an object through touch. Various haptic devices have already been introduced for the learning of children. The haptic device's primary function is to introduce the operator's external force into the virtual environment and allow the operator to feel the force there, ensuring the operator's feeling of realism and immersion while engaging with the virtual environment. Different combinations of modalities are used through various tasks and devices as shown in Table 9.

A group of researchers (Bingham & Snapp-Childs, 2019) from the US developed an automated method based on haptic-based tasks to facilitate the manual compliance control and prospective control of the stylus presented in Fig. 8(e). In this experimental study, 7–8-year-old 16 children were selected with 8 Developmental Coordination Disorder (DCD) and 8 TD children. There were pre and post-training performance comparisons and participants were trained for 5 weeks. Different level of training tasks was provided like pushing a bead along a Three Dimensional (3D) wire path which is magnetically attractive to the stylus and the difficulty of the path increases with the completion of tasks. The developed automated method improved the ability of children drawing and handwriting.

Table 9 Summary of haptic-based interventions

Sr.No	Ref	Modalities used				Effects of approaches	Study approach
		Visual	Auditory	Kinesthetic	Tactile		
1	(Park et al., 2019)	✓	✗	✓	✓	Handwriting skills	Longitudinal experimental study
2	(Park et al., 2021)	✓	✗	✓	✓	Handwriting skills	Longitudinal experimental study
3	(Bingham & Snapp-Childs, 2019)	✓	✗	✓	✓	Prospective control of movements used in drawing performance	Experimental study
4	(Am Faleel et al., 2021)	✓	✗	✓	✓	Handwriting skills	Experimental study
5	(Elbaggari et al., 2021)	✓	✓	✓	✓	Read musical notation	Experimental study

In this study (Park et al., 2019) a group of researchers from Dubai investigated different haptic guidance methods' roles in normal children's handwriting skills outcomes. The study follows a 9-week longitudinal experimental approach total of 42 children participated aged 4–7 years. Participants were divided into 5 groups full guidance ($N=9$), partial guidance ($N=9$), disturbance guidance ($N=8$), no haptic guidance ($N=8$), and the control group ($N=8$). For the 4 groups except for the control group, the researchers designed haptic guidance methods in which different calculated haptic force is set up. There were pre and post-training tests for all children which includes 10 characters (e, a, r, i, o, t, n, s, b, and g), and divided these characters into low, medium, and high complexity. 5 sets of these characters were assigned to each student according to their guidance category except for the control group. The results were evaluated by 3 teachers which shows that for high-complexity tasks the disturbance haptic guidance was most effective. For medium-complexity tasks, the full and partial haptic guidance shows the best results and for the low-complexity tasks, the full guidance was most effective. In addition, the effectiveness of the haptic guidance depends on the handwriting task difficulty.

Another group of researchers from Dubai (Park et al., 2021) provided a haptic-based training platform as shown in Fig. 8(f); to facilitate the handwriting of adults and children. This study follows a longitudinal experimental study approach and 12 children who participated in this study have intellectual difficulties, fine motor difficulties, and griping difficulties. These children were divided into two groups the targeted group who completed the haptic-based guided training, as well as the pre and post-training test, and the control group only, participated in the pre and post-training pencil-and-paper test. The children participate once a week in the experiment for nine weeks in which different tasks will be performed like copy numbers, letters, shapes, and emoticons. This research summarizes that the effectiveness of haptic guidance crucially depends on the provided training tasks. When the activity is visually familiar but haptically challenging, haptic guidance greatly improves motor function of the handwriting ability in children with cognitive and fine motor deficits.

In this study (Am Faleel et al., 2021) a group of researchers from Canada and Columbia used a Haply force feedback device and a Writely application to determine the effect of force feedback on the handwriting of the non-dominant hand. In this experimental study, there were 2 sessions per day for 7 days and each session have 28 alphabet writing tasks. In this study writing activities are done using 3 feedback conditions the user's guidance, anti-guidance, and no-force feedback. The writing activity contains different tasks in which letters are created from a series of line segments and the forces guide during the writing task. For evaluation, data is collected before, in the middle, and after the experiment. Haply and Writely show a positive effect on the visual quality of non-dominant handwriting like smoothness and consistency with the help of jerk and acceleration provided during writing. Further study is suggested to utilize the Haply device more and provide a complete experimental method.

4.4 Research questions

4.4.1 RQ1: What interventions are currently employed to facilitate the learning of pupils with dyslexia, and what are the key characteristics of these interventions?

The gathered data shows that there are two categories of interventions 1) non-technological and 2) technological. The technological interventions are further divided into apps/games and haptics. However, in most of the non-technological interventions, the researcher used traditional and ordinary practices for the learning of pupils with dyslexia. In addition, most of the non-technological interventions utilized cards, puzzle games, painting, sandpaper, and clay. These interventions mainly focused on the reading, writing, spelling, and memory of these pupils with dyslexia. Somehow these interventions positively impact these factors. All these interventions are reliable and helpful for the learning of pupils with dyslexia with positive results in various studies. One challenge associated with non-technological interventions is that teachers bear the responsibility of providing personalized attention, feedback, and guidance to students individually, making it demanding to manage the diverse needs of the entire class effectively. This may lower the positive impact of the non-technological interventions for the learning of these pupils with dyslexia.

The other most employed intervention category is technological. The technological intervention is subdivided into apps/games and haptics. These interventions widely utilized mobile and computer for games and apps. These games and apps are mostly based on educational practices and some of them have entertainment-based games that help pupils with dyslexia in learning and cognitive skills. These interventions reduced teacher dependency and were also very helpful during the corona pandemic when schools and centers were closed. Some of these interventions have feedback and guidance system during practices in the form of visual and auditory. The lack of tactile and kinesthetic motor function techniques is one disadvantage of these apps and games.

Haptics-based technological interventions utilizing different devices can provide kinesthetic movements and tactile sensation. Researchers investigate the kinesthetic movements and tactile sensation ability of these devices. One group of researchers also investigates the different levels of guidance provided by these devices in the form of force feedback. Some researchers just used these devices only for data entry purposes. Another group of researchers used a 3D wire path that is magnetically attractive to the stylus. The haptic interventions are at the very initial stage. One disadvantage is that these interventions did not utilize the feedback and guidance ability of these devices for the learning of pupils with dyslexia.

4.4.2 RQ2: What primary approaches serve as the foundation for the pupils with dyslexia learning interventions, and what factors contribute to the prevalence of specific approaches?

These interventions are based on multisensory approaches. Different combinations of VAKT are utilized to intervene in the learning of pupils with dyslexia as shown in

Tables 7, 8, and 9. Interventions are based on multisensory approaches because dyslexia is a disorder of brain processing which have effects on learning and cognitive skills and multisensory approaches can evoke and intervene in different areas of the brain. As discussed early in this study Sect. 4.2 most of the researchers utilized visual and auditory modalities for the interventions. But in the haptics the visual, kinesthetic, and tactile are widely used and the auditory modality is used in one study. To utilize these modalities most of the interventions are based on Apps/Games and also non-technological approaches. All four modalities were utilized by two researchers through non-technological interventions which used different modules for these intervention activities and these interventions lack feedback and guidance in the form of kinesthetic and tactile. In one haptic-based intervention a researchers utilized all four modalities but they also lack to utilized feedback and guidance for the learning purpose. Most of the interventions targeting the reading, writing, and spelling difficulties of pupils with dyslexia, for which the visual modality is important. Auditory is also widely utilized because pupils with dyslexia have difficulty in phonological awareness.

4.4.3 RQ3: What research gaps exist in the current understanding of dyslexia learning interventions, and what improvements to the learning process can be made for pupils with dyslexia by addressing these gaps?

According to the findings of this systematic review and the answers to the earlier RQs, it is obvious that there are many challenges and limitations that researchers and developers still need to go through to create learning-based interventions for pupils with dyslexia. The majority of the challenges and limitations that must be resolved for developing interventions to become a feasible platform for learning pupils with dyslexia are related to not only the technology itself but how the interventions are designed, how the interventions are adapted, and how reliable the control is from the perspective of the pupils.

The first challenge is the feedback and guidance provided to pupils with dyslexia during the interventions. Feedback and guidance are the two main factors that influence learning. According to the current study, the instructor provides visual and auditory feedback and guidance in non-technological and apps/games-based interventions. On the other hand, haptic technology provides tactile sensation and kinesthetic movements. However, researchers just utilized these devices for data entry, compliance training, and pen perspective control during handwriting activities. The current research is lacking in providing tactile and kinesthetic feedback for the learning of pupils with dyslexia. A haptic device may be helpful to provide tactile and kinesthetic feedback and guidance during the learning intervention for pupils with dyslexia. The feedback and guidance must be considered by intervention designers in light of this constraint.

The second challenge is to use the VAKT approach while incorporating all visual, auditory, kinesthetic, and tactile techniques into a single module. Previous research has shown that multisensory techniques help dyslexic students learn more easily however, using the VAKT approach in various modules is a slow and difficult learning approach from the pupil's as well as the teacher's perspective. In this review

study, all the interventions are based on the VAKT approaches but all the techniques are implemented in various modules some of them are used a combination of two techniques. All of the senses are engaged in non-technological interventions through various activities, but in technological apps and games, the visual and auditory are frequently used, touch is used for data entry which lacks the feel of immersion, and the kinesthetic is completely disregarded. Games that use a haptic device may help resolve this issue because the haptic device may provide tactile feelings and kinesthetic movements in addition to the visual and audio sensations that apps and games can also deliver. The VAKT approach in one module must be considered by intervention designers in light of this constraint.

The third challenge is to measure the effect of the intervention on the processing areas in the brains of pupils with dyslexia. Prior research has demonstrated that multimodal techniques affect different processing areas of the brain. According to earlier studies, visual, auditory, kinesthetic, and tactile stimuli are processed in the visual cortex, the auditory cortex, the somatosensory cortex, and the motor cortex, respectively. In the current review study, intervention evokes distinct impulses using VAKT approaches that process the various brain areas. These interventions, which use a VAKT approach to evoke various impulses, may enhance brain processing. During the intervention, it is important to monitor the brain's behavior and measures its processing.

5 Discussion

This review's primary results and main findings are discussed in this section, particularly with respect to the RQs. Based, on the strengths and flaws of the examined interventions, conclusions about the results are reached. On the findings and the information gathered throughout the review, further observations were also made.

In this review, we investigate different publicly available articles that are used for the intervention of pupils with dyslexia. Review findings show that, currently, the interventions are employed to facilitate the learning of pupils with dyslexia in two ways: technological and non-technological. But in this digital era, technology is at its peak; but in the past years' non-technological practices are seeking attention, interest, and adoption by educators, students, or researchers in the current period, possibly due to the base of intervention approaches (Rahmatullah et al., 2022; Yoon & Kwon, 2022). A notable finding is that all of the included studies in this review employed the VAKT approaches for intervention in various combinations as shown in Tables 7, 8, and 9.

Studies have revealed that different individuals have distinct learning preferences. According to studies visual learners prefer to process information through images, graphs, charts, and other visual aids (Tzenios, 2020). They learn best when they can see and observe information. Auditory learners learn effectively through listening and verbal communication (Ariastuti & Wahyudin, 2022). They grasp information best when it is presented through spoken words, discussion, and lectures. Kinesthetic learners learn by doing and engaging in hands-on activities (Stamm et al., 2021). They thrive when they can physically interact with the

subject matter, such as through experiments or simulations. Tactile learners are similar to kinesthetic learners but specifically learn through touch and physical sensations (Montero-SaizAja, 2022). They benefit from activities that involve the manipulation of objects or textures.

Some of the main characteristics of these interventions are that VAKT approaches create stronger neural connections, neural pathway activation, neurotransmitter release, improve motor, and sensory processing (Ziadat, 2021). Incorporating VAKT strategies into teaching practices can maximize brain engagement and optimize the learning experience for students (Redcay, 2023). By stimulating multiple sensory channels and promoting neural plasticity, these strategies support the brain's natural capacity for learning and adaptation.

The current literature review shows the formation of interventions has two main stages: the development and deployment stages as shown in Fig. 9. In-depth, the development stage mainly focused on the utilized sensory modalities and different learning and teaching approaches. This study shows that the VAKT approach is utilized and all four types of modalities are used with different combinations to develop a learning and teaching intervention for pupils with dyslexia. As mentioned in the introduction section, that dyslexia is a learning disorder in which they have difficulty how to process information. Different information is processed in different areas of the brain as shown in Fig. 3. The researchers utilized various modalities with different combinations because it helps to evoke the different areas in the brain of dyslexia pupils (Redcay, 2023). To utilize these combinations of modalities, various approaches are used by researchers non-technological, apps/games, and haptics as discussed in the individual study section.

The "Apps/Games" category includes technological innovations like educational games and mobile apps. These interventions make use of technology-based learning to offer individualized instruction, involve dyslexic students, and provide

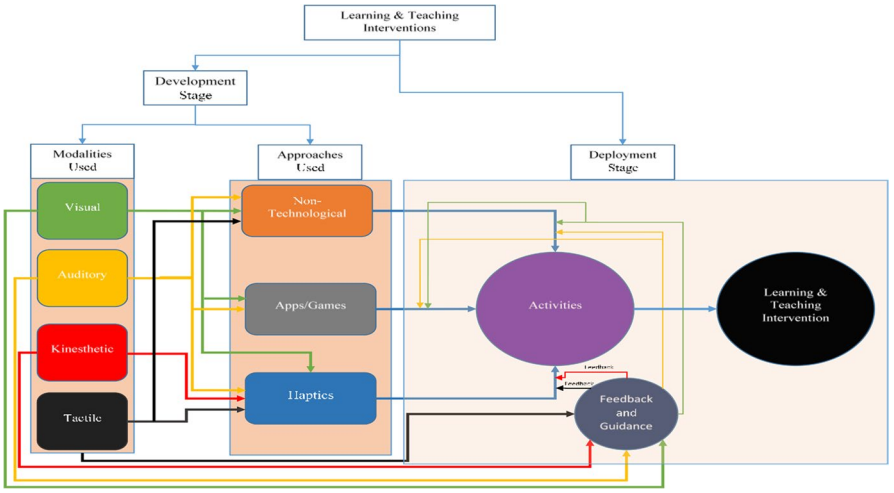


Fig. 9 Current-state-of-art framework

chances for practice and reinforcement. Interventions utilizing tactile feedback devices and touch-sensitive interfaces fall under the "Haptics" category as shown in Table 10. These interventions emphasize sensory-based learning, promoting kinesthetic learning and enhancing the multisensory experiences of dyslexic learners. The "Non-Technological Interventions" section, on the other hand, includes interventions that do not use technology. This group includes well-known strategies like explicit instruction, phonics-based instruction, and multisensory teaching as shown in Table 10. With a focus on multiple aspects of the development of reading and language skills, these evidence-based interventions have been widely used to address dyslexia challenges.

Most of the non-technological approaches utilized VAKT modalities with different combinations some of the researchers used all four modalities to evoke all of their senses, but they do not offer tactile or kinesthetic feedback and guidance as mentioned in Table 11. When teaching pupils with dyslexia, the commonly employed non-technological approaches lack to provide the primary training components—feedback and guidance—that were not always given in the best way. The instructor usually gives feedback and guidance during these interventions in visual and auditory forms, which did not train the motor cortex and somatosensory cortex areas of the brain, which are responsible for kinesthetic and tactile processing (Fugate et al., 2019). Somehow there are tactile and kinesthetic-based interventions that use the motor cortex and somatosensory cortex area of the brain, but they are not used to their full potential due to the absence of aspects that provide feedback and guidance. In these non-technological approaches, all the multisensory interventions are implemented in different modules which are very slow and difficult teaching strategies. Particularly in a crisis, pandemic, or emergency, such as the current global COVID-19 problem, technology has proven to be important.

Regarding the intervention development based on technology, the researchers utilized technology to help pupils with dyslexia in learning. Researchers introduce different apps and game approaches according to the needs of dyslexic children's learning. These apps and games have different reading, writing, pronunciation, and spelling practices which improve the learning of dyslexic children. Researchers mostly concentrate on the games and apps that have primarily focused on VAKT-based interventions. For these interventions, the researcher made extensive use of the visual, auditory, and tactile senses. In these interventions, tactile functions are not exploited; rather, the tactile was only used to enter data and not for its sensation function. Most of the games and apps are mobile-based in which the touch screen completely lacks in providing tactile feedback. A user can not feel any guidance through the mobile touch screen. Apps and games completely lack to use of the brain area which processes tactile and kinesthetic information. So these apps and games practices used visual, and auditory as a learning intervention that practices only the visual and auditory information processing area.

The current review literature shows that some practices used tactile and kinesthetic as an intervention but these interventions are based on non-technological practices. The employment of haptic technology to aid pupils with dyslexia in their learning is quite unusual. This technology was used by researchers for tactile and

Table 10 Summary of Interventions for learning of dyslexic children

Intervention	Characteristics	Approach	Common usage and reasons
Apps/Games	Mobile applications and educational games	Technology-based learning	Increasingly used for individualized instruction, engagement, and practice
Haptics	Tactile feedback devices and touch-sensitive interfaces	Sensory-based learning	Employed to enhance multisensory experiences and kinesthetic learning
Non-Technological Interventions	Multisensory teaching, phonics-based instruction, explicit instruction	Various approaches	Widely used and evidence-based interventions addressing dyslexia challenges

Table 11 Summary of feedback and guidance

S.No	Intervention	Feedback	Guidance
1	Non-Technological	Provided by the instructor Visual or Auditory	Yes, provided by the instructor Visual or Auditory
2	App/Game	Provided in the form of result/score Visual or Auditory	Yes, provided in the form of prompt instructions Visual or Auditory
3	Haptic device	Provided by the device in the form of force feedback in real-time kinesthetic, and tactile	No, can be provided by the device in the form of force feedback in real-time kinesthetic, and tactile
4	App/Game with Haptic device Recommended	Can be provided in the form of Visual, Auditory, kinesthetic, and tactile	Can be provided in the form of Visual, Auditory, kinesthetic, and tactile

kinesthetic interventions, to process impulses in the motor cortex and somatosensory cortex regions of the brain. The use of tactile and kinesthetic feedback is used but guidance is lacking in the research. Haptic is the technology of touch and also provided kinesthetic movements. Some researcher investigates the different level of haptic force guidance. One research group used to push a bead along a 3D wire path that is magnetically attractive to the stylus, the task improved the manual compliance control and prospective control of a stylus which have a positive impact on the drawing and handwriting. There are some haptic devices like Phantom Omni, Touch, and Touch X which have the ability to provide real-time tactile and kinesthetic feedback and guidance. The haptic device can improve the independency of pupils with dyslexia.

In the deployment stage, these approaches are utilized in the form of different learning and teaching-based activities as discussed in the individual study section. The most commonly used activities are alphabet puzzles, repetition of the rhyme, selection of phonemes among pictures, drawing the shape of grapheme with the finger, and word tracing. Performing these activities, pupils with dyslexia need feedback on their performance and also guidance to improve their learning. The learning feedback and guidance provided to pupils with dyslexia during these activities are based on visual, auditory, kinesthetic, and tactile modalities as shown in Fig. 9. The non-technological and apps/games approaches provided feedback and guidance in the form of visual and auditory but haptics used kinesthetic and tactile only as feedback. Using different modalities, approaches, activities, guidance, and feedback provides different levels of interventions for the learning and teaching of pupils with dyslexia.

In regards to general directions for the design and implementation of interventions, it is recommended to try to evoke all the VAKT processing areas in the brain because pupils with dyslexia have difficulty processing data. The multisensory approach works better to evoke the different areas of the brain. Some researchers used all these modalities VAKT which are implemented in different modules which is a very slow teaching style and also very difficult for instructors. So a recommended intervention is to introduce all modalities of VAKT in one module. According to studies, when students were given the proper support at the correct moment in the form of feedback and guidance, their learning was boosted (Ajjawi et al., 2022; Lodge et al., 2018). The complicated relationship between the design and the promptness of feedback, guidance, and assistance given to students during the learning activity or task is the cause of the challenges experienced by learners in any content (Lodge et al., 2018). One another recommendation as mentioned in Table 11 and Fig. 10 is to introduce the haptic technology for the implementation of recommended intervention because haptics with the combination of apps/games can provide visual, auditory, tactile, and kinesthetic feedback and guidance in real time which is still not provided by the apps/games and non-technological interventions individually.

Researchers working with dyslexic pupils face several challenges that can have an impact on the research process. Firstly, finding a sufficient number of willing participants among the dyslexic student population is difficult. Researchers must actively seek out participants and ensure their willingness to participate in the study, which is taking time and demand extensive outreach efforts. The lack of resources is a major

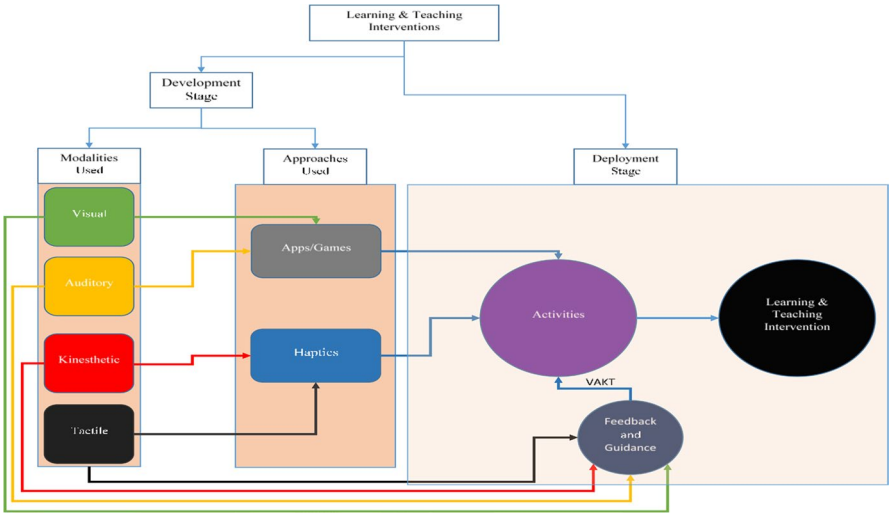


Fig. 10 Recommended multi-sensory modalities, feedback, and guidance-based learning intervention for pupils with Dyslexia

obstacle. To carry out their studies successfully, researchers frequently need specialized assessment equipment, technological resources, or funding. These resources are not readily available and accessible, which may present challenges and limit the scope of the research and affect the accuracy of the results. In research involving dyslexic students, ethical considerations are also very important. The ethical conduct of studies must be ensured by researchers, who must also obtain informed consent, maintain participant confidentiality, and protect participants' welfare throughout the research process. It takes serious planning and consideration to follow these ethical standards. Dyslexic students have trouble focusing and paying attention, especially when conventional teaching methods are used, making it difficult to involve them in the learning process. To create a stimulating and welcoming learning environment that encourages the interest and attention of dyslexic students, educators should investigate advanced instructional approaches that incorporate technology, interactive activities, and multisensory techniques.

While our SLR on dyslexic learning interventions offers valuable insights, it is important to acknowledge several limitations. Firstly, we excluded articles related to the diagnosis of pupils with dyslexia, potentially missing crucial perspectives and insights related to the diagnostic process. Secondly, our scope focused solely on learning interventions, neglecting other domains affected by dyslexia. Thirdly, there is a possibility of publication bias, as studies with statistically significant or positive results may have a higher chance of being published. Moreover, our review had a time constraint, potentially excluding more recent studies and developments. Lastly, our study was limited to English-language publications, potentially introducing a language bias. Recognizing these limitations provides avenues for future research to address these gaps and enhance our understanding of dyslexic learning interventions.

6 Conclusion

In conclusion, our review aimed to present an overview of the current state of interventions for pupils with dyslexia, considering both non-technological and technological approaches. Through an extensive search of various databases, we classified relevant studies into different learning intervention categories, with a particular focus on multisensory techniques. Our analysis revealed that haptic-based interventions, supplemented with apps or games that engage multiple senses simultaneously, represent the most recent and promising development in this field.

Furthermore, we identified the importance of feedback and guidance systems in each category of intervention. Although multisensory approaches are commonly utilized in dyslexic learning interventions, our findings indicate that they alone may not be sufficient in assisting these pupils. Therefore, understanding how these multisensory approaches can provide effective feedback and guidance is crucial for the development of more impactful interventions.

The results of this study have implications for researchers and developers working on dyslexic learning interventions. By leveraging insights from advanced interventions and the latest research, these professionals can incorporate more effective strategies and technologies into their work. However, it is important to acknowledge the limitations of this SLR. Specifically, we excluded articles related to the diagnosis of pupils with dyslexia, which warrants a separate in-depth review to gain new insights into learning interventions. Additionally, a more comprehensive examination of brain processing in relation to multisensory approaches may uncover valuable information for enhancing dyslexia learning interventions.

Future work in this field should focus on addressing the limitations identified in our review and expanding our understanding of dyslexic learning interventions. Firstly, conducting an in-depth review of pupils with dyslexia diagnosis approaches would provide valuable insights into tailoring interventions to specific needs. Understanding the relationship between diagnostic processes and intervention outcomes can help inform more effective and targeted interventions. Secondly, further research is needed to explore the impact of multisensory approaches on brain processing in dyslexic individuals. Investigating the underlying neural mechanisms involved in multisensory interventions can provide a deeper understanding of how these approaches facilitate learning and guide the development of more effective interventions. Additionally, future studies should aim to incorporate diverse populations and languages to overcome the limitations of language bias and expand the generalizability of findings. Lastly, longitudinal studies examining the long-term effectiveness and sustainability of dyslexic learning interventions are needed to assess their impact over time and guide the development of evidence-based practices. By addressing these future research directions, we can advance the field of dyslexic learning interventions and provide better support for individuals with dyslexia.

Appendix

Table 12 List of abbreviations and acronyms

S.No	Abbreviation	Description
1	VAKT	Visual, Auditory, Kinesthetic, and Tactile
2	PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
3	RQs	Research Questions
4	SLR	Systematic literature Review
5	STS	Superior Temporal Sulcus
6	ICT	Information and Communications Technology
7	VTM	Visual Tracking Magnifier
8	LDs	Learning Disorders
9	DCD	Developmental Coordination Disorder
10	TD	Typically developing
11	3D	Three Dimensional

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Data availability Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Conflicts of interest There are no relevant conflicts of interest to mention.

Human and animal rights There is no involvement of human participants and animals.

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