

Digital Intervention in Children with Developmental Language Disorder: A Systematic Review

Zhaowen Zhou, Cheng Deng, Dongling Yin, Qiaoxue Yang, Zhuoming Chen

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Digital Intervention in Children with Developmental Language Disorder: A Systematic Review

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Abstract

Background: Developmental language disorder (DLD) is one of the most common neurodevelopmental disorders. Effective intervention is vital to improving the quality of life for individuals with DLD and preventing negative effects in adulthood. Digital interventions have the potential to complement conventional language intervention, reducing the workload for therapists and increasing accessibility to language training in homes or schools. However, the effectiveness of digital intervention and its influential factors are not yet reported.

Objective: This systematic review aimed to assess the effectiveness of digital interventions on language outcomes of children with DLD and to identify influential factors.

Methods: The study protocol was registered in the International Prospective Register for Systematic Reviews (PROSPERO) and was ascribed to the CRD42023477946 registration code. Literature published to May 2023 was retrieved by searching four databases: "PubMed", "Scopus", "PsycInfo", and "IEEE Xplore", following a method adapted from PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Inclusion criteria include studies recruiting patients diagnosed with DLD; Articles that reported digital interventions based on apps, video games, augmented reality, or any other type of software based on language outcomes; and English language articles. Reviews, letters, conference proceedings, abstracts, editorials, and articles not published in English were removed. The titles and abstracts of the identified records were initially screened and selected by two independent and blinded reviewers. Data extraction and quality assessment were performed by three independent reviewers.

Results: Overall, sixteen studies were included; 975 children (61.35% males) with DLD underwent a digital intervention. The mean age ranged from 3.47 to 11.19 years. Eight were randomized control trials (RCT), five were quasi-experimental studies, two were case series, and one was a case report. Targeting domains of digital intervention were phonological skills (n=5), general language function (n=4), vocabulary (n=3), grammar (n=3), and spelling (n=1).

Conclusions: The present systematic review indicates that digital interventions were effective in improving phonological and vocabulary skills in children with DLD. There was less evidence supporting its effectiveness in expressive language skills, which indicates a need to upgrade expressive language digital training programs in the future. Further higher-level evidence, such as RCT studies in this area, is needed to direct the development of digital programs.

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Original Manuscript

Review

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Abstract

Background: Developmental language disorder (DLD) is one of the most common neurodevelopmental disorders. Effective intervention is primarily important for improving the language and communication skills of children with DLD, and strengthening these skills ensures quality of life and prevents negative effects in adulthood. Digital interventions have the potential to complement conventional language intervention, reducing the workload for therapists and increasing accessibility to language training in homes or schools.

Objective: This systematic review aimed to explore the language domain that most frequently targeted by digital intervention in children with DLD.

Methods: The study protocol was registered in the International Prospective Register for Systematic Reviews (PROSPERO) and was ascribed to the CRD42023477946 registration code. The initial search was conducted on May 2023 from four databases: "PubMed", "Scopus", "PsycInfo", and "IEEE Xplore", following a method adapted from PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Inclusion criteria include studies recruiting patients diagnosed with DLD; Articles that reported digital interventions based on apps, video games, augmented reality, or any other type of software based on language outcomes; and English language articles. Reviews, letters, conference proceedings, abstracts, editorials, and articles not published in English were removed. The titles and abstracts of the identified records were initially screened and selected by two independent and blinded reviewers. Data extraction and quality assessment were performed by three independent reviewers.

Results: Overall, thirteen studies were included; 961 children with DLD underwent a digital intervention. The mean age ranged from 3.47 to 11.19 years. Eight were randomized control trials (RCT), and five were quasi-experimental studies. Targeting domains of digital intervention were phonological skills (n=5), general language function (n=3), grammar (n=3), and vocabulary (n=2).

Conclusions: The present systematic review indicates that phonological skills are the most

frequently targeted language domain by digital interventions in children with DLD. Given the limited number and the heterogeneity of the studies included, it is still unclear whether digital intervention was effective in improving different language skills in children with DLD. There was less evidence supporting its effectiveness in expressive language skills, which indicates a need to update expressive language digital training programs in the future. Further higher-level evidence, such as RCT studies in this area, is needed to direct the development of digital programs.

Keywords: Developmental Language Disorder; Digital Intervention; Systematic Review

Introduction

Developmental language disorder (DLD) is one of the most prevalent neurodevelopmental disorders that has profound and lasting effects on individual development [1]. It occurs in around 7.6%~8.5% of preschool children around the world [2, 3]. According to the International Classification of Diseases 11th Revision (ICD-11), DLD is characterized by persistent deficits in the acquisition, understanding, production or use of language (spoken or signed), that arise during the developmental period, typically during early childhood, and cause significant limitations in the individual's ability to communicate. The individual's ability to understand, produce or use language is markedly below what would be expected given the individual's age. The language deficits are not explained by another neurodevelopmental disorder or a sensory impairment or neurological condition, including the effects of brain injury or infection. [4]. The term DLD has been suggested to replace earlier terms, such as specific language impairment (SLI), language impairment, language disorder, and primary spoken language disorder. However, for clarity purposes, in the present review, we will use DLD, although due to its recent introduction, the articles included in the present work used SLI as a diagnostic label.

Language development is a critical domain of children's overall development. Language skills are an important means of communication, which comprises the ability to send and receive information through oral and written language [5]. DLD can affect different aspects of language processing, such as the form of language (phonetic, phonological, morphological, morpho-syntactic, and syntactic processing); content (semantic-lexical and phrasal processing); and use (pragmatic and discursive processing) [6]. Individuals with DLD may not only experience difficulties in communication but also face challenges from other different domains such as reduced engagement in playing and academic learning [7]. DLD may also increase the risk of poor health-related quality of life [8], including mental health problems such as anxiety and depression [9, 10]. In addition, DLD has an impact on the development of cognitive functioning [11, 12], sensorimotor functioning [11, 13], or behavioral functioning [14]. DLD can coexist with many other conditions such as learning disorders, delayed motor milestones, auditory processing disorders, attention-deficit/hyperactivity disorder, lack of coordination, and other motor disorders [15, 16]. The impact of DLD may persist to adulthood and have long-term effects on cognitive function, community function, interpersonal relationships, and employment [17-19]. Therefore, effective interventions during childhood are essential to improve the quality of life of individuals with DLD and to prevent further negative effects in adulthood.

Convention interventions for DLD are usually conducted one-by one in person by speech and language pathologists (SLPs). During treatment sessions, SLPs will design challenging interventions for children using interesting toys and activities, to stimulate children's language

skills and teach language learning strategies. However, that requires SLPs to be well-trained and experienced. Limited by the number of therapists, the geographic distance between the SLP and the recipient of services, and economic conditions, in-person training is not always available to children with DLD [20].

Digital interventions have the potential to be used as an adjunct to conventional language intervention, which could reduce therapists' workload and increase children's accessibility to language training in settings such as homes or schools, enabling them to practice under the supervision of caretakers or teachers [21]. Digital intervention provides repeated training of particular skills easier; it motivates children by giving automated timely feedback in a game-like format [22]; digital intervention can also be programmed to respond adaptively to the child's level of performance so that training is focused on materials that are just beyond current competence; every response made by the child can be detailly recorded for further analysis. In the economic aspect, digital intervention also has the potential to increase accessibility to care, reduce patients' travel and costs, and develop culturally appropriate services, especially for different language speakers [23].

There is a wide range of digital interventions for children with DLD that are aimed at different language domains. The aim of this review was to systematically analyze which language domains are most frequently supported by digital interventions for children with DLD.

Methods

Study identification

This systematic literature review was performed according to the methodology described in the Cochrane Handbook for Systematic Reviews [24] and was reported based on the PRISMA statement for reporting systematic reviews [25]. Additionally, the study protocol was registered in the International Prospective Register for Systematic Reviews (PROSPERO) and was ascribed to the CRD42023477946 registration code.

The initial search was conducted on May 2023 by searching the databases "PubMed", "Scopus", "PsycInfo", and "IEEE Xplore" using the following search terms: (("developmental language disorder" OR "language delay" OR "speech delay" OR "language impairment*" OR "speech impairment*" OR "language disorder*" OR "speech disorder*" OR "language difficult*" OR "speech difficult*") AND ("Child*" OR "Preschool") AND ("computer-based" OR "computer assisted therapy" OR "computer games" OR "software" OR "websites" OR "computer*" OR "digital*" OR "electronic" OR "gaming" OR "internet*" OR "video game*" OR "online" OR "on-line" OR "web*"))

No limitations in the search strategy were applied to the publication date, study design, or language. References of considered studies were also searched to identify any further relevant data.

The records identified by the search were uploaded on "Rayyan" [26] to organize the study selection more efficiently. The titles and abstracts of the identified records were initially screened and selected by two independent and blinded reviewers (Z.Z. + C.D.) based on their pertinence to the review topic. Conflicts and disagreements were resolved by consensus. The following set of pre-defined inclusion criteria were then individually applied to the selected articles in their full-text version: (i) Studies recruiting patients diagnosed with DLD; (ii) Articles that reported digital interventions based on apps, video games, augmented reality, or any other type of software based on language outcomes; (iii) English language articles. Reviews, letters, conference proceedings, abstracts, editorials, case report and case series were excluded. Articles not published in English were removed. Articles in which the targeted

populations were children with cognitive delay, deafness, autism spectrum disorders, genetic syndromes (Down syndrome, Klinefelter syndrome), neurological deficits, pervasive developmental disorders, traumatic brain injuries, primary disorders (sensory, neurological, psychiatric), children with dysphonia, dysarthria, dysrhythmias or stuttering, dyslalias or specific speech articulation disorder, bilingualism were excluded.

Data extraction and quality assessment

Data extraction and quality assessment were performed by three independent reviewers (Z.Z., C.D., and D.Y.). The extracted data and results of the quality assessment are reported in Table 1. The quality of retrieved articles was assessed by the Joanna Briggs Institute (JBI) appraisal tool [27]. The JBI checklist for randomized controlled trials (RCTs) [28] and for quasi-experimental studies [29] were utilized according to the study design of included studies. JBI appraisal tool evaluates internal validity and statistical conclusion validity of the targeted studies. For RCTs, questions related to internal validity were further separated to assess bias related to selection and allocation, administration of intervention/exposure, assessment, detection and measurement of outcome, and participant retention. And for quasi-experimental studies, domains of internal validity include the bias related to temporal precedence, selection and allocation, confounding factors, administration of intervention/exposure, assessment, detection, and measurement of the outcome, participant retention.

The purpose of this appraisal is to assess the methodological quality of studies and to determine the extent to which a study has addressed the possibility of bias in its design, implementation, and analysis. Studies with percentage scores of < 49% were classified as weak, studies between 50% and 79% were moderate, and studies $\geq 80\%$ were classified as high in quality with reduced bias. This classification has been used in prior systematic reviews [30].

Treatment fidelity assessment

A 40-item checklist with definitions of intervention fidelity domains and relevant examples were utilized to assess the treatment fidelity[31]. The authors used the checklist to assess the presence of strategies identified in the five specific domains: treatment design, training providers, delivery, receipt, and enactment. Intervention fidelity information was categorized and coded as “present (1)”, “not present but should be present (0)”, or “not applicable (NA)”. Authors coded articles independently and discussed and reconciled any discrepancies.

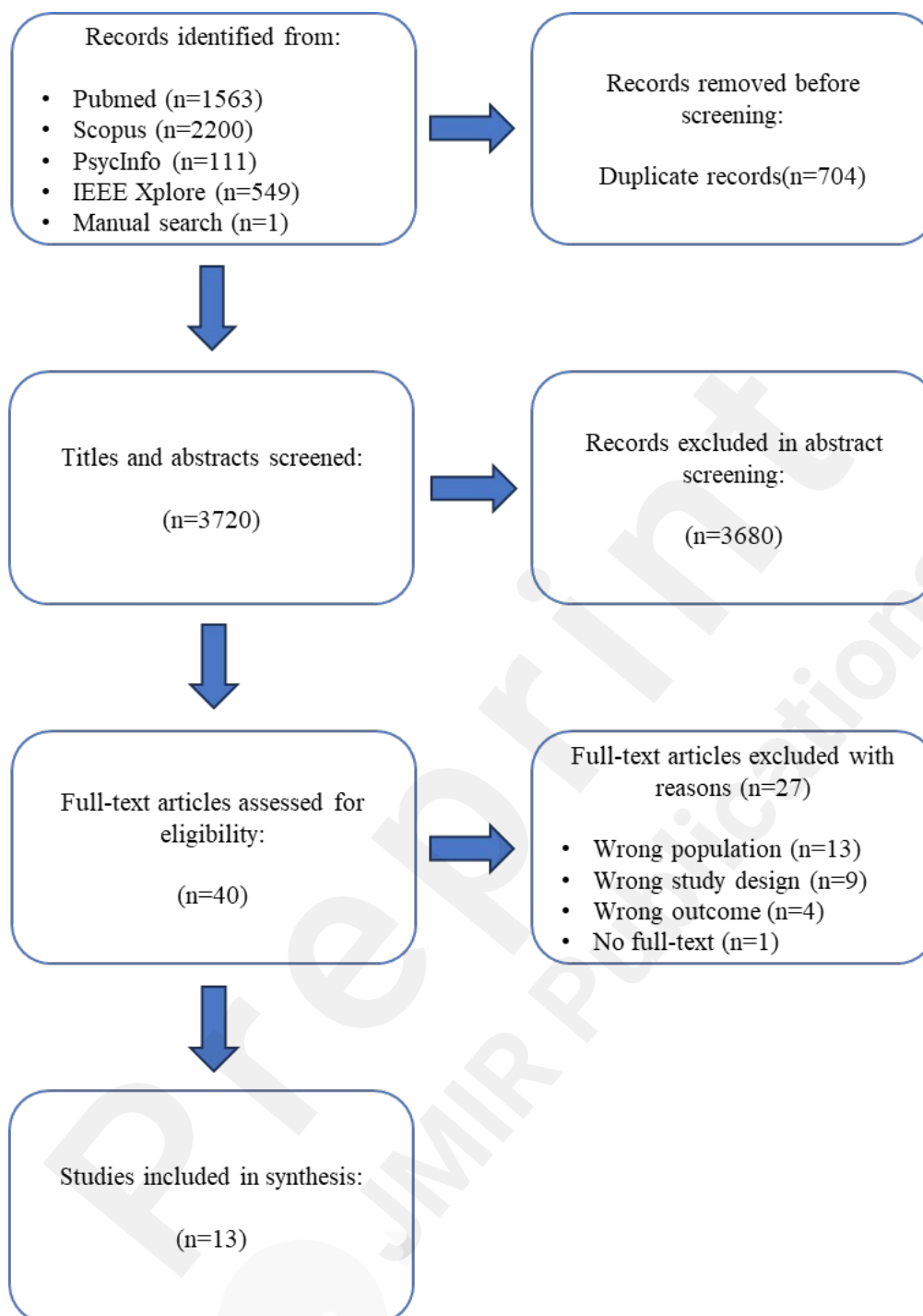


Figure 1. PRISMA Flow Chart Describing the Inclusion Process of the Articles

Results

The following records were identified via electronic databases: PubMed (n = 1563); Scopus (n = 2200), PsycINFO (n = 111), and IEEE Xplore (n = 549), which yielded 4423 unique records. One additional record was identified via manual searching. The flow diagram in Figure 1 shows the records remaining at each stage and the reasons for exclusion of articles reviewed at the full-text stage. One full-text article could not be sourced for review and was excluded at the full-text stage. A total of thirteen articles met the inclusion criteria for this study. Of the 13 studies that met the inclusion criteria, 8 were randomized control trials [32-39], 5 were quasi-experimental studies [40-44]. According to the quality assessment, six studies were

of high quality, seven were of moderate quality out of 13 studies. The oldest study was conducted in 2005, and the most recent study was conducted in 2022.

Overall, 961 children diagnosed with DLD were included, 51.14% were male and 38.65% were female (gender proportion not reported in four studies). Mean age ranges from 3.47 to 11.19 years old.

The digital intervention programs employed included: *Fast Forward (FFW)* [40] (n=6), *Reading Doctor* [32] (n=1), *TipOn* [33] (n=1), *My Sentence Builder* [39] (n=1), *Jingyun Rehab Platform* [43] (n=1), *My PlayHome* [37] (n=1), *Dr. Neuronowski* [34] (n=1), and a program developed by Heikkilä et al. [41] and was run with Presentation software (Neurobehavioral systems; n=1).

Among the eight programs mentioned above, seven of them are software for computers, tablets, or mobile phones, *Jingyun Rehab Platform* is a website for computers, tablets, and mobile phones. Four of the programs were developed in English, two of them were developed in Chinese (*TipOn* and *Jingyun Rehab Platform*), one was in Finnish, and one was in Polish.

Of the 13 studies included, 5 had a follow-up of 5 weeks to 6 months after the end of the intervention. Four of these studies showed that the intervention effects of digital intervention on language functioning in children with DLD were maintained or improved at follow-up.

Phonological skills were the most frequently targeted skill in digital intervention for DLD (4 out of 13). General language function and grammar were each reported in three studies. Vocabulary was reported in two studies.

Phonological Skills (n=4)

The effectiveness of digital intervention in phonological skills for children with DLD was reported in four studies. These studies were targeted on phonological skills, including phoneme awareness, letter-sound aptitude, and early decoding ability. The programs employed to conduct phonological skills training in four studies were varied, including the *Reading Doctor* iPad application, *TipOn* (mobile application), *FFW*, and *Dr. Neuronowski*. The duration of the digital intervention was 4 to 9 weeks. The main design of the game to train receptive phonological skills was based on improving basic auditory processing skills, either through non-speech stimuli such as sounds and tones or through speech stimuli such as syllables and words. In these games, the sound or an audiovisual video of the targeted letter, syllables or words was provided, and children were required to point to the best-matched picture among the distractors, or type the correct spelling of the word. Significant improvement in receptive phonological skills was found in four studies [32-34, 41] compared with the control group. Results showed that audiovisual speech might be more effective than auditory speech in training phonological skills in children. However, in the study targeted spelling [40], which is higher level of phonological skills, trained groups did not differ from the untrained control group in spelling. In the studies targeting phonological skills, researchers also aimed to improve participants' word learning and reading [32, 33, 40] through phonemic awareness training. Bishop et al. [40] suggested that digital intervention did not improve word and nonword reading compared to the untrained group, whereas Carson et al. [32] found a significant improvement in word reading skills in the digital intervention group compared to the control group. Also, Chen et al. [33] found that the total number of games played and the accuracy in games were significantly correlated with the performance of the pre-post gain in the word definition task, which asked children to say the meaning of a vocabulary word they heard.

General (n=3)

There were three studies [35, 36, 42] that examined interventions targeting more than one

domain, including phonological skills, vocabulary and grammar. The same digital program and intervention procedures were applied to both studies. Children participated in the *FFW* program for 1 hour and 40 minutes (100 minutes: five games of 20 minutes each) each weekday for 6 weeks (30 days). The intervention ended when they reached the dismissal criterion established by Scientific Learning Corporation of 90% completion on 5 of 7 exercises or until they exhibited plateaus in performance for 10 days before the 6-week end date. *FFW* included games that targeted discrimination of tones (viz., Circus Sequence), detection of individual phoneme changes (viz., Old McDonald's Flying Farm), matching phonemes to a target (viz., Phoneme Identification), identifying matched syllable pairs (viz., Phonic Match), discriminating between minimal pair words (viz., Phonic Words), recalling commands (viz., Block Commander), and comprehending grammatical morphemes and complex sentence structures (viz., Language Comprehension Builder). RCTs conducted by Cohen et al. [35] and Gillam et al. [36] revealed that though participants gained improvement from *FFW*, there was no additional effect for computer-intervention compared to conventional intervention. However, Loeb et al. [42] found no significant improvement in phonological skills and reading.

Grammar (n=3)

Three studies included grammar as the primary focus of digital intervention for DLD, of which two examined the effectiveness of *FFW*, and one investigated *My Sentence*. Both Hsu et al. [38], and Bishop et al. [44] employed *FFW* to implement receptive training of grammatical skills. Children heard a spoken sentence and then moved or activated objects on the computer screen to match the spoken sentence. Children in these two studies both showed greater accuracy in the training program but showed no significant improvement on standardized tests of receptive grammar. Washington et al. [39] used *My Sentence* to address expressive grammar deficits in DLD. Results showed that computer-based training significantly outperformed conventional intervention, but no significant differences in treatment gains were found between computer-based training and non-computer-based training.

Vocabulary (n=2)

Among the thirteen studies included, two targeted vocabulary learning. Yi et al. [43] and Zwitterlood et al. [22] focus on the receptive vocabulary of children with DLD, using pictures of online platforms or software games. During the vocabulary training, Zwitterlood et al. designed play activities with the digital game, and exposed children to the targeted words with symbolic play sessions, narrative, natural interaction and language facilitation strategies. Yi et al. presented the sound of words or syllables and pictures to the children, and instructed them to point at the picture that matched the word best. The intervention periods of intervention for vocabulary skills were 1~3 months. Both studies showed that digital interventions were beneficial for children's vocabulary skills.

Table 1. Description And Main Outcomes of Digital Intervention Studies for Children With DLD.

Speech and language abilities trained	Studies	Gender (M, %) and mean age	No. of Participants (Cases and Controls)	Intervention	Setting	Provider	Results	Follow-up period	Follow-up result	JBI Score (quality)	Study design
Phonological skills	Bishop et al. [40]	Group M: mean age 10.78±1.86; Group S: mean age 11.19±1.12; Group U: mean age 10.28±0.88. Gender of each group was not reported.	N=36. Modified speech (M, N=14), ordinary speech (S, N=13), and untrained control (U, N=9).	Modified speech (M): <i>FFW</i> , 5 sessions per week, each 15 minutes, 4 weeks Ordinary speech (S): usual special educational input Untrained control (U): no intervention.	school	school staff	Children presented with <i>FFW</i> do less well than those trained with ordinary speech. Trained groups did not differ from the untrained group in terms of gains made on standardized tests of	-	-	9/9 (high)	Quasi-experimental

Phonological skills	Carson et al. [32]	M 13 (54.17%), mean age 4.75. Age and gender of each group were not reported.	N=24. Intervention (N=14); Control (N=10)	Intervention: Reading Doctor (RD) iPad applications, twice a week, each 20-25min, 8-week Control: teacher-delivered small-group activities related to letters and sounds.	preschool	teachers, SLP students and initial teacher education (ITE) students.	spelling or word and nonword reading.	-	-	7/13 (moderate)	RCT
Phonological skills	Chen et al. [33]	Intervention: mean age 5.85±0.53; Control: mean age 5.65±0.53. Gender of each group was not reported.	N=49. Intervention (N=34); Control (N=15).	Intervention: TipOn, 1 session per week, each 1 hour, 9 weeks Control: delayed intervention	home	parents	Children in the experimental group exhibited significantly greater pre-post gains in word definition tasks and lexical tone than the control group. Positive relationship between the total number of phonetic games played and the pre-post gain in the word definition production task.	-	-	8/13 (moderate)	RCT
Phonological skills	Dacewicz et al. [34]	Experiment group: M 13 (72.22%), mean age 6.3±1.0; Control group: M 13 (72.22%), mean age 6.0±0.8.	N=36. Experiment group (N=18); Control group (N=18).	Experiment: Dr. Neuronowski, four sessions per week, each 1 hour, 6 weeks. Control: other computer games for identification and discrimination of syllables and words, four sessions per week, each 1 hour, 6 weeks.	a separate room at the Nencki Institute or the Early Intervention Centre.	a trained consultant	In the experimental group, MMN amplitude enhancement was observed in both ISI conditions. In both experimental and control groups, P3a amplitude was enhanced in both ISIs.	-	-	9/13 (moderate)	RCT
Phonological skills	Heikkilä et al. [41]	Audiovisual training group: M 6 (60.00%), mean age 8.75; Auditory training group: M 7 (70.00%), mean age 9.08.	N=20. Audiovisual training group (N=10); Auditory training group (N=10).	Audiovisual: program developed by authors and run with Presentation software, 5 days a week, each 10-15 minutes, 6 weeks Auditory: same program with the screen blocked. 5 days a week, each 10-15 minutes, 6 weeks	Valteri Onerva School	SLP	Training with audiovisual speech can improve the phonological skills of children with DLD in the repetition of nonsense words. Audiovisual speech might be more effective than auditory speech in training phonological skills in children.	-	-	9/9 (high)	Quasi-experimental
General	Loeb et al. [42]	FFW: M 14 (58.33%), mean age 7.42±9.97; CALI: M 17 (58.62%), mean age 7.33±11.35; ILI: M 17 (68.00%), mean age 7.58±8.72; AC: M 18 (72.00%), mean age 7.33±10.48.	N=103. FFW (N=24), CALI (N=29), ILI (N=25), AC (N=25).	FFW: FFW, 5 days a week, each 100 min, 6 weeks CALI: other software targeted phonological skills, 5 days a week, each 100 min, 6 weeks ILI: literature-based intervention, 5 days a week, each 100 min, 6 weeks AE: software not	School	SLP	Children in the FFW, CALI, and ILI conditions showed significant improvement in blending sounds compared to the AC group immediately after the test.	6 months	After 6 months, long-term gains were moderate for blending sounds, but not significant.	8/9 (high)	Quasi-experimental

				for language development, 5 days a week, each 100 min, 6 weeks.							
General	Cohen et al. [35]	FFW: M 16 (69.57%), mean age 7.34±1.29; Computer software: M 22 (81.48%), mean age 7.43±1.21; Control: M 17 (62.96%), mean age 7.41±1.17.	N=77, FFW (N=23); Computer software (N=27); Control (N=27).	Group A: FFW, 5 days a week, each 90 min, 6 weeks Group B: Computer software, educational software packages, 5 days a week, each 90 min, 6 weeks Group C: Control. No intervention.	home	parents	Each group made significant gains in language scores, but there was no additional effect for either computer intervention.	6 months	Group A showed significant gains in the scores of Expressive and Receptive Language on the CELF-3UK and the rhyming skills.	9/13 (moderate)	RCT
General	Gillam et al. [36]	CALI: M 34 (62.96%), mean age 7.42; FFW: M 29 (53.70%), mean age 7.50; ILI: M 38 (70.37%), mean age 7.67; AE: M 35 (64.81%), mean age 7.58.	N=216. CALI (N=54), FFW (N=54), ILI (N=54), AE (N=54).	CALI (computer-assisted language intervention): software for phonological skills, 5 days a week, each 100 min, 6 weeks FFW: FFW, 5 days a week, each 100 min, 6 weeks ILI (individualized language intervention): literature-based, 5 days a week, each 100 min, 6 weeks AE (academic enrichment): computer software not for language development, 5 days a week, each 100 min, 6 weeks	a quiet area	SLP	FFW was not more effective at improving general language skills or temporal processing skills than a nonspecific comparison treatment (AE) or specific language intervention comparison treatments (CALI and ILI) that did not contain modified speech stimuli.	3 months and 6 months	Participants in the FFW-L and CALI conditions earned higher phonological awareness scores than children in the ILI and AE conditions at the 6-month follow-up testing.	12/13 (high)	RCT
Grammar-receptive	Hsu et al. [38]	DLD-trained: mean age 8.6±1.32; TD-Grammar-matched: mean age 9.1±1.32; TD-age-matched: mean age 5.8±0.86; DLD-untrained: mean age 8.9±0.77. Gender of each group was not reported.	N=96. DLD-trained (N=28); TD-Grammar-matched (N=28); TD-age-matched (N=20); DLD-untrained (N=20)	DLD-trained: FFW, 5-7 min per day, 4 sessions in 4-6 days TD-Grammar-matched: FFW, 5-7 min per day, 4 sessions in 4-6 days TD-age-matched: FFW, 5-7 min per day, 4 sessions in 4-6 days DLD-untrained: no intervention	not mentioned	not mentioned	Children with DLD showed greater accuracy with repeated sentences compared with unique sentences. Training did not improve children's performance on a standardized test of receptive grammar.	-	-	7/13 (moderate)	RCT
Grammar-receptive	Bishop et al. [44]	Group M: mean age 11.08±1.13; Group S: mean age 10.85±1.79; Group U: mean age 10.28±0.88. Gender of each group was not reported.	N=36. Modified speech (M, N=13), ordinary speech (S, N=15) and untrained control (U, N=9).	Modified speech (M): FFW, 5 sessions per week, each 15 minutes, 4 weeks Slow speech (S): trainings with a 1.2-second delay between the end of one sentence segment and the start of the next Untrained group (U): continued to receive their regular educational input	school	school staff	Responses speeded up, and most children performed well above chance, accuracy typically remained below 95% correct. Trained groups did not differ from untrained children on language or auditory outcomes. Acoustically modified speech input did not enhance comprehension.	-	-	9/9 (high)	Quasi-experimental
Grammar-expressive	Washington et al. [39]	CAT: M 8 (72.73%), age range 3.92-4.50;	N=34. CAT (N=11); nCAT (N=11); No treatment	CAT (computer-assisted treatment): My sentence	not mentioned	SLP	C-AT and nC-AT participants significantly	3 months	C-AT and nC-AT participants significantly	8/13 (moderate)	RCT

		nCAT: M 8 (72.73%), age range 4.17–4.83; No treatment: M 11(91.67%), age range 3.50–4.92.	(N=12).	builder, once a week, each 20 min, 10 weeks nCAT (non-computer-assisted treatment): “table-top” procedures, once a week, each 20 min, 10 weeks No treatment: children awaiting treatment			outperformed controls pre-to-post to 3 months post-treatment in both assessment contexts. No significant differences in treatment gains were found between C-AT and nC-AT.		outperformed controls pre-to-post to 3 months post-treatment in both assessment contexts.		
Vocabulary-receptive	Yi et al. [43]	Intervention: M 44 (52.38%), mean age 4.88±0.79; Control: M 42 (53.85%), mean age 4.69±0.85.	N=162. Intervention (N=84); Control (N=78).	Intervention: Jingyun Rehab Platform, daily task, 3 months Control: conventional home-based rehabilitation recommendations, 3 months	home	parents	Children with DLD in the cloud-based rehabilitation group performed significantly better in language abilities than the control group. The frequency of training sessions was proportional to their performance on language, memory, and cognition tasks.	-	-	9/9 (high)	Quasi-experimental
Vocabulary-receptive	Zwitserslood et al. [37]	Intervention: M 26 (72.22%), mean age 3.47±0.17; Control: M 25(69.44%), mean age 3.53±0.21.	N=72. Intervention (N=36); Control (N=36).	Intervention: My PlayHome, 12 sessions in an 8–9-week period, each 10-min Control: intervention based on real objects, 12 sessions in an 8–9-week period, each 10-min	daycare center	SLP	Children in both groups learned significantly more target words than control words. No significant differences in gains between the two intervention conditions were found.	5 weeks	At the end of the 5-week retention period, there was a significant growth in target words, and the newly learned words were still known.	8/13 (moderate)	RCT

Fidelity of the studies

Table 2 presented the treatment fidelity for the included articles, and supplementary material presented the scores of fidelities for each study.

There are two domains which the treatment fidelity scores were above 50%, including the “Treatment design” domain at 75% (SD=0.15) and the “Enactment” domain at 58% (SD=0.18). The lowest mean proportion of adherence to strategies was found in the “Receipt” domain, where, on average, only 4% (SD=0.09) of strategies were reported among the studies. Finally, the mean proportion of adherence to strategies in the “Training providers” and “Delivery” domains was 16% (SD=0.17) and 19% (SD=0.15), respectively. The mean proportion of adherence to treatment fidelity strategies included across all 5 domains for all studies was 43% (SD=0.10).

Based on the fidelity scoring by Borrelli [31], where 50% constitutes low-fidelity scoring, 69% (9/13) of the interventions scored a low treatment fidelity across all 5 domains. In total, 31% (4/13) of the studies, including Chen et al. [33], Loeb et al. [42], Gillam et al. [36] and Zwitserslood et al. [37], scored >0.50 in the overall treatment fidelity (range 0.50 to 0.58).

Table 2 Treatment fidelity for the included articles

fidelity domains	1. treatment design	2. training providers	3. delivery	4. receipt	5. enactment	overall fidelity proportion per study
Bishop et al. [40]	0.63	0.14	0.11	0.00	0.50	0.34
Carson et al. [32]	0.63	0.00	0.00	0.25	1.00	0.34

Chen et al. [33]	0.88	0.14	0.44	0.00	0.50	0.53
Dacewicz et al. [34]	0.88	0.14	0.22	0.00	0.50	0.47
Heikkilä et al. [41]	0.88	0.29	0.00	0.00	0.50	0.45
Loeb et al. [42]	0.88	0.29	0.22	0.00	0.50	0.50
Cohen et al. [35]	0.88	0.00	0.33	0.00	0.50	0.47
Gillam et al. [36]	0.88	0.29	0.33	0.00	0.50	0.53
Hsu et al. [38]	0.56	0.00	0.00	0.00	0.50	0.26
Bishop et al. [44]	0.56	0.00	0.00	0.25	1.00	0.32
Washington et al. [39]	0.81	0.29	0.11	0.00	0.50	0.45
Yi et al. [43]	0.50	0.00	0.33	0.00	0.50	0.32
Zwitsers et al. [37]	0.88	0.57	0.33	0.00	0.50	0.58
Mean proportion (SD)	0.75 (0.15)	0.16 (0.17)	0.19 (0.15)	0.04 (0.09)	0.58 (0.18)	0.43 (0.10)

Discussion

This systematic review aimed to explore the language domain that most frequently targeted by digital intervention in children with DLD. Phonological skills were the most researched skills among all included studies, especially receptive phonological skills. Phonological awareness is the skill of being aware of sounds in spoken language. It ranges from dividing words into syllables, recognizing and producing rhymes, and matching words with the same beginning sound, to more complex abilities such as separating and processing individual sounds or phonemes, which are causally related to early word decoding skills [45]. Studies showed that digital intervention is helpful in improving phonological skills. Digital intervention programs have the advantage of providing grading acoustically modified speech signals and image or video resources [42]. Hierarchically auditory and visual cueing is crucial in phonological training [46]. Digital interventions are designed to adapt the level of difficulty and cues of the training according to the success of the child on multiple trials, which might be the reason digital intervention is effective.

Word learning ability has also been proven to be improved through phonological skills digital training, while the conclusion is still controversial. Word learning involves processes such as encoding, working memory, lexical access and mapping of phonological form to meaning [47, 48]. Phonological skills, especially phonemic awareness skills, were proven to be the strongest predictor of children's word reading ability [49]. Children with DLD might suffer from impaired mapping of phonological form to meaning given their less sensitivity to the pronunciation of the words and the information within words during the word learning phase [50]. Digital intervention, featuring visual-auditory stimuli and a game format, has the potential to better engage participants' attention during the intervention. However, Bishop et al. [40] found that participants in the digital intervention group were not better improved in word learning, which might be caused by the short intervention period (4 weeks). Also, it is suggested that children with language impairment and poor reading skills need a more comprehensive approach to improve their reading skills that extends beyond an emphasis on phonemic awareness [42]. General language and speech function was the second most concerned topic in digital interventions. Results showed that only half of the children with DLD gained progress after

training. Cohen et al. [35] indicated that children with DLD already received intensive specialist therapy and educational support, while digital interventions were not sufficient in and of themselves to confer additional therapeutic benefits. The varied results between individuals combined with the generally inconsistent patterns of performance on certain games create uncertainty as to which elements of *FFW* are producing improvements [51]. A meta-analysis conducted by Strong et al. [52] also indicated that there was no significant effect of *FFW* on any outcome measure in comparison to active or untreated control groups. Therefore, further studies are needed to evaluate the effectiveness of specific training games or formats of digital interventions.

Studies targeting grammar deficits in DLD showed greater accuracy after intervention but no significant improvement on standardized tests of receptive grammar, or no significant differences in treatment gains between computer-based training and non-computer-based training. In grammar training games, accuracy could be improved by simply rote learning the meaning of the whole sentence, or by memorizing the correct answers [38]. Therefore, even if children with DLD have difficulties in analyzing the sentence structure, they can still behave well in the training. For this reason, when targeting higher language functions such as grammar, more diverse materials, and learning patterns are needed to promote the generalization of functions. Since the number of studies included in this review was limited, further studies with follow-up periods were needed to examine the effectiveness of digital intervention in receptive and expressive grammar.

In studies targeting vocabulary skills, digital intervention was of promising effectiveness. Children with DLD showed significant improvement after 2~3 months of intervention. Vocabulary training might involve cognitive functions and enhance more global skills [53, 54]. Yi et al. [43] suggested that children's language development can promote growth hormone secretion in children, stimulate brain development, promote children's intellectual development, and have a positive role in improving children's language communication skills. Therefore, it is recommended that children with DLD receive vocabulary training. Although digital interventions for DLD were proven effective in several studies, there was evidence showing that DLD did not additionally benefit from digital intervention. Several factors might need to be considered when delivering digital treatment for DLD: The first factor to be considered is the targeting domain of intervention. In the domains discussed above, digital interventions are demonstrated to be practical and effective in improving basic language and speech skills such as phonological skills and vocabulary skills. Training of these skills requires lots of repetition and hierarchical audiovisual input, which can be easily achieved by digital techniques [42]. Phonological skills and vocabulary skills are also the prerequisites for learning higher language skills such as grammar and reading [55, 56]. However, digital interventions targeting higher language functions such as grammar, which might involve more cognitive functions [57], were required to be more diversified and more interesting.

Expressive language tended to receive less attention in digital interventions compared to receptive language. Only one study included in this review focused on expressive language. Law et al. [58] reported that in-person speech and language therapy interventions were effective for expressive phonological and expressive vocabulary difficulties. However, in computer-based training for expressive language skills, in-time feedback is not provided automatically, which might lower children's motivation to participate. With the development of computerized language analysis techniques, in-time feedback from the digital program might make expressive language evaluation and training more effective [59, 60].

People and places to deliver the intervention might affect the effectiveness of digital interventions. In the included studies, digital interventions were delivered in clinical settings,

schools, or at home, and people who carried out digital interventions were speech therapists, schoolteachers, parents, or a combination of two or all three. Digital language training facilitated by trained therapists in clinical settings was shown to be more effective. The reason might be that in home environments, children used to play the game on their own and tend to ignore the instruction during intervention [22]. Also, interventions delivered in school might take away time from their regular classes, which to some extent could be detrimental to their language development [40]. Yi et al. [43] applied the intervention pattern with therapists deciding on the training topics and sending them to the patient's account, and parents led the training at home. This kind of cooperation proved to be beneficial for children during COVID-19 or children living in remote areas.

The last factor is duration and intensity. The duration of the included studies ranges from 4~12 weeks, and intensity ranges from 15~100 minutes per day. The literature regarding dosage was unclear in optimal intensity, frequency, and duration to maximize efficacy. It seems that interventions carried out for 6 weeks or longer are more effective than those less than 6 weeks. Further investigation of the optimal dosage is necessary. Yi et al. [43] and Chen et al. [33] suggested that the number of training sessions was directly proportional to the performance of children with DLD in language training tasks.

However, the optimal duration and intensity of digital intervention that can meet both treatment needs and avoid the negative effects caused by excessive screen time remain to be resolved. Frizelle et al. [61] conducted a systematic review and narrative synthesis, suggested that frequent, short sessions ($2/3 \times$ per week, approximately 2 min) and less frequent, long sessions ($1 \times$ per week, approximately 20 min) have yielded the best outcomes when composite language measures have been used. For the dosage form, explicit instruction was more beneficial compared with implicit instruction [62]. Variability in input, elicited production, and gestural and other visual supports were beneficial to language development [62]. The amount of screen time was cumulatively and negatively linked to the children's lexical and general language abilities [63, 64]. Also, the early onset of screen exposure had negative effects on language development [65]. It is suggested that no more than 2 hours of screen time per day has minimal negative effects on development [66]. Better-quality screen use such as educational programs and co-viewing was associated with stronger child language skills [64].

The usability and practicality of the digital intervention should also be taken into consideration. Digital intervention for children with DLD uses interactive elements, making the intervention engaging for children. Tablets or mobile phones, with touch screens, provided children with multisensory and direct interaction [37]. Personalization and progress tracking are other advantages of digital intervention. The online intervention platform utilized by Yi et al. [43] would automatically pop up the training results, reaction times, and training plan suggestions after each training and automatically adjust the training plan. Also, digital intervention can offer teachers and families a time-efficient and cost-effective alternative to close learning gaps and avoid the implications of growing disparities in skills due to lengthy waiting times [32]. However, digital intervention might be too distracting and restrict the use of language-facilitating techniques and language interaction between the SLP [37].

Intervention fidelity is an important aspect of designing and implementing intervention effectiveness studies [67]. Most studies have poor treatment fidelity in the areas of "training providers", "delivery" and "receipt". There was a lack of training for the intervention providers such as parents or school staff. The reason may be related to the characteristics of the digital intervention. In part of the studies, the intervention process is already set in the digital intervention program, which reduces the professional requirements for the providers of the intervention. However, if the treatment protocols were not set in advance in the software, and non-medical professionals are allowed to use the digital intervention program freely, it is

difficult to ensure the effectiveness of the digital intervention of DLD.

Limitation

This study had some limitations. First, the number of studies regarding the effectiveness of digital intervention in children with DLD in each language domain was insufficient, and most of which have no follow-up period, making it difficult to draw a convincing conclusion. Also, influential factors such as dosage varied among included studies, and due to the heterogeneity of included studies, the validity of the review analysis might be limited. Besides, this review included research on various research designs, different populations and interventions. The inclusion of studies with different research designs increases the number of studies included, thereby broadening the perspective on this issue. However, at the same time, the risk of bias is also increasing. Also, the quality of the included studies was varied, and more rigorous studies were needed in the future. Regarding the intervention domain, more studies focused on the effects of digital interventions for receptive language skills training than for expressive language skills training. Therefore, results showing that receptive language skills training is more effective need to be further examined. Regarding the targeting population, further research could examine the efficacy of digital interventions in children with DLD with different predominant language impairments separately to explore the optimal population for digital interventions.

Conclusion

The present systematic review indicates that phonological skills are the most frequently targeted language domain by digital interventions in children with DLD. Given the limited number and the heterogeneity of the studies included, it is still unclear whether digital intervention was effective in improving different language skills in children with DLD. There is less evidence supporting digital interventions are effective for expressive language skills. Due to the lack of normality of children's language development and speech analysis technology, digital programs are unable to respond to children's errors in a timely manner. Addressing these issues is critical to ensure that mHealth technology is effective in expressive language interventions for children with DLD. Further higher-level evidence such as RCT studies in this area is also needed to direct future updates the digital programs. Digital intervention could be complementary to regular in-person language interventions.

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Conflicts of Interest

The authors declare no conflict of interest.

Abbreviations

DLD: developmental language disorder

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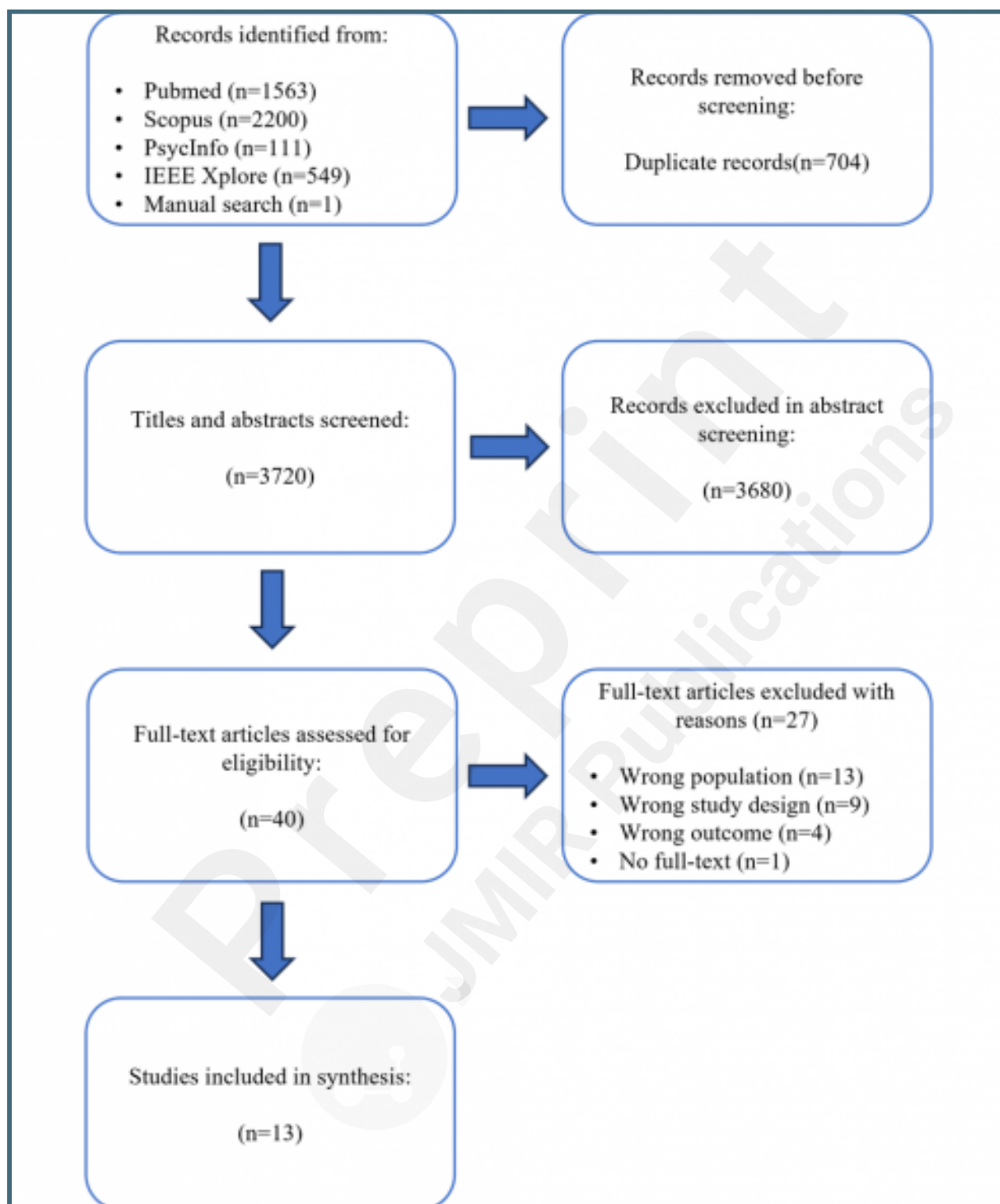
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Supplementary Files

Figures

PRISMA Flow Chart Describing the Inclusion Process of the Articles.



Multimedia Appendixes

Fidelity scores of the included studies.

URL: <http://asset.jmir.pub/assets/d499beef54ed616489e9f7a89c1ffcfd.xlsx>



CONSORT (or other) checklists

PRISMA checklist.

URL: <http://asset.jmir.pub/assets/f32ab828eff0d26f8745d084581d0a44.pdf>