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SURVEY

A Systematic Literature Review of XR Interventions to Improve Motor Skills Development Among Autistic Children

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ABSTRACT Autism is a developmental condition that affects motor skill development. There is a lack of comprehensive research exploring the potential benefits of extended reality (XR) technologies, including virtual reality (VR) and augmented reality (AR), for improving motor skills in autistic children. This systematic literature review (SLR) addresses this research gap by investigating XR-based interventions targeting motor skill development in autistic children. The SLR analysed 15 primary studies published between 2012 and 2024, examining the use of VR and AR to improve motor skill development in autistic children. The interventions ranged from one session to 12 weeks, lasting 12 to 45 minutes, and targeted various body movements. XR platforms and devices used included VR headsets, motion capture systems, and exercise bikes. Recurrent neural networks, dynamic difficulty adjustment, and behaviour trees were employed to enhance intervention dynamics and extract valuable insights from collected data. The results suggest that using XR interventions has significant potential to improve physical activity levels and motor skills development among autistic children. However, the research designs varied, with only one study including their intervention framework's generalisation and maintenance phases. This study offers an encouraging avenue for future research and intervention design in this field.

INDEX TERMS Augmented reality, autism spectrum disorder, data collection, extended reality, inclusive, education, motor skills, research design, systematic review, virtual reality.

I. INTRODUCTION

Autism is a complex neurodevelopmental condition that manifests itself as persistent challenges with social interaction, communication, and repetitive behavioural patterns [1]. In addition to the challenges outlined in *The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* **(DSM-5)**, on average, 83% of autistic children face significant challenges achieving their age-appropriate motor skill development targets [2]. These delays in motor skill development can significantly affect daily functioning and quality of life [3]. Over the last few decades, the number of children diagnosed with autism has increased significantly. In the United States, the rate of children diagnosed with autism increased from a rate of 1:150 to 1:44 between 2000 and 2018 [4]. This increase in the rate of children diagnosed with autism is not limited to the United States. In the United Kingdom, between 1998 and 2018, the rate of autism diagnosed increased by 787% [5].

These escalating diagnosis rates are causing professionals to grapple with providing timely and effective early interventions [6], [7]. The escalating demand has resulted

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in long waiting times and a shortage of trained healthcare professionals, which in turn is hindering rapid access to autism interventions [7], [8]. These delays in accessing appropriate interventions can significantly impact the outcomes for autistic children, particularly concerning their physical well-being. Autistic children, on average, have lower levels of physical activity than non-autistic children [9], [10], [11]. This, in turn, puts them at a significantly higher risk than their non-autistic peers of being overweight or obese [2], [11]. Some impediments that prevent autistic children from participating in physical activities are the following. Autistic children may need increased monitoring levels, adults may lack the knowledge necessary to involve them in physical activities, and other children could exclude them from physical activities [12]. In recent years, there has been a growing trend among researchers to utilize technology-based interventions to bridge the growing gap between autistic children and the services they need. These interventions not only aim to address the timely access to necessary services but also to promote physical activity, overall well-being, and the development of motor skills.

Technology-based interventions can be cost-effective and accessible; they can also address some of the barriers to traditional interventions, such as limited resources and geographical constraints [13]. By incorporating these interventions into therapy and educational programs, barriers to physical activity for autistic children can be mitigated. Using technology-based interventions can provide interactive and engaging platforms that can motivate children to participate in physical activities, thereby reducing sedentary behaviour and the risk of obesity [14], [15]. In addition, these interventions can specifically target motor skill development, offering tailored activities and feedback to improve motor skills in autistic children. By breaking down barriers to entry and promoting active participation, technology-based interventions hold promise in improving the physical well-being and motor skills of autistic children.

One of the most promising technologies currently being investigated is *Extended Reality* (**XR**) technologies. XR technologies encompass all immersive technologies that extend the reality we experience by blending the physical and digital worlds. It covers the entire spectrum from fully immersive *Virtual Reality* (**VR**) environments to real-world *Augmented Reality* (**AR**) environments, providing new ways for users to perceive and interact with the world around them [16]. AR Technologies overlays or merges computer-generated alphanumeric, symbolic, or graphical data with the real world, allowing users to interact with the augmented environment. This means digital elements are superimposed onto the physical world, enhancing users' perception and interaction with real-world surroundings [17]. VR Technologies, on the other hand, fully immerse the user in a virtual environment. Users can interact to differing degrees with this entirely digital environment, which is independent of the real world. VR creates a simulated experience which can be similar to or completely different from the real world [17]. Previous research has highlighted that XR is effective at attracting the attention of autistic children [18].

As far as can be discerned through extensive inquiry, this *Systematic Literature Review* (**SLR**) is the first to explore the utilisation of XR interventions aimed at enhancing motor skill development in autistic children. TABLE 1 provides a compelling illustration of the novelty and significance of the current survey/review. This SLR aims to investigate the current state-of-the-art research in using XR for autistic children, to assist them in developing their motor skills and provide recommendations for future research in this field. The methods used to perform this SLR are described in **Section II**. In **Section III**, the results of this SLR are presented. Next, in **Section IV**, the research findings of the SLR are discussed. Finally, **Section V** concludes this SLR and highlights directions for future work in this area of research.

II. METHODS

This SLR follows the process defined in [44]. This section discusses the process of conducting the SLR, with each subsection highlighting the steps and explaining what each step entails.

A. PLANNING THE REVIEW

The initial phase of this research involved formulating a comprehensive set of research questions (RQ). At this phase's conclusion, eleven research questions were developed to facilitate a thorough examination of the subject matter. These research questions provide the framework for the SLR, which identifies primary studies aimed at improving the motor skills of autistic children using XR-based interventions. From this point forward, the article refers to these studies as primary studies. The RQ investigated in this SLR are outlined below:

- **RQ1:** What are the recent trends in publication demographics for the primary studies?
  - **RQ1** aims to analyse the publication demographics in terms of publication years, countries of origin, and types of publications associated with the primary studies in the field of XR-based interventions for motor skill enhancement of autistic children.
- **RQ2:** Was AR or VR utilised in the primary research studies?
  - **RQ2** analyses the primary studies to determine whether an AR-based intervention or a VR-based intervention was used in their study.
- **RQ3:** Where were the interventions implemented in the primary studies?
  - **RQ3** examines the diverse locations where the intervention in the primary studies took place.
- **RQ4:** What were the participants' characteristics in the primary studies?
  - **RQ4** scrutinises the demographics of the participants engaged in the primary studies and distils these details. This includes the number of

TABLE 1. Comparison of reviews/surveys investigating XR-based interventions for autistic children.

Works	Year	Virtual Reality	Augmented Realtiy	Primarily Focuses on Motor Skill Development
This work	2024	✓	✓	✓
[19]	2024	✓	✗	✗
[20]	2024	✗	✓	✗
[21]	2024	✓	✓	✗
[22]	2023	✓	✗	✗
[23]	2023	✗	✓	✗
[24]	2023	✓	✗	✗
[25]	2023	✓	✓	✗
[26]	2023	✓	✓	✗
[27]	2022	✗	✓	✗
[27]	2022	✗	✓	✗
[28]	2022	✓	✗	✗
[29]	2022	✓	✓	✗
[30]	2022	✓	✗	✗
[31]	2022	✗	✓	✗
[32]	2022	✓	✗	✗
[33]	2022	✓	✗	✗
[34]	2022	✓	✓	✗
[35]	2021	✓	✓	✗
[36]	2021	✗	✓	✗
[37]	2021	✓	✓	✗
[38]	2021	✗	✓	✗
[39]	2021	✗	✓	✗
[40]	2021	✓	✓	✗
[41]	2021	✗	✓	✗
[42]	2021	✓	✓	✗
[43]	2021	✓	✓	✗
[38]	2021	✗	✓	✗
[41]	2021	✗	✓	✗
[44]	2020	✗	✓	✗
[45]	2020	✗	✓	✗
[46]	2020	✓	✗	✗
[47]	2020	✗	✓	✗
[48]	2020	✗	✓	✗
[49]	2019	✗	✓	✗
[50]	2018	✓	✗	✗
[18]	2018	✓	✗	✗
[51]	2018	✓	✗	✗
[52]	2018	✓	✗	✗
[53]	2017	✓	✗	✗

participants, the presence of control groups, the prevalence of autism among participants, age distribution, gender composition, and other pertinent demographic characteristics.

- **RQ5:** What hardware devices were utilised in the interventions in the primary studies?
  - **RQ5** dissects the technological apparatuses employed during interventions, examining the specifics of hardware utilisation, technical requirements, obsolescence status, and spatial prerequisites for implementation.
- **RQ6:** What were the data sources and collection methods employed in the primary studies?
  - **RQ6** probes into the realms of data sources and collection methods deployed within primary studies, illuminating the diverse sources from which data was procured and the methodologies employed for data collection.
- **RQ7:** What data processing techniques were applied to the collected data in the primary studies?
  - **RQ7** delves into the intricate domain of data processing techniques applied to collected data, unravelling the intricacies of procedures or algorithms employed for data analysis and interpretation.
- **RQ8:** What platform or framework was employed in the primary studies?
  - **RQ8** ventures into the technological landscape, exploring the platforms or frameworks underpinning interventions within primary studies, thereby elucidating the overarching technological infrastructures.
- **RQ9:** What research designs were employed in the primary studies?
  - **RQ9** sheds light on the methodological underpinnings, uncovering the diverse research designs adopted within primary studies, thus offering insights into the methodological approaches and experimental designs employed.
- **RQ10:** How long were the interventions, and what body movements did they primarily target?

TABLE 2. Breakdown of keywords used in the search query.

Category	Keywords
1	ASD, autistic, Autism Spectrum Disorder, Asperger, Asperger Syndrome, Autistic Disorder
2	Augmented Reality, Virtual Reality, Extended Reality
3	children, adolescent, adolescents, teen, teens, teenager, teenagers, school, pupil, pupils, kid, kids, child

TABLE 3. The breakdown of the PICO model used to determine the papers included in this section.

PICO Item	Description
Population	Autistic Children
Intervention	XR Based Intervention to improve motor skills in Autistic Children
Control	Use of conventional methods
Outcome	The main outcomes obtained

  - **RQ10** seeks to understand the duration and focus of the interventions within primary studies. This involves investigating the total duration of the interventions and the duration per session. Additionally, the aim is to determine whether the interventions are primarily aimed at movements of the lower body, upper body, or full body.
- **RQ11:** To what extent did the primary studies facilitate the generalisation and maintenance of skills acquired throughout their intervention?
  - **RQ11** scrutinises the enduring impact of interventions, delving into how primary studies facilitated the generalisation and maintenance of acquired skills beyond the intervention period.

B. SEARCH STRATEGY

The process employed to generate the search terms comprised several sequential steps. Firstly, significant keywords were identified from each research question. Utilising the Boolean operator OR, the keywords within each category were combined to broaden the search scope. Furthermore, employing the Boolean operator AND, the keywords across different categories were interconnected to refine the search parameters. TABLE 2 shows each of the categories and the keywords associated with the said category. The query generated based on the keywords in each category is as follows:

(autism OR ASD OR autistic OR "Autism Spectrum Disorder" OR Asperger OR "Asperger Syndrome" OR "Autistic Disorder") AND ("Augmented Reality" OR "Virtual Reality" OR "Mixed Reality") AND (children OR adolescent OR adolescents OR teen OR teens OR teenager OR teenagers OR school OR pupil OR pupils OR kid OR kids OR child).

Once the search terms string was generated, the databases SCOPUS, Web of Science, PubMed and EBSCO were searched using the search query. The following restrictions were added to the database searches to refine the results further. Since extended reality technologies have advanced quickly in recent years, database searches were restricted to research published between the first of January 2012 and the third of March 2024. Additionally, only peer-reviewed studies published in English were reviewed during the search.

C. STUDY SELECTION

Following the initial search of the four databases, duplicate records were removed, resulting in 1221 unique records. Subsequently, the titles and abstracts of these records were screened according to predefined inclusion and exclusion criteria. The Population, Intervention, Control, and Outcome (PICO) framework is used to determine the inclusion/exclusion criteria. The breakdown of the PICO model used for study selection is provided in TABLE 3. Articles that did not meet the eligibility criteria were excluded, leading to the exclusion of 1138 records. The remaining 83 articles underwent full-text screening, where an additional 68 articles were excluded based on the predetermined criteria. This systematic selection process, depicted in FIGURE 1, ensured the inclusion of all relevant journal articles and conference papers that utilised XR-based interventions to improve motor skills in autistic children. As such, this SLR encompasses a comprehensive review of current research on XR-based interventions for this specific population.

Ultimately, 15 articles met the inclusion criteria and were included in the systematic review.

III. RESULTS

The following section of the SLR answers the eleven RQ posed in the previous section. An overview of the primary studies in terms of setting, participants, and research design can be seen in TABLE 4 and an overview of the primary studies in terms of device types, data sources, and data processing can be seen in TABLE 10. Subsequent subsections delve into each research question, offering focused insights derived from the collective findings of the primary studies.

A. RQ1: WHAT ARE THE RECENT TRENDS IN PUBLICATION DEMOGRAPHICS FOR THE PRIMARY STUDIES?

After an investigation into the publication demographics of the primary studies regarding trends in publication years, the countries where research was conducted, and the types of publications, the following insights were obtained. Firstly, the analysis of years of publication reveals a notable surge in studies focusing on XR-based interventions for enhancing motor skills in recent years; this can be seen in (FIGURE 2). Next, the examination of the geographic distribution of research activities highlights key countries leading in this field, including South Korea, the United States, China, and Spain; this can be seen in (FIGURE 3). Finally, the analysis of publication types shows that the majority of research outputs are disseminated through academic journals, with a significant portion also presented in conference papers; this can be seen in (FIGURE 4).

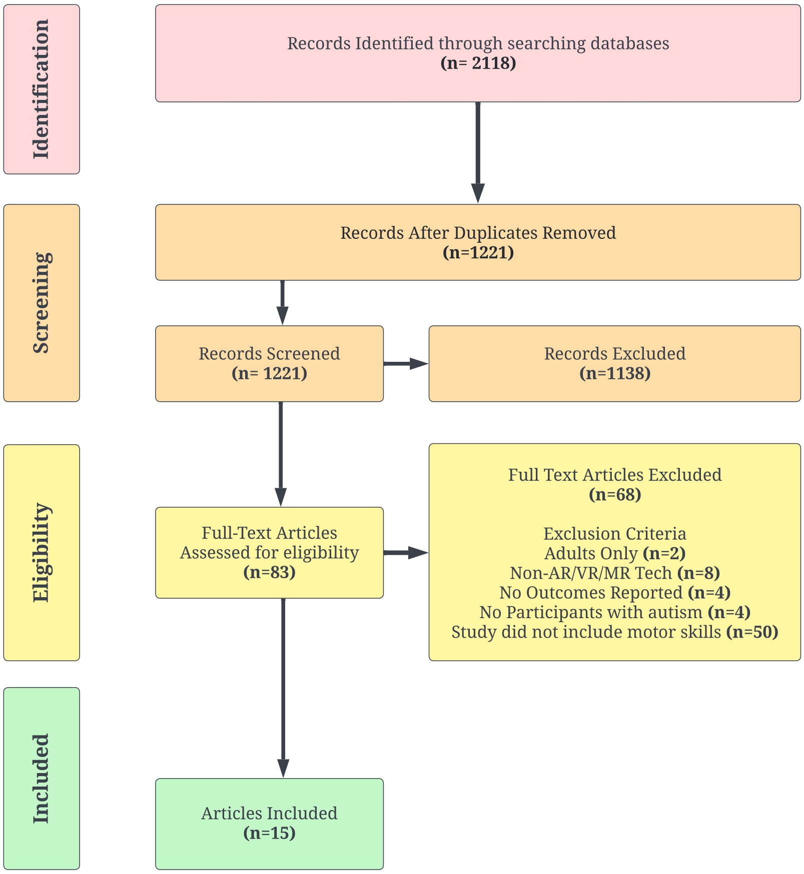

FIGURE 1. PRISMA flowchart of the study selection procedure.

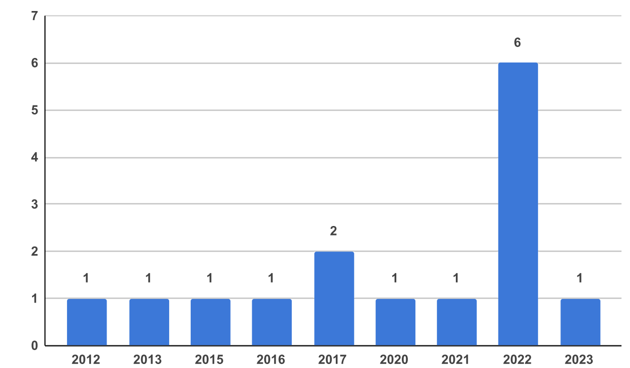

FIGURE 2. Publication years of the primary studies.

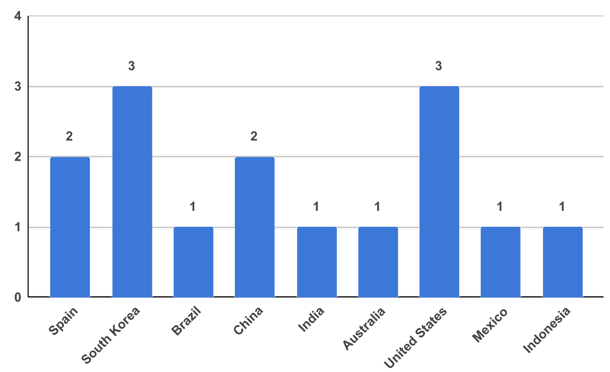

FIGURE 3. Country where primary studies were conducted.

B. RQ2: WAS AR OR VR UTILISED IN THE PRIMARY RESEARCH STUDIES?

An exploration of the use of AR and VR in primary research studies uncovered an intriguing pattern. Out of the fifteen studies analysed, VR was utilised in thirteen cases. On the other hand, AR was only present in the remaining two studies. This highlights that VR is the technology that is more commonly employed presently. This distribution highlights the higher frequency of VR utilisation in the research field under review. FIGURE 5 provides a clear visual representation of this delineation.

C. RQ3: WHERE WERE THE INTERVENTIONS IMPLEMENTED IN THE PRIMARY STUDIES?

The examination of how interventions were implemented in primary studies uncovered valuable findings. After analysing the primary studies, it was discovered that five interventions took place in a classroom setting, while the majority of ten interventions were carried out in a research environment. A detailed summary of this information, including which primary studies utilised which environment for intervention implementation, can be found in TABLE 4.

TABLE 4. Overview of the settings, participants and research design for the primary studies.

Citation	Enviroment	Participant Demographic	Research Design
[54]	Research Environment	40 (m=26, f=14) (ASD=20, NT=20);	Post-Test
[55]	School Environment	52 (m=37, f=15) (ASD=30, ID=22);	Pre-Test and Post-Test
[56]	Research Environment	23 (m=21, f=2) (ASD=6, ID=14, DS=1);	Pre-Test and Post-Test
[57]	Research Environment	22 (m=22, f=0) (ASD=22);	Post-Test
[58]	Research Environment	10 (m=9, f=1) (ASD=10);	Pre-Test and Post-Test
[59]	Research Environment	12 (ASD=12);	Pre-Test and Post-Test
[60]	Research Environment	4 (m=3, f=1) (ASD=1, FAS=1, ID=1, DS=1);	Post-Test
[61]	Research Environment	2 (ASD=2);	Post-Test
[62]	School Environment	109 (m=91, f=18) (ASD=39%);	Post-Test
[63]	Research Environment	10 (ASD=10);	Post-Test
[64]	School Environment	5 (5=ASD);	Post-Test
[65]	School Environment	7 (m=6, f=1) (ASD=7);	Post-Test
[66]	Research Environment	5 (m=4, f=1) (ASD=4, LD=1);	Pre-Test and Post-Test
[67]	School Environment	24 (m=22, f=2) (ASD=24);	Pre-Test and Post-Test
[68]	Research Environment	7 (ASD=7);	Pre-Test and Post-Test

ASD = Autism Spectrum Disorder, NT = Neuro Typical, ID = Intellectual Disability, DS = Down Syndrome, FAS = Fetal Alcohol Syndrome, LD = Learning Disability

TABLE 5. Overview of the studies, age ranges, and interaction devices.

Citation	Age Ranges	Interaction Device
[54]	3-7	Kinect Azure DK, Projector(s), Computer(s), CAVE
[55]	7-12	Kinect Azure DK, Projector(s), Computer(s), CAVE
[56]	7-12	Oculus Quest, VZFit Sensor, GENEActiv, Fit Bit Charge 2, Computer(s)
[57]	10-16	Computer, Monitor, Web camera, TV/Monitor, Computer(s)
[58]	10-17	HTC Vive Pro, Computer(s)
[59]	6-8	HTC Vive, TV/Monitor, Computer(s)
[60]	14-21	HTC Vive, Virzoom Bike, Apple Watch 2, Computer(s)
[61]	6	Kinect for Windows, TV/Monitor, Computer(s)
[62]	5-16	Espresso VR Bike
[63]	8-20	BodyMedia SenseWear armband, Polhemus Fastrak Electromagnetic Sensors, Projector(s), Computer(s)
[64]	3-4	Kinect for Windows, Projector(s), Computer(s), CAVE
[65]	7-10	Kinect for Windows, Projector(s), Computer(s), CAVE
[66]	4-8	Kinect (Xbox 360), TV/Monitor, Xbox 360, Computer(s)
[67]	6-18	Kinect for Windows, TV/Monitor, Computer(s)
[68]	N/A	N/A

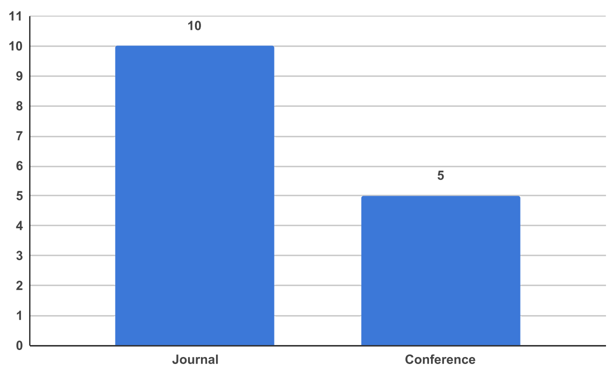

FIGURE 4. Publication type of primary studies.

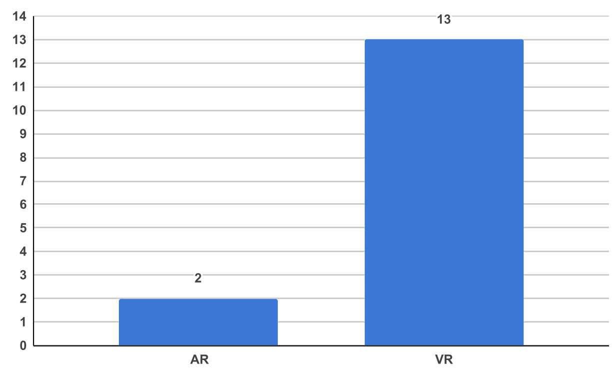

FIGURE 5. AR/VR trends in primary studies.

D. RQ4: WHAT WERE THE PARTICIPANTS' CHARACTERISTICS IN THE PRIMARY STUDIES?

The 15 studies analysed a total of 332 participants, with sample sizes ranging from 2 to 109 individuals. Of these participants, 241 were male, 55 were female, and the gender of the remaining 36 was not reported. All studies included individuals with autism, while 3 of the primary studies also included participants with Intellectual Disabilities **(ID)**, 2 included individuals with Down Syndrome **(DS)**, 1 contained participants with Learning Disabilities **(LD)**, and 1 of the primary studies contained a participant with Fetal Alcohol Syndrome **(FAS)**. Additionally, 1 of the primary studies included individuals who were Neurotypical **(NT)**. Regarding the age ranges of the participants, the minimum age observed was three years, while the maximum age varied across studies, reaching up to 21 years. The mean age across

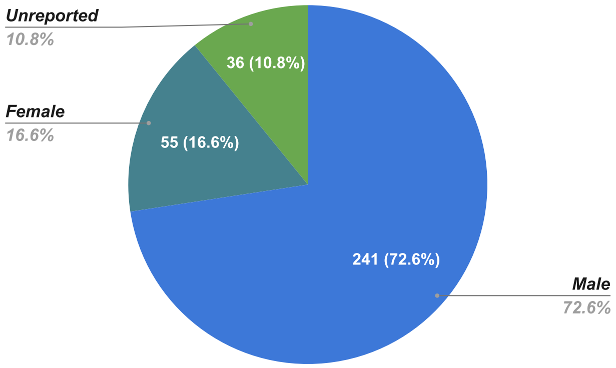

FIGURE 6. Overall gender distribution of primary studies.

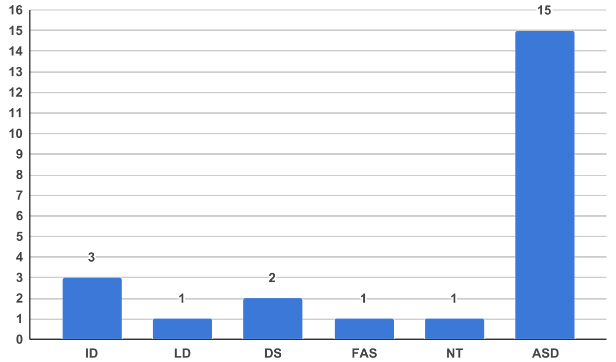

FIGURE 7. Categorisation of participants in primary studies.

all studies was approximately 9.9 years old, representing a diverse range of age groups. The age ranges with the highest frequency were 7-12 years and 10-16 years, observed in two studies each. Notably, the study by [68] did not discuss the age range of its participants. A more detailed breakdown of the participant's demographics can be seen in TABLE 4, TABLE 5, FIGURE 6 and FIGURE 7 in the SLR.

While our primary focus was on XR-based interventions to improve motor skills in autistic children, it is important to note that some of the primary studies included age ranges that encompassed adults. Specifically, only three primary studies included participants aged 18 years and above. In [63], there were 2 adults participating. In [60], there was 1 adult participant. In [67], the exact number of participants aged 18 years was not reported; however, the mean age and standard deviation of both the study group and the control group were 14.42±5.14 and 14.17±5.09, respectively. These instances were minimal and represented a very small fraction of the total participant pool, allowing us to maintain our primary focus on interventions for children.

E. RQ5: WHAT HARDWARE DEVICES WERE UTILISED IN THE INTERVENTIONS IN THE PRIMARY STUDIES?

Across the 15 primary studies, the researchers have used various devices/hardware as part of their interventions. Noteworthy among the employed devices are the Kinect series of devices, including Kinect for Xbox 360, Kinect for Windows v1, and Kinect for Windows v2, originating from Microsoft. These motion-sensing peripherals were pivotal in various interventions targeting motor skill enhancement in autistic children. However, despite their successful application, it is unfortunate that all Kinect devices have been discontinued, with Microsoft ceasing production of their most recent iteration, the Microsoft Kinect Azure, towards the end of 2023 [69]. This cessation of production signifies the end of an era for the Kinect range of devices, which have substantially contributed to assistive technology and interactive interventions for individuals with autism.

The primary studies employed a range of display technologies, including traditional TVs, computer screens, projectors, and Head-Mounted Displays (HMD). These interfaces were utilised to deliver intervention content and engage participants in virtual environments. Interestingly, immersive devices like the HTC Vive, HTC Vive Pro, and Oculus Quest were also utilised, providing an engaging experience for participants to interact with intervention materials.

In some of the primary studies, stationary bikes were integrated into the intervention setup. These included devices such as the Virzoom Bike and the Espresso VR bike, which allowed participants to engage in physical activities while immersed in virtual environments. Additionally, the ZFit sensor was utilised, converting a stationary bike into a controller for interacting with virtual content, thus blending physical exercise with interactive experiences.

Several studies incorporated wearable body sensors to monitor participants' health metrics and activity levels throughout the interventions. The Apple Watch 2, Body-Media SenseWear armband, and Fitbit Charge 2 were health monitors, providing real-time data on heart rate, activity levels, and sleep patterns. Additionally, motion sensors like the Polhemus Fastrak electromagnetic sensor were utilised to capture movement data, enhancing the understanding of participants' physical interactions within virtual environments.

Some interventions utilised Cave Automatic Virtual Environment (CAVE) systems, which create immersive virtual environments by projecting images onto multiple surfaces surrounding the participant. These systems offer a highly immersive experience, allowing participants to interact with virtual content in a three-dimensional space, enhancing engagement and immersion.

It is important to acknowledge that certain devices, such as HMDs and CAVE systems, demand substantial physical space for installation, which can restrict their application in certain contexts. Furthermore, the cost of procuring and upkeep of such equipment may present obstacles for researchers and institutions lacking ample resources.

The majority of the devices mentioned earlier necessitate the use of a computer to operate optimally. Whether it be for rendering virtual environments, processing sensor data, or managing device functionality, a computer is imperative for these devices to function within the intervention setup. This requirement introduces an additional level of intricacy and cost to implementing these technologies in research and clinical settings. An overview of what devices were used, what they were used for and the primary studies they were used in can be found in TABLE 6.

F. RQ6: WHAT WERE THE DATA SOURCES AND COLLECTION METHODS EMPLOYED IN THE PRIMARY STUDIES?

As part of the primary studies, numerous data sources were utilised. Tracking the user's body position played a crucial role in several interventions examined in these studies. Various devices, including the Kinect series, HTC Vive, and Polhemus Fastrak electromagnetic sensors, were employed for this purpose. These devices allowed interventions to monitor the user's body position and movement without requiring direct attachment to the user's body. Furthermore, in some interventions, such as those discussed by Davison et al. and McMahon et al., indirect tracking of the user's body movements was achieved through interaction with stationary exercise bikes. Intervention output was displayed through various devices, including the HTC Vive series, televisions, the Espresso VR bike, and projectors. Each device provided unique methods of presenting content to the user and offered different immersive experiences tailored to the intervention's objectives. Several studies focused on monitoring the user's vitals, particularly heart rate. Devices such as the Apple Watch Series 2 and the BodyMedia SenseWear Armband were employed for this purpose, allowing researchers to track users' physiological responses during intervention sessions and providing valuable data for assessing the intervention's effectiveness. A breakdown of the data sources used in the primary studies can be seen in TABLE 7.

G. RQ7: WHAT DATA PROCESSING TECHNIQUES WERE APPLIED TO THE COLLECTED DATA IN THE PRIMARY STUDIES?

Several studies have explored the utilisation of data processing techniques in XR-based interventions. Four primary studies, in particular, have incorporated data processing techniques to enhance the dynamics of interventions and extract more information from the data collected during the intervention. An overview of the data processing techniques can be seen in TABLE 8.

Firstly, [58] used Recurrent Neural Networks (RNN) to enable the platform to recognise ten distinct actions, including jumping jack, jump forward, jump backwards, jump right, jump left, walk, step forward, step back, touch nose, and idle. The RNN was created and trained in Keras, and the action recognition network was implemented in Unity using TensorFlow Sharp. This approach facilitated temporal dynamic behaviour due to the backward connections between nodes, enabling the output from some nodes to influence the input to subsequent iterations of the same nodes.

Secondly, [59], [63] used Dynamic Difficulty Adjustment **(DDA)** in their platforms. DDA is the process in which a game's features, behaviours, scenarios and difficulties are altered in real-time based on the player's skill in the game. The goal of DDA is to stop the player from becoming frustrated or bored while playing the game.

Thirdly, [59] utilised behaviour tree technology to enable dynamic NPC decision-making in their platform. The behaviour tree structure follows an upside-down tree model comprising various node types, including behaviour, conditional, modification, and combination nodes. The parallel, sequence, and selection nodes are among the options for combined nodes. The behaviour node executes specific actions, while modification and condition nodes add additional conditions and assess whether the conditions have been met, respectively.

Finally, [60] computed the total calories burned during the session by processing the average heart rate and the duration of the session data.

H. RQ8: WHAT PLATFORM OR FRAMEWORK WAS EMPLOYED IN THE PRIMARY STUDIES?

RQ8 investigates the platforms and frameworks used in the primary studies. This inquiry examines the specific tools or systems that researchers use to conduct their investigations. It reveals the technological foundations of the studies and provides insights into current trends and preferences in the field. The rest of this section reviews the platforms and frameworks in each of the primary research studies. In FIGURE 8, the overview of the interactions of each device type, data sources and their data processing can be seen.

In [54], a sophisticated VR system was employed within their research, tailored to the specific needs of the study's objectives. This system comprised a three-surface CAVE configuration, characterised by dimensions of 4m × 4m × 3m, and was equipped with three ultra-short lens projectors meticulously positioned within the ceiling. Remarkably, the virtual environment was projected onto the central surface, while the lateral surfaces remained unlit to enhance focus. Interaction within the VR environment was facilitated by the Azure Kinect DK, strategically mounted on a tripod 40 cm in height before the central surface, ensuring an unobstructed view for users. The depth camera of the Azure Kinect DK boasts a resolution of 640 × 576 and a frame rate of 30 frames per second, ensuring reliable body tracking throughout the CAVE. Notably, participants were immersed in a virtual world where they visualised a customisable virtual human figure reflecting their own head, trunk, and limb movements, fostering a sense of presence and meta-self-recognition. The development of the VR setting and the implementation of the serious games were executed utilising Unity software, offering a seamless and intuitive user experience. Furthermore, user interaction within the virtual environment was predicated on collision with predefined virtual areas, ensuring an interactive and engaging experience for participants.

Similarly, [55] focused on the development process of an ICT-based exergame program for children with developmental disabilities (DD). The development comprised planning, development, and effectiveness verification stages.

TABLE 6. Device types that were used in the primary studies.

Primary Studies	Device Used	Description
[66]	Kinect (Xbox 360)	Computer Vision Motion Sensor
[58], [61], [64], [65], [67]	Kinect for windows	Computer Vision Motion Sensor
[54], [55]	Kinect Azure DK	Computer Vision Motion Sensor
[57]	Computer, Monitor, Web camera	Computer Vision Motion Sensor
[58]	HTC Vive Pro	HMD with body tracking
[59], [60]	HTC Vive	HMD with body tracking
[56]	Oculus Quest	HMD with body tracking
[60]	Virzoom Bike	Stationary VR bike controler
[62]	Espresso VR Bike	Stationary VR bike
[56]	VZFit Sensor	Stationary bike motion sensor
[56]	GENEActiv	Health Monitor
[56]	Fit Bit Charge 2	Health Monitor
[60]	Apple Watch 2	Health Monitor
[63]	BodyMedia SenseWear armband	Health Monitor
[63]	Polhemus Fastrak Electromagnetic Sensors	Body Mounted Motion Sensor
[54], [55], [63]–[65]	Projector(s)	Media Display
[57], [61], [66], [67]	TV/Monitor	Media Display
[66]	Xbox 360	Platform Controller
[54]–[61], [63]–[65], [67]	Computer(s)	Platform Controller
[54], [55], [63]–[65]	CAVE	VR Room

TABLE 7. Data sources for the included research in this section.

Data Source	Devices used	Description
Body Position / Movements	Kinect for Xbox 360, Kinect for Windows v1, Kinect for Windows v2, HTC Vive, HTC Vive Pro, Polhemus Fastrak Electromagnetic Sensors, Azure Kinect, Virzoom Bike, Espresso VR Bike	To allow the user to interact with the intervention
Visual Output	HTC Vive, Oculus Quest HTC Vive Pro, Televisions, Espresso VR Bike, Projectors	Used to display the intervention platform to the users
Heart Rate	Apple Watch Series 2, Body-Media SenseWear	Used to track the user's heart rate during the intervention

TABLE 8. Data Processing for the primary studies.

Processing Type	Description	Citation
RNN	Action Recognition	[58]
Behaviour Tree	Dynamic decision making	[59]
Total Calories burned	Energy expended	[60]
DDA	Dynamic difficulty adjustment	[59], [63]

A thorough review of the relevant literature concerning the behaviour and movement characteristics of children with DD, as well as exergame implementation for this population, informed the program's design. The research team, consisting of ten experts specialising in various relevant disciplines, collaborated on this endeavour. These experts brought expertise in adapted physical education, motor learning and control, exercise physiology, psychology, occupational therapy, and computer science. The exergame program was meticulously tailored to accommodate the cognitive, affective, and psychomotor characteristics of children with DD. Specifically, considerations were made to ensure that the program's mechanics were easily understandable and that task activities were designed to engage children's concentration and physical performance levels. The program aimed to enhance fundamental motor skills and physical fitness among children with DD by providing appropriate task activities within three domains: psychomotor, cognitive, and attractive. A preliminary evaluation process was conducted to determine the necessary and proper contents of the exergame program, taking into account the developmental and performance characteristics of children with DD, as well as their interests. The program was implemented in a classroom-sized space equipped with VR projections, speakers, personal computers, and monitors to generate visual and auditory simulations. These simulations were designed to create a relaxed environment conducive to engagement for children with DD.

In [56], a specific platform for their VR-based physical activity (PA) program was utilised, comprising of the VZFit sensor from virzoom.com and the Oculus Quest goggle from oculus.com. The VZFit platform offers an immersive VR exercise experience compatible with any stationary bike, facilitated by pairing with a cadence sensor in the pedal. As participants pedal the stationary bike, the VZFit platform serves as a controller for various VR games, dynamically adjusting the speed of in-game vehicles based on pedalling intensity. Concurrently, participants can explore a 360∘ view of the interactive virtual game world using the Oculus Quest goggles. Both the bike and the goggles were adjustable to accommodate participants' height and head size. The intervention protocol included a 5-minute warm-up session followed by three 8-minute gaming sessions, with 2-minute breaks interspersed to mitigate potential discomforts associated with wearing the goggles, such as dizziness or decreased concentration. Specifically, the VZFit Play application offered 11 different games, each categorised by comfort rating—comfortable, moderate, or intense. To tailor the intervention to the unique needs of children with developmental disabilities, participants selected three games from options including Thunder Bowl (tank; comfortable mode), Le Tour (bike; comfortable mode), Oval Race (race car; moderate mode), or Gate Race (Pegasus; intense mode).

Heart rate monitoring was maintained between 116 and 141 bpm using the Fitbit Charge 2, which ensured that the intensity of the VR-based PA program remained moderate.

In [57], researchers did not directly engage in the design of the platform utilised in their intervention. Instead, the VR platform employed in the intervention was developed by the School of Arts, Sciences, and Humanities of the University of São Paulo (EACH/USP). Participants were situated comfortably in a chair, customised to accommodate their individual requirements. Prior to commencing the task, the examiner provided a verbal explanation and demonstration regarding the operation of the VR system. The game on this platform featured falling spheres within four imaginary columns on a computer screen, synchronised to a chosen musical accompaniment. Participants were tasked with intercepting these spheres before they descended fully, utilising designated targets positioned at two heights on each side of the screen. The software used for this intervention represents an evolution of a prior version utilised in interventions targeting motor performance enhancement in autistic children and children with other developmental disabilities. The game facilitated data collection to assess motor performance by tracking participants' movements via Webcam without necessitating physical contact. Alternatively, participants could interact with the game using a Touch Screen, requiring direct contact with the computer screen within the space allocated for the spheres. Feedback on successful hits (+1) was provided alongside a cumulative score visible on the screen, wherein each successful interception was rewarded with 10 points.

In [58], researchers designed a platform that aims to improve gross motor skills in autistic children. The Unity game engine was used to create and distribute the VR games on this platform. GaitWayXR used the Kinect for Windows v2 and the HTC Vive Pro. The data sources for this platform were the Kinect for Windows v2, which tracked the user's position and the HTC Vive Pro, which allowed the user to view the VR environment. They also ran several assessments alongside the platform as separate data sources. These assessments were the SSQ, the BOT-2SF, the SRS-2 and the DCCS. The platform used RNN to determine the user's activity in real-time and give it one of ten labels. A game called Candy Dance was played on the GaitWayXR platform. Participants in this game were required to execute movements shown by an animated character. The physical activities that the participants undertook during this intervention were the following: jumping jacks, jumping forward, jumping backwards, jumping right, jumping left, walks, steps forward, steps back, and nose touches. Candy Dance includes five levels of increasing difficulty. Ten participants were involved in the intervention, and each participant had six sessions (20 minutes a session) using the platform. The result of this work backed up their assumption that the VR intervention is safe, with no significant adverse events and a minimal number of minor to moderate side effects. The most deterring factors for adopting the system for home therapy were cost and space, even though a significant percentage of parents indicated they would use the VR game at home.

In [59], the platform was designed to be an auxiliary treatment system for autistic children. Their platform aims to improve the hands-on ability, social skills and physical coordination of autistic children. The platform was built in the Unity game engine and the application Maya was used as the modelling tool to create the VR environment and characters. In their intervention, they used the HTC Vive to allow users to interact with their platform. The data source for this platform was also the HTC Vive. The platform used behaviour trees to allow the NPCs to be flexible and dynamic when interacting with the user. The platform was broken down into five levels to improve different skills. These areas were life skills, body coordination, social interaction, colour cognition and hands-on training. Life skill physical activities included watering and garbage sorting tasks. Obstacle-crossing and shooting tasks were used in the body coordination physical activities to test the child's capacity for accurate judgement. The physical activity in the social interaction task involved having the participant greet NPCs in the scene. The physical activity for colour coordination had the participant collect books of different colours from around the classroom. The participant organised the toys in the scene and put them on the designated shelf as part of the hands-on physical activity. Six children participated in the study, and six children were in the control group for the study. Each of the study's active participants participated for three months, three times a week. The sessions lasted 30 minutes. Before the intervention began, the twelve participants had their skill levels assessed and then again at the end of the study. These assessments showed that the children who participated in the intervention improved their skill levels, while the control group mostly had no improvement [59].

In [60], researchers designed a platform to increase the level of physical activity of high school students with IDD. They used the HTC Vive, the virzoom exercise bike and the Apple Watch Series 2. Their platform utilised three games: a race car game, a kayak game and a bike race game. The platform used in this intervention was not explicitly designed for autistic children. The data sources for this platform were the virzoom exercise bike, which allowed the user to interact with the VR environment, and the Apple Watch Series 2, which was used to gather data on the average heart rate and duration of a participant session. They also conducted a social validity questionnaire at the end of the intervention to collect data on the children's experiences using their platform. Using the data gathered from the Apple Watch (average heart rate during the session and duration of the session), they calculated the total calories expended during each session. The participants undertook to cycle the virzoom exercise bike. The faster the participants cycled the bike, the faster they would go in the VR environment. There were four participants in the study. Each participant participated in a maximum of twenty sessions. Each session lasted for a maximum of 30 minutes, but the participants could end the session by stating they were done. This study showed that everyone who participated increased their physical activity in both the duration and level of exertion. It is also worth noting that this study did not focus specifically on autistic children but looked at children with intellectual and developmental disabilities. This study was included because one of the three test participants was a child diagnosed with autism.

In [61], researchers designed their platform with the goal of athletic ability rehabilitation for autistic children. Their platform used the Kinect for Windows v1 as its sole device. The data source for this platform was also the Kinect for Windows v1. Two participants took part in this intervention. The physical activities the participants underwent were a static balance ability test, a sense of hearing/body movement coordination test and a hand-eye coordination ability test. It is not specified how many sessions were undertaken during this intervention or the duration of the session. It is specified that the intervention time was too short. The results of this intervention demonstrate that autistic children can accept VR-based interventions for rehabilitation. It is not directly stated if they developed this system or if it is an off-the-shelf solution. It is assumed it is custom-designed.

In [62], an off-the-shelf platform that comes with the espresso VR exercise bike was utilised. They aim to create a VR-based physical activity and exercise intervention to help autistic children with behavioural issues improve behavioural regulation and classroom functioning. This platform allows users to play bike-driven video games, ride virtual courses, and compete against one another. The device used during this intervention was the Espresso VR exercise bike. The espresso VR exercise bike was also used as the data source for the participants. The following data points were obtained: age, heart rate, average watts, intensity score (watts/heart rate), number of sessions, total duration, and total distance covered in a session. This study also ran several surveys/assessments throughout the intervention. These were the TOC survey, CATRS-10, PACER, NHANES, Exercise motivation inventory, Harter's self-perception profile, and the physical activity enjoyment scale. During the intervention, the participants engaged in physical activity by cycling the espresso VR bike. There were 109 participants in this intervention. Participants were broken up into classrooms of 14 and were assigned to undertake the intervention in the spring or fall. The intervention lasted seven weeks, with two sessions each week. The duration of sessions ranged from 10-20 minutes. The results of this intervention show that physical activity has both long and short-term psycho-physiological effects on the behavioural functioning of children with neurodevelopmental disorders. This platform was not designed specifically for autistic children. The off-the-shelf software comes with the Espresso VR exercise bike.

In [63], a platform called AstroJumper was created with the goal of improving physical activity and motivation levels in autistic children. Points gradually accumulate in this platform if the user avoids encountering obstacles. Points accumulate at a base rate of one point per second, but this rate can be raised by obtaining golden suns that add bonus score multipliers. The increase of the player's score is momentarily frozen, and any previously accumulated bonus score multipliers are reset if the player's body collides with any of the obstacles. There are also periodic UFO battles. An alien ship appears during these battles, firing red laser beams at the player. To complete the UFO battle, the user must dodge these beams while firing green lasers. The user must make a strong throwing or punching motion to fire the green lasers. They used a CAVE system to implement their platform, which consisted of two Barco Gemini projectors for each of the three rear-projected stereoscopic screens. A BodyMedia SenseWear armband, four Polhemus Fastrak electromagnetic sensors, and polarised glasses. The platform was run on a PC using three NVIDIA GTX 260 graphics cards, a quad-core Intel Core i7 3.33GHz and 12 GB of RAM. The data sources for this platform were the Body-Media SenseWear armband and the four Polhemus Fastrak electromagnetic sensors. They also ran a demographic survey before the intervention and a pre-intervention questionaire after both intervention sessions. Their platform processes the user's progress in real-time to allow it to make *Dynamic Difficult Adjustments* (**DDA**). There were ten participants in the intervention. Each participant took part in two sessions. The sessions ranged from one and a half minutes to twelve minutes of physical activity. This research demonstrated that most participants could engage in vigorous physical activity levels. Additionally, it revealed that the children expressed high levels of enjoyment and indicated they would continue to play these games if they were readily available.

In [64], they created a platform to assess whether an AR-based intervention for assisting autistic children in picking up specific skills is feasible. The platform allowed users to view themselves in a mirror world enhanced by virtual objects via an AR mirror. The platform was run using a CAVE system. The CAVE uses a projection screen, a projection system, possibly a retro-projection system, a computer, a Kinect for Windows v1, and speakers. The data source for this is the Kinect for Windows v1. Five participants took part in a single session lasting up to 15 minutes. This research shows that AR-based interventions are feasible for improving specific skills in autistic children and that Kinect can be used to create these interventions.

In [65], a platform called FroggyBobby was created to deliver a motor therapeutic intervention to children with severe autism to improve their focus and develop their motor skills, enabling them to gain the coordination needed to follow a visual target. This platform encourages users to move their upper limbs to perform eye-body coordination exercises. The game's objective is to assist an avatar of a frog in eating as many flies as possible. When kids use FroggyBobby, their limb motions control the frog avatar's tongue. Limb movements include lateral or cross-lateral movements of the left or right arm to reach a visual target. When they catch flies, the children receive points and coins. Later, they can use their earned coins to buy avatar accessories like hats, eyeglasses, and shoes. They used a CAVE system to implement their platform. Their CAVE system consisted of a Kinect for Windows v1, a multimedia projector, two speakers, two cloud video cameras, a keyboard and a mouse. The data source for this platform was the Kinect for Windows v1. There were seven participants in this intervention. Each participant participated in 12 sessions during the intervention, lasting about 30 minutes. This study showed that participants remained focused throughout the intervention and had reduced aimless limb movements and increased aimed limb movements.

In [66], researchers did not design the platform used in their intervention. Instead, they utilised an Xbox 360 and a Kinect for Xbox 360 as the devices, and on these, they used several off-the-shelf VR games. These games were Carnival Games (Monkey See Monkey Do) and Kinect Adventures. This intervention aimed to examine the application of VR-based games to enhance motor skills in children with developmental disabilities. The data sources for this intervention were pre and post-test scores of their skills from the therapist administering the intervention sessions. Five participants were involved in the intervention. Participants engaged in between 4 and 6 sessions during the intervention, each lasting between 20 and 30 minutes. The results of their intervention underline the potential advantages of using VR-based interventions to create enjoyable and successful interventions for kids with developmental disabilities. It also highlights that these VR-based interventions can keep children motivated while they develop their skills.

In [67], an intervention utilising the UINCARE device (UINCARE-82B, UINCARE Corp., Seoul, Korea), a rehabilitation platform employing a motion capture system facilitated by a Kinect sensor was implemented. This device encompasses an array of rehabilitation training programs with real-time audio-visual feedback. The intervention entailed participants engaging in two sets of 15-minute sessions integrating cognitive and motor training through the game contents of the UINCARE device. Exercises targeted gross motor movements across the upper extremity, trunk, and lower extremity, alongside cognitive tasks such as attention, memory, calculation, and task planning. The program, operable without specialised markers or sensors, facilitated incremental difficulty adjustments based on participants' performance, accompanied by auditory and visual feedback during gameplay. Games within the UINCARE device included diverse perspectives such as top-down, side-scrolling, first-person, and third-person viewpoints, enabling participants to experience varied visual standpoints. Developed on three-dimensional graphics, the games were executed on a computer operating with Windows 10 and a monitor boasting a resolution of 1920×1080 pixels.

In [68], a study was conducted to assess the effectiveness of a physical-motor training model for autistic children utilising VR technology. Employing a quasi-experimental research design, the study followed a one-group pre–and post-test protocol. Initially, participants underwent a pre-test to measure the dependent variable, followed by administering experimental treatment involving physical activities facilitated by VR devices. Subsequently, a post-test was conducted to evaluate the impact of the intervention. The analysis utilised the Wilcoxon Matched-Pairs Signed-Ranks test to assess the significance of differences between pre-test and post-test scores. Prior to engaging in activities with the VR devices, participants were instructed to undergo relaxation exercises, adhering to strict health protocols. During the treatment phase, subjects followed instructions for activities, with each session lasting 3-5 minutes. Post-treatment, subjects participated in activities aimed at normalising their condition. Results indicated a significant improvement in motor function training capabilities post-intervention, particularly when aided by VR technology, with an average capability score increase of approximately 41.62% compared to manual training methods alone.

I. RQ9: WHAT RESEARCH DESIGNS WERE EMPLOYED IN THE PRIMARY STUDIES?

This SLR has identified two overarching categories for the research designs utilised by primary studies: those implementing a pre-test and post-test design and those using a post-test design. The pre-test and post-test design evaluates specific variables before and after the intervention. In contrast, the post-test design solely assesses outcomes after the intervention without conducting a pre-intervention evaluation.

Out of the 15 primary studies analysed, eight of the primary studies employed a post-test design, which focused on evaluating the intervention's outcomes at the end of the intervention period. Conversely, the remaining seven studies used a pre-test and post-test design, which allowed for measuring variables before and after the intervention to assess its impact. TABLE 4 provides a comprehensive summary of this information, including the research design utilised by each primary study.

J. RQ10: HOW LONG WERE THE INTERVENTIONS, AND WHAT BODY MOVEMENTS DID THEY PRIMARILY TARGET?

The interventions examined in the primary studies exhibited a wide range of durations, with the shortest observed lasting for a single day and the longest extending over 12 weeks. Such a broad spectrum of durations highlights the heterogeneity of the interventions employed. Moreover, the mean duration of interventions across the primary studies was approximately 10.1 weeks, further emphasising the diversity of the interventions.

Similarly, the primary studies displayed a wide variation in session durations, with the shortest session observed lasting for a mere 12 minutes and the longest extending up to 45 minutes. This breadth of durations implemented across interventions underscores the variability of the research interventions. Furthermore, the mean duration of sessions across the primary studies was approximately 28.6 minutes,

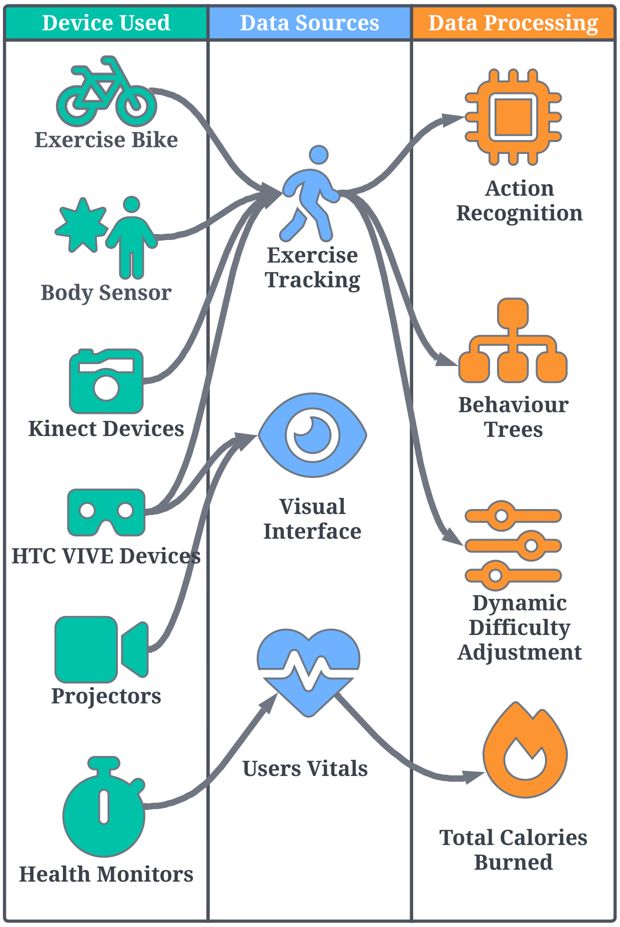

FIGURE 8. Overview of how devices, data sources, and data processing.

emphasising the range of session lengths employed in the interventions.

Lastly, the primary studies presented variations in the type of physical activity participants engaged in. Seven of the primary studies focused on full-body physical activity, while three primary studies explicitly targeted lower-body and four targeted upper-body physical activity. One study did not specify the targeted body region. TABLE 9 provides a comprehensive breakdown of intervention characteristics for each of the primary studies.

K. RQ11: TO WHAT EXTENT DID THE PRIMARY STUDIES FACILITATE THE GENERALISATION AND MAINTENANCE OF SKILLS ACQUIRED THROUGHOUT THEIR INTERVENTION?

Upon reviewing the primary studies, it was found that only one [59] had incorporated both a generalisation phase and a maintenance phase in their intervention framework. This particular study focused on physical coordination training and a shooting task, where participants were required to shoot a moving basketball into a basket displayed on a screen, demanding high levels of physical coordination and concentration. Initial scores showed values between 12 and 18 points, with an average score of 14.7, indicating a low level of physical coordination amongst the participants. However, following the intervention, significant improvements were noted in the experimental group, with post-test scores ranging from 22 to 28 points for most participants, indicating substantial enhancements in physical coordination. Moreover, the group's progress was tracked over time, revealing sustained improvements in the maintenance phase.

TABLE 9. Intervention characteristics for primary studies.

Citation	Session Duration	Intervention Duration	Physical Activity Targeted
[54]	20 min	1 Session	Upper Body
[55]	N/A	12 Weeks	Full Body
[56]	40 min	12 Weeks	Lower Body
[57]	12 min	5 Weeks	Upper Body
[58]	20 min	2 Weeks	Full Body
[59]	30 min	12 Weeks	Upper body
[60]	30 min	N/A	Lower Body
[61]	N/A	N/A	Full Body
[62]	30-40 min	7 Weeks	Lower Body
[63]	45 min	1 Week	Full Body
[64]	15 min	N/A	Full Body
[65]	N/A	6 Weeks	Full Body
[66]	20-30 min	4 Weeks	Full Body
[67]	30 min	4 Weeks	Upper Body
[68]	10-15 min	N/A	N/A

IV. DISCUSSION

This section of the SLR provides a comprehensive insight into the research area. The SLR achieves this by exploring the current trends and potential future challenges revealed by each research question addressed in this SLR. The objective is to offer a comprehensive insight that enhances your understanding of the topic.

A. RQ1: PUBLICATION DEMOGRAPHICS

The results of the publication demographics uncovered in RQ1 provide valuable insights into the current trends of XR-based interventions that aim to enhance motor skills in autistic children. Firstly, the observed increase in publication rates highlights a growing recognition of XR-based interventions' effectiveness in improving motor skills in autistic children. This reflects a broader acknowledgement in the research community of the potential benefits that immersive technologies offer in addressing developmental challenges. Secondly, the prominence of countries such as South Korea, the United States, China, and Spain in driving research in this area underscores the global scope of XR-based interventions. Finally, the prevalence of academic journals as the primary dissemination channel for XR-based research highlights the rigorous evaluation and peer-reviewed scrutiny. While conference papers also contribute significantly to the literature, the prevalence of academic journals emphasises the importance of comprehensive and in-depth exploration of XR interventions and their impact on motor skill development. These findings demonstrate the dynamic and multidimensional nature of research in XR-based interventions for motor skills, emphasising the collaborative efforts of researchers worldwide and the importance of rigorous scholarly inquiry in advancing the field.

TABLE 10. Overview of devices used, data sources and data processing used in each of the primary studies.

Citation	Devices Used	Data Sources	Data Processing
[54]	Projectors, Azure Kinect, Computer	Azure Kinect	N/A
[55]	Projectors, Azure Kinect, Computer	Azure Kinect	N/A
[56]	GENEActiv, VZFit sensor, Oculus Quest, Fitbit Charge 2	GeneActiv, VZFit sensor, Fitbit Charge 2	
[57]	Web Camera	Web Camera	N/A
[58]	HTC Vive Pro headset with two base stations, Kinect for Windows, Computer	HTC Vive Pro, Kinect for Windows	Action Recognition (RNN)
[59]	HTC Vive, Computer	HTC Vive	Dynamic decision making (Behaviour Tree) & Dynamic difficulty adjustment (DDA)
[60]	Virzoom exercise bike, HTC VIVE, Apple Watch 2, Computer	Virzoom exercise bike, Apple Watch 2	Energy expended (Total Calories burned)
[61]	Kinect for windows, Computer, Monitor	Kinect for windows	N/A
[62]	Espresso model VR exergaming stationary bicycles	Espresso model VR exergaming stationary bicycles	N/A
[63]	Projectors, Electromagnetic sensors, BodyMedia SenseWear armband, Computer	Electromagnetic sensors, BodyMedia SenseWear armband	Dynamic difficulty adjustment (DDA)
[64]	Projector, Kinect for Windows, Computer	Kinect for windows	N/A
[65]	Projector, Kinect for Windows, Computer	Kinect for windows	N/A
[66]	Kinect for Xbox 360, TV, Xbox 360	Kinect for Xbox 360	N/A
[67]	Kinect for windows, Monitor, Computer	Kinect for windows	N/A
[68]	N/A	N/A	N/A

The research question at hand has brought to light a couple of challenges that require attention in the future. Conducting further research in this area is crucial, as the current systematic literature review yielded only 15 articles over the last 12 years. Additionally, exploring the effectiveness of this research in other regions through replication is imperative.

B. RQ2: XR INTERVENTION TYPE

Upon analysing the integration of AR and VR in primary research studies, a current trend has emerged that warrants discussion. Of the fifteen studies examined, VR was utilised in thirteen instances, making it the predominant technology. AR, on the other hand, was incorporated in the remaining studies. This clear delineation between the two technologies highlights VR's dominance in the primary studies. Several factors may account for this trend, including VR's maturity and accessibility, established effectiveness in various applications, and availability of robust development frameworks and tools.

The emergence of more powerful AR technology in recent years presents unique opportunities for research and application in the field of motor skill interventions. While AR has not been as prevalent in previous studies as VR, it is worth noting that AR technology has been growing out of its infancy in recent years. This growth has made AR devices more cost-effective and accessible than VR devices, opening up new possibilities for research.

However, there are still a number of challenges that researchers in this area need to address in order to fully understand the potential benefits of AR technology. For example, there is a need to investigate the efficacy of AR-based interventions, particularly in comparison to other types of interventions. Additionally, it is important to explore the unique affordances of AR technology, such as overlaying digital content onto the real world, and how these can be leveraged to support motor skill development. These challenges underscore the need for further investigation and development in this area.

Despite these challenges, the future of research in this area appears promising. AR technology offers unique opportunities for researchers to explore new avenues for motor skill interventions, particularly in terms of accessibility and affordability. With ongoing research and development, AR technology is poised to play an increasingly important role in shaping the future of motor skill interventions.

C. RQ3: INTERVENTION LOCATION

The analysis of intervention settings used in primary studies has revealed some intriguing patterns that merit attention. After examining the primary studies, it became evident that most interventions (10 out of 15) were conducted in a research environment, while the remaining five were conducted in a classroom setting. This distribution highlights the tendency for interventions to be executed in controlled research environments rather than real-life classroom situations.

While research settings can provide the conditions necessary for rigorous experimentation and data collection, the limited number of interventions implemented in classroom settings raises concerns about the generalizability and validity of findings in real-world educational contexts. Factors like logistical challenges, ethical considerations, and the need for standardised protocols may contribute to the preference for research settings in intervention implementation.

However, future studies should consider implementing interventions in authentic environments such as classrooms, homes, and community centres to assess their effectiveness and bridge the gap between research and practice. Addressing this discrepancy helps researchers better understand the applicability and relevance of intervention findings, ultimately leading to more meaningful implications for educational practice and policy.

It is crucial to acknowledge that this trend reflects broader patterns in educational research, where controlled environments offer conducive conditions for rigorous experimentation and data collection. However, by embracing authentic contexts in intervention implementation and critically evaluating their outcomes, researchers can pave the way for more meaningful insights and impactful educational interventions.

Researchers can accurately assess their effectiveness and relevance by prioritizing the implementation of interventions in authentic environments. This will enhance our understanding of the applicability of intervention findings and effectively inform educational practice and policy.

D. RQ4: PARTICIPANT CHARACTERISTICS

The analysis of participant demographics in the primary studies reveals the following trends and challenges that require further discussion. Firstly, there is a significant gender disparity in research participation, with male participants being more prevalent across the primary studies. This raises questions about the representativeness of research findings and the extent to which interventions are tailored to the needs of all individuals, regardless of gender. There is a need to address gender disparities in future research participation by ensuring balanced gender representation. Achieving gender parity in participant recruitment is crucial for understanding potential gender differences in intervention outcomes and ensuring interventions meet the needs of all individuals.

Secondly, the broad age range of participants, from three to 21 years old, highlights the diverse developmental stages within the target population. This underscores the importance of adaptable interventions that cater to individuals across different age groups, ensuring that strategies effectively address the population's diverse needs. Tailoring interventions to diverse age groups and developmental stages presents a significant challenge. Future research must be adaptable to accommodate the target population's wide range of developmental trajectories. This necessitates a nuanced understanding of how interventions can be modified to address specific developmental needs.

Lastly, some primary studies have shown a need for more detailed demographic information, as with this, transparency and reproducibility are maintained. Comprehensive data reporting is crucial for understanding the generalizability of findings and assessing how interventions may vary based on participant characteristics. Standardised reporting guidelines ensure consistency across studies, facilitate replication, and enable researchers to draw accurate conclusions from the available evidence. Implementing standardised reporting practices will enhance future research and the quality and reliability of research findings in the field of developmental disabilities intervention.

E. RQ5: DEVICE TYPES

The extensive use of Kinect devices in primary studies has underscored their significance in interventions targeting motor skill enhancement in autistic children. However, with Microsoft's discontinuation of all Kinect devices, researchers and practitioners relying on Kinect technology face challenges in exploring alternative hardware options for their interventions. This development highlights the importance of considering the longevity and sustainability of hardware solutions when designing interventions for long-term use.

The diverse range of display technologies employed in the primary studies reflects the versatility required to cater to different intervention needs and participant preferences. From traditional TVs to immersive devices like the HTC Vive and Oculus Quest, researchers have leveraged various interfaces to engage participants in virtual environments effectively. The selection of display technologies should align with intervention goals while considering cost, accessibility, and user experience. However, a potential future challenge that researchers should be aware of is that Head-Mounted Displays (HMDs) in interventions may introduce sensory issues for autistic children, potentially aggravating discomfort and anxiety. Addressing these sensory challenges is critical for ensuring that interventions are effective and tolerable for participants. Future research should explore alternative display options or implement strategies to mitigate sensory sensitivities, such as providing breaks or incorporating sensory-friendly design elements into virtual environments. By prioritising the comfort and well-being of participants, researchers can maximise the effectiveness and inclusivity of interventions utilising immersive technologies.

Integrating stationary bikes and wearable sensors in interventions introduces a novel approach to blending physical activity with interactive experiences. This innovative method, utilising devices like the GENEActiv, the BodyMedia Senseware Armband, the Apple Watch 2 and the Fitbit Charge 2, promotes physical exercise and allows for real-time monitoring of participants' health metrics. This integration opens up possibilities for designing interventions that target both physical and cognitive domains, potentially enhancing overall outcomes for individuals with autism.

While immersive devices like HMDs and CAVE systems offer compelling experiences, their high cost, complexity, and space requirements pose significant challenges. Limited availability of large open spaces and budget constraints may impede the adoption of CAVE systems. Overcoming these challenges will require innovative approaches to reducing costs and streamlining setup processes, ensuring that immersive experiences remain accessible and feasible for interventions targeting individuals with autism.

The dependence of most hardware devices on computers highlights the intertwined relationship between hardware and software components in intervention setups. Ensuring compatibility and optimal performance across different devices and software platforms requires careful planning and resource allocation. Moreover, the need for computers adds a layer of complexity and cost to intervention implementations, reinforcing the importance of comprehensive resource planning and technical support.

Researching hardware devices utilised in interventions across primary studies reveals opportunities and challenges in leveraging technology to support individuals with autism. While advancements in hardware technology offer innovative ways to engage participants and monitor their progress, considerations such as device longevity, cost-effectiveness, and practical feasibility are paramount in designing sustainable interventions. Researchers and practitioners must continue exploring emerging technologies while prioritising accessibility, scalability, and user-centred design in intervention development efforts.

F. RQ6: DATA SOURCES

The SLR illuminates the diverse technological landscape employed in interventions aimed at monitoring and improving user health and fitness. The findings regarding data sources and collection methods in the primary studies underscore the potential of technology-driven approaches in promoting health and fitness, emphasising the need for continued research and innovation in this domain.

One significant aspect highlighted is the reliance on tracking the user's body position and movement. Several devices, such as the Kinect series, HTC Vive, and Polhemus Fastrak electromagnetic sensors, were used to achieve this. The advantage of these devices lies in their ability to monitor user movement without direct attachment to the body, providing a non-intrusive yet accurate means of data collection. Additionally, the indirect tracking of body movements through interaction with stationary exercise bikes presents an innovative approach observed in some interventions, showcasing the versatility in data collection methods.

Another notable finding is the diverse array of devices used to display intervention output to users. Devices such as the HTC Vive series, televisions, the Espresso VR bike, and projectors were employed for this purpose, each offering unique immersive experiences tailored to the objectives of the intervention. This variety in visual output not only enhances user engagement but also allows for flexibility in intervention design, catering to different preferences and requirements.

The inclusion of devices for monitoring users' vitals, particularly heart rate, underscores the importance of assessing physiological responses during intervention sessions. Devices like the Apple Watch Series 2 and the BodyMedia SenseWear Armband enable researchers to gather valuable data on users' physiological states, contributing to a comprehensive evaluation of intervention effectiveness.

Overall, the findings imply a growing trend towards integrating advanced technology into health and fitness interventions, enabling more personalised and immersive experiences for users. By leveraging devices for body position tracking, visual output, and physiological monitoring, interventions can provide real-time feedback and tailored recommendations, enhancing user motivation and adherence to fitness goals. Furthermore, the diverse range of devices utilised underscores the importance of considering individual preferences and technological accessibility when designing interventions, ensuring inclusivity and effectiveness across diverse user demographics.

G. RQ7: DATA PROCESSING

Integrating XR-based interventions in various fields has increased interest in data processing techniques that can be applied to the collected data. These techniques enhance intervention dynamics and extract valuable insights from the gathered data. This discussion section presents the findings of four primary studies that employed distinct data processing techniques and elucidated their implications.

In [58], a Recurrent Neural Network (RNN) was implemented in their study to facilitate action recognition within XR environments. The authors trained an RNN using Keras and implemented it in Unity with TensorFlow Sharp, successfully recognising ten distinct actions. The approach enabled real-time recognition and facilitated temporal dynamic behaviour, which is crucial for immersive XR experiences.

Dynamic Difficulty Adjustment (DDA) emerged as a prominent technique, as observed in the studies by [59] and Finkelstein et al. This adaptive mechanism alters game features and difficulty levels in real-time based on player performance, aiming to maintain engagement and prevent frustration. Incorporating DDA ensures personalised experiences, catering to individual skill levels and enhancing overall user satisfaction.

Furthermore, [59] leveraged behaviour tree technology to enable dynamic NPC decision-making within their XR platform. The system facilitated complex decision-making processes by employing a hierarchical tree structure comprising various node types, such as behaviour, conditional, modification, and combination nodes. This technique enhances realism by simulating human-like behaviour and contributes to the adaptability and responsiveness of XR environments.

Lastly, [60] focused on computing the total calories burned during XR exercise sessions by processing average heart rate and session duration data. This approach provides valuable feedback on energy expenditure, enabling users to track their fitness progress and optimise workout routines within XR environments effectively.

In summary, applying diverse data processing techniques in XR-based interventions underscores the multifaceted nature of enhancing user experiences and extracting meaningful insights from collected data. By employing methodologies such as RNNs, DDA, behaviour trees, and calorie computation, researchers can effectively tailor interventions, optimise engagement, and promote user well-being within immersive XR environments. However, further research is warranted to explore the efficacy and scalability of these techniques across different XR applications and user populations.

H. RQ8: PLATFORMS/FRAMEWORKS

The realm of interventions for individuals with developmental disabilities, especially autism, has witnessed an intriguing and diverse landscape of platforms and frameworks in recent years. These studies employ cutting-edge technologies, ranging from VR systems to AR platforms, to cater to specific therapeutic objectives. In this regard, this paper delves into the implications of these findings, elucidating the technological nuances and their significance within the field.

A notable trend across several studies is utilising VR systems, which underscores the growing prominence of immersive technologies in therapeutic interventions. Studies by [54], [56], and [60] employ VR setups coupled with motion-tracking devices to deliver interactive experiences aimed at enhancing physical activity and motor skills. These interventions showcase the potential of VR to engage participants in tailored exercise routines while fostering enjoyment and motivation, which are essential elements for sustained participation and adherence to therapy.

Moreover, the platforms' adaptability and versatility emerge as key strengths, accommodating diverse user needs and preferences. References [55] and [61] emphasise the importance of tailoring interventions to the cognitive and psychomotor characteristics of children with developmental disabilities. By involving multidisciplinary expertise and incorporating insights from literature reviews, researchers ensure that the platforms are not only technologically robust but also pedagogically sound, aligning with therapeutic goals and participant requirements.

Furthermore, the choice of hardware and software components reflects a balance between accessibility, functionality, and scalability. While some studies opt for off-the-shelf solutions such as Kinect for Windows and Espresso VR exercise bikes, others develop custom-built platforms tailored to specific intervention objectives. This spectrum of approaches highlights the diverse strategies available to researchers, allowing flexibility in addressing unique research questions and clinical needs.

Additionally, the integration of real-time feedback mechanisms and adaptive difficulty adjustments emerges as a common feature, enhancing the efficacy and engagement of interventions. Platforms like AstroJumper and UINCARE leverage dynamic difficulty adjustments (DDA) and real-time audio-visual feedback to tailor experiences according to participants' performance levels, fostering an optimal balance between challenge and skill.

However, cost-effectiveness and accessibility remain persistent challenges in this field. Several studies have raised concerns regarding VR setups' affordability and space requirements, which could limit widespread adoption, especially in home-based therapy settings. Addressing these barriers necessitates ongoing efforts to optimise resource utilisation, explore alternative delivery models, and leverage advancements in consumer-grade VR technology.

In conclusion, the findings underscore the transformative potential of technology-enabled interventions in supporting individuals with developmental disabilities, particularly autism. By harnessing the capabilities of VR, AR, and other immersive technologies, researchers can create engaging, tailored experiences that promote physical activity, skill development, and overall well-being. Moving forward, interdisciplinary collaboration, technological innovation, and a focus on accessibility will be critical in realising the full therapeutic benefits of these platforms. It is also important for future research that develops platforms and frameworks to be open for others to use, build upon, modify, etc. Replication and transparency of the software, hardware, setup costs, and methodologies are becoming increasingly essential. The openness of future platforms/frameworks will facilitate collaboration, accelerate innovation, and ensure that interventions can be adapted to different contexts and populations.

I. RQ9: RESEARCH DESIGNS

This RQ sheds light on the methodological diversity of research designs employed in intervention research. One prominent trend highlighted is the prevalence of post-test designs in evaluating interventions. While this approach offers valuable insights into immediate outcomes, it questions interventions' sustainability and lasting impact over time. This raises a critical challenge: How can researchers ensure XR-based interventions produce enduring effects beyond the short term?

One potential solution that holds significant promise lies in adopting pre-test and post-test designs. These designs allow for a more comprehensive assessment of interventions by capturing baseline data and tracking changes over time. However, implementing such designs requires careful consideration of various factors, including resources, time constraints, and potential confounding variables. This presents a challenge for researchers in terms of balancing methodological rigour with practical constraints.

Moreover, the distribution of research designs across primary studies underscores the importance of methodological diversity in intervention research. While post-test designs may offer simplicity and efficiency, they may need to provide a complete picture of intervention effectiveness. On the other hand, pre-test and post-test designs offer a more robust framework but may require more resources and time to implement.

Future research in this field should address these challenges by adopting mixed-method approaches that combine the strengths of both post-test and pre-test/post-test designs. By doing so, researchers can gain a more holistic understanding of intervention effectiveness, encompassing immediate outcomes and long-term impact. However, achieving this balance will require individual effort and collaboration across disciplines and innovative methodological approaches.

J. RQ10: INTERVENTION CHARACTERISTICS

The present study reveals significant variability in the duration of interventions, ranging from a single day to 12 weeks. The heterogeneity in the approaches taken by researchers in designing and implementing interventions emphasises the need for tailored interventions based on the specific needs and preferences of participants and the desired outcomes. Additionally, the variability in the types of body movements targeted by interventions suggests that researchers are exploring different aspects of physical activity and its impact on various body regions.

The diversity in intervention durations, session lengths, and targeted body movements observed across the primary studies indicates the complexity and variability inherent in designing and implementing physical activity interventions. Understanding interventions' optimal duration and intensity can help optimise their effectiveness in achieving desired outcomes. Incorporating technologies such as VR and exergaming can provide opportunities for individualised and engaging interventions.

Further investigation is required to delve deeper into the specific mechanisms underlying the effects of different intervention durations and targeted body movements on outcomes such as physical fitness, functional abilities, and quality of life. Longitudinal studies are needed to assess the sustained impact of interventions over time. These findings have several implications for future research and clinical practice. By tailoring interventions to individual needs and exploring the optimal duration and intensity, researchers and practitioners can maximise the potential benefits of physical activity for health and well-being.

K. RQ11: MAINTENANCE AND GENERALISATION

The results related to RQ11 provide valuable insights into the critical aspect of skill generalisation and maintenance in intervention programs, especially regarding physical coordination training. The analysis discovered that only one primary study, conducted by [59], integrated both generalisation and maintenance phases in their intervention framework.

During this study, participants underwent physical coordination training alongside a shooting task that involved a moving basketball and a screen-displayed basket. This task required physical coordination and concentration, making it an ideal context for evaluating skill acquisition and retention. Initial assessments indicated that participants had a low level of physical coordination, as demonstrated by their pre-intervention scores ranging from 12 to 18 points, with an average score of 14.7.

Post-intervention, the experimental group demonstrated significant improvements, with most participants achieving post-test scores ranging from 22 to 28 points. These results indicate a notable enhancement in physical coordination abilities as a direct result of the intervention.

Furthermore, the study's inclusion of a maintenance phase allowed for monitoring participants' progress over time. Remarkably, the findings showed sustained improvements in physical coordination skills during this phase, indicating the intervention's effectiveness not only in facilitating initial skill acquisition but also in ensuring its long-term retention.

Overall, these findings emphasise the importance of including generalisation and maintenance phases in intervention programs aimed at skill development. By addressing the transferability of acquired skills to real-world contexts (generalisation) and ensuring their persistence over time (maintenance), such programs can significantly impact individuals' overall skill development and performance enhancement.

V. CONCLUSION AND FUTURE WORK

A. CONCLUSION

In conclusion, this systematic literature review provides valuable insights into the landscape of XR-based interventions aimed at enhancing motor skills in autistic children. The review sheds light on the diverse approaches and methodologies used in this domain by analysing the primary studies spanning from 2012 to 2024, employing both virtual reality (VR) and augmented reality (AR).

The interventions exhibited a wide range of durations, session lengths, and targeted body movements, reflecting the heterogeneity of approaches employed across studies. From single-session interventions to 12-week programs and from full-body to upper-body or lower-body activities, researchers explored various strategies to promote motor skill development in autistic children.

Key findings reveal the potential of XR interventions to improve physical activity levels and motor skills among autistic children. Utilizing XR platforms and devices such as VR headsets, motion capture systems, and exercise bikes, researchers leveraged innovative techniques like recurrent neural networks (RNN) and dynamic difficulty adjustment (DDA) to enhance intervention dynamics and glean insights from collected data.

However, the review also highlights certain limitations and areas for improvement. The diversity in research designs underscores the need for more standardised approaches, with only one study incorporating generalization and maintenance phases in their intervention framework. Future research should prioritize adopting better research designs that encompass pre-and post-tests and include phases for generalization and maintenance. Additionally, addressing limited geographical diversity, promoting AR over VR where applicable, implementing interventions in authentic environments like classrooms or homes, striving for gender-balanced interventions, and adopting future-proofed device types are all crucial considerations for advancing this field.

In essence, while XR-based interventions show promise in enhancing motor skills among autistic children, continued interdisciplinary collaboration, methodological refinement, and technological innovation are essential for realizing their full potential. Addressing these challenges and building upon existing research further enriches the understanding and efficacy of interventions to support the motor development and well-being of autistic children.

B. FUTURE WORK

This SLR has provided valuable insights into the field's current and potential future directions. Building upon these insights, several future research avenues emerge, addressing methodological considerations and substantive areas of inquiry.

- **Enhancing Geographical Diversity:** The limited geographical diversity observed in primary studies highlights the need for broader representation and cross-cultural validation of XR interventions. Future research should prioritize collaborations across diverse regions to ensure interventions' generalizability and cultural relevance. Engaging researchers, practitioners, and stakeholders from different backgrounds can foster a more inclusive and globally representative body of knowledge in the field.
- **Transition to AR:** As AR technology matures and becomes more accessible, there is growing potential for widespread adoption in interventions targeting motor skills in autistic children. Future research should explore the unique affordances of AR, such as overlaying digital content onto real-world environments, to create immersive and contextually relevant interventions. Comparing the effectiveness of AR versus VR interventions can provide valuable insights into optimal technology selection and intervention design.
- **Utilizing Authentic Environments:** Shifting interventions from controlled research environments to authentic settings, such as classrooms and homes, holds promise for enhancing ecological validity and real-world applicability. Future research should investigate the feasibility and effectiveness of interventions implemented in authentic environments, considering logistical challenges, participant engagement, and intervention fidelity. By embracing authentic contexts, researchers can bridge the gap between research and practice and better support skill generalization and maintenance.
- **Promoting gender-balanced Interventions:** Addressing gender disparities in research participation is crucial for ensuring the inclusivity and relevance of interventions. Future research should strive for gender-balanced recruitment strategies and consider gender-specific needs and preferences in intervention design. Promoting gender diversity in research participation and reporting advances equity and inclusivity in XR-based interventions.
- **Adopting Future-Proofed Device Types:** With the rapid evolution of technology, future-proofing interventions require careful consideration of device selection and compatibility. Researchers should prioritize using versatile and adaptable hardware solutions that can withstand technological advancements and changes in market availability. Investing in modular and interoperable devices ensures the longevity and scalability of interventions over time.
- **Harnessing Data Processing:** Leveraging advanced data processing techniques, such as machine learning algorithms and artificial intelligence, can unlock new insights and capabilities in XR interventions. Future research should explore the potential of data-driven approaches for personalizing interventions, optimizing feedback mechanisms, and predicting outcomes. Harnessing the power of data processing enhances intervention efficacy, efficiency, and scalability.
- **Open-Source Platforms/Frameworks:** Creating open-source platforms and frameworks can democratize access to XR technology and promote collaboration and innovation. Future research should prioritize the development of open-source tools, libraries, and repositories that facilitate the creation, sharing, and customization of XR interventions. An open and collaborative ecosystem accelerates progress and empowers diverse stakeholders to contribute to advancing XR-based interventions.
- **Improving Research Designs:** Future research should employ robust research designs that incorporate pre-test and post-test assessments and generalization and maintenance phases. By adopting mixed-method approaches and longitudinal study designs, researchers can capture both immediate and long-term outcomes of interventions and their transferability to real-world contexts. Enhancing methodological rigour and comprehensiveness can generate more reliable and actionable evidence to guide intervention development and implementation.
- **Maintenance and Generalisation:** Future research should prioritize the inclusion of maintenance and generalization phases in intervention designs. Maintenance phases ensure the sustainability of intervention effects over time, while generalization phases assess the transferability of acquired skills to real-world contexts. By systematically incorporating these phases into intervention protocols, researchers can assess interventions' long-term impact and real-world applicability, thereby enhancing their effectiveness and relevance in supporting individuals with autism spectrum disorder. Additionally, investigating factors that facilitate or hinder maintenance and generalization can inform the development of strategies to optimize intervention outcomes and promote skill retention in diverse settings.

C. LIMITATIONS OF THE CURRENT STUDY

While this SLR provides a comprehensive overview of XR-based interventions to improve motor skills in autistic children, several limitations were encountered throughout the review. These limitations are discussed in the remainder of this section of the SLR.

- **Scope and Inclusion Criteria:** The primary inclusion criteria for this systematic literature review (SLR) required studies to focus on XR-based interventions to improve motor skills in autistic children. Studies needed to include autistic children as participants and report outcomes related to motor skills development. Exclusion criteria encompassed studies focusing solely on adults, non-XR interventions, lack of reported outcomes, absence of autistic participants, and studies not specifically targeting motor skills. While these criteria were necessary to maintain focus and relevance, they may have limited the pool of eligible studies, potentially omitting relevant research that only explicitly met some inclusion criteria.

- **Methodological Challenges:** The research area of XR-based interventions for improving motor skills in autistic children is relatively nascent, which posed challenges in locating a sufficient number of studies meeting the inclusion criteria. The SLR only included articles published in English and searched databases back to 2012, which may have restricted the breadth and diversity of included studies. Methodological inconsistencies and varying levels of detail in reporting findings or methodologies across studies also posed challenges in synthesizing results and drawing comprehensive conclusions.
- **Publication Bias and Database Coverage:** There is a possibility of publication bias in the selected studies, as positive outcomes may be more likely to be published. In contrast, studies with null or negative results may be underrepresented. Additionally, the SLR focused on English-language publications and studies from 2012 onwards, potentially excluding relevant research published in other languages or before this timeframe. Limited database coverage or search terms may have further restricted the identification of all relevant studies.

1) FUTURE DIRECTIONS

Despite these limitations, this SLR provides valuable insights into the current landscape of XR-based interventions for enhancing motor skills in autistic children. Future research should address these limitations by expanding search criteria to include non-English publications and older studies, improving standardization of methodologies and reporting practices, and addressing potential biases through comprehensive search strategies and inclusion criteria refinement. The findings of this SLR are valuable and set the stage for future improvements and research directions in this evolving field.

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