applied system innovation

MDPI

Article

Unlocking Potential: The Development and User-Friendly Evaluation of a Virtual Reality Intervention for Attention-Deficit/Hyperactivity Disorder

Ka-Po Wong [1,*], Bohan Zhang [2] and Jing Qin [2]

[1] Department of Applied Social Sciences, The Hong Kong Polytechnic University, 11 Yuk Choi Road, Hong Kong
[2] Centre for Smart Health, School of Nursing, The Hong Kong Polytechnic University, 11 Yuk Choi Road, Hong Kong; bohan.zhang@connect.polyu.hk (B.Z.); harry.qin@polyu.edu.hk (J.Q.)
* Correspondence: portia.wong@polyu.edu.hk

Abstract: (1) Background: Attention-Deficit/Hyperactivity Disorder (ADHD) is typically first diagnosed in early childhood. Medication and cognitive behavioural therapy are considered effective in treating children with ADHD, whereas these treatments appear to have some side effects and restrictions. Virtual reality (VR), therefore, has been applied to exposure therapy for mental disorders. Previous studies have adopted VR in the cognitive behavioural treatment for children with ADHD; however, no research has used VR to develop social skills training for children with ADHD. This study aimed to develop a VR-based intervention (Social VR) to improve social skills in children with symptoms of ADHD. Prior to conducting the pilot trial to assess the effectiveness of Social VR, valuable user feedback was gathered regarding the mechanics of Social VR, satisfaction and motion sickness. This study presented the development and preliminary usability of Social VR to enhance social interaction skills among children with ADHD. (2) Methods: The development process of the Social VR intervention was demonstrated. The Social VR intervention consisted of three scenarios, namely MTR, Campus and Market and Restaurant. In the usability study, 25 children with ADHD were recruited to test the Social VR during the preliminary usability stage of a clinical trial at preinclusion. The participants completed a survey about their experience of playing Social VR, satisfaction, and motion sickness. (3) Results: The participants indicated the three conditions had easy-to-follow instructions, were easy to pick up, and that they understood when the situations changed. The control and beauty of the graphics of Market and Restaurant were relatively lower compared with those of MTR and Campus. The three scenarios are applicable to children diagnosed with any subtype of ADHD. (4) Conclusion: The participants were satisfied with Social VR. Social VR was generally considered realistic and immersive. Further trials to assess the feasibility and efficacy were discussed. If proven effective, VR-based intervention can be an adjunctive approach to current multimodal training for children with ADHD.

Keywords: attention-deficit/hyperactivity disorder; virtual reality; social skills; cognitive behavioural therapy; usability; motion sickness

Citation: Wong, K.-P.; Zhang, B.; Qin, J. Unlocking Potential: The Development and User-Friendly Evaluation of a Virtual Reality Intervention for Attention-Deficit/Hyperactivity Disorder. *Appl. Syst. Innov.* **2023**, *6*, 110. https://doi.org/10.3390/asi6060110

Received: 10 October 2023
Revised: 9 November 2023
Accepted: 15 November 2023
Published: 16 November 2023

1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterised by persistent inattention, hyperactivity, or impulsivity that interferes with cognitive and social functioning [1]. ADHD is classified into three subtypes, based primarily on the presentation of symptoms. Individuals with the inattentive subtype may have difficulty maintaining attention, organizing tasks, following instructions, and completing assignments or activities [1]. Individuals with the hyperactive–impulsive subtype may frequently fidget, squirm, or feel restless and have difficulty staying seated, engage in excessive talking, and have a strong need for movement or physical activity [2]. Individuals with

the combined subtype exhibit symptoms of both inattention and hyperactivity–impulsivity. This subtype often presents with a wide range of symptoms that can vary in severity [2]. Impaired social functioning can lead to inappropriate social interactions, poor peer relationships, and even peer rejection. Specific behaviours associated with social rejection among children with ADHD include aggression, explosiveness, inflexibility, control, bossiness, inattention during activities, and rule violations [2]. About 60% of children with ADHD experience peer rejection [3] because they are usually disliked in the initial social interaction [4], which results in reduction in future opportunities to practice social skills. Persistent peer rejection or social impairment is related to a significant risk for many unhealthy outcomes in adolescent development. Numerous studies have shown that social impairment is associated with depression and anxiety [5,6].

Medication (e.g., methylphenidate) is the most effective way to manage ADHD-related symptoms by increasing the activities in the brain [7]. However, once patients stop taking the medication, the symptoms return [8]. It was found that these medications have side effects, including sleep problems, loss of appetite, headaches or stomach pains [9]. As a result, some parents may not provide medication for their children with ADHD [10]. In addition to medication, cognitive behavioural therapies such as social skill interventions are one of the common and widespread approaches for improving social skills among children with ADHD [11]. According to the meta-analysis of Storebø et al. [11], the forms of social skills intervention often include roleplays, games, and exercises performed individually or in small groups. These traditional approaches can offer real-life practice opportunities in a supportive environment [12]. Specific social skills can be taught to the children based on their unique needs and preferences. Immediate feedback can be provided by the instructors to allow the children better understanding of their improvement and weaknesses [13]. Even so, these traditional training approaches possibly bring some limitations to the learning process of children with ADHD, for instance, time and space constraints, and distractions caused by the environment. These children have symptoms of inattention; face-to-face training can easily be interfered with by other factors.

Virtual reality (VR) has emerged as a promising tool for the rehabilitation of psychological disorders, such as ADHD, and for providing a safe and effective learning environment [14,15]. VRs create a three-dimensional environment that allows users immersion and interaction with the virtual world [16]. Although numerous VR applications for children and adolescents with ADHD have been demonstrated [15,17–19], these VRs are mainly used for enhancing attention, hyperactivity, impulsivity and executive functions in a safe environment. To the best of our knowledge, research on the use of VR to improve social skills in children with ADHD is limited. Yet, several studies assessed the efficacy of VR on social skills among children with autism spectrum disorder and intellectual disability and found better performance on social skills after VR-based interventions [20–22]. Given the benefits of VR in creating a better learning environment and a limited amount of research on the development of VR-based social skills training for children with ADHD, it is critical to develop a VR-based social skills intervention for children with ADHD.

A VR-based social skills training program (Social VR) has been developed. Before initiating the pilot trial to evaluate the effectiveness of Social VR, comprehensive user feedback was gathered pertaining to the mechanics of Social VR, levels of satisfaction, and instances of motion sickness. This study demonstrated the initial phase of designing, developing, and testing the preliminary usability stage of Social VR in a small sample of children with ADHD. The goals and theoretical background were defined in the initial design phase; the prototypes were created in the development phase; the usability and satisfaction of the prototypes were tested. The main purpose was to collect feedback on the operation of Social VR and improve it. Therefore, the research questions framed for this study were as follows:

- What were the design principles in developing the Social VR intervention?
- What were the participants' perceptions and satisfaction levels regarding the mechanics of the Social VR intervention?

- Were there differences in mechanics underlying the three conditions of Social VR among the three ADHD subtypes?
- What was the level of participants' satisfaction with the Social VR intervention?
- What was the severity of motion sickness experienced by participants during the Social VR intervention?

2. Deconstructing Social VR: Theoretical Background, Design and Development

2.1. Development Stages

Social VR is the result of interdisciplinary collaboration among healthcare researchers, professionals, an educator, and virtual reality development engineers. The development process of Social VR is shown in Figure 1. The basic information and comparability of the descriptor of the Social VR are demonstrated in Table 1. Table 1 is a prototype table which was conceptualised and proposed by Baranowski [23] to delineate the essentials of a new game.

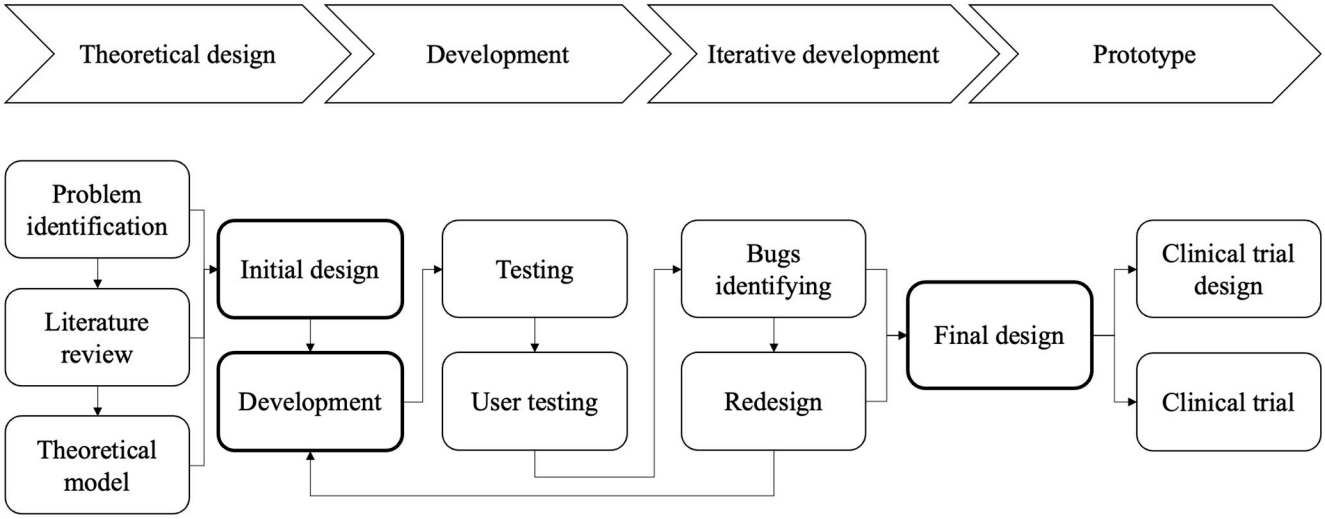


Figure 1. Design and development process.

Table 1. Brief description of Social VR characteristics.

Social VR Characteristics	Description
General characteristics	
Health topics	Social skills for attention-deficit/hyperactivity disorder
Targeted age groups	Children aged 6–12 years
Other targeted group characteristics	Exclusion criteria: with an IQ lower than 85; with severe physical or learning disabilities; perceived dizziness and motion sickness while using VR
Short description of the game idea	A VR program aimed at enhancing social interaction skills and ADHD-related symptoms
Target players	Individual
Guiding knowledge, behaviour change theory models, or conceptual frameworks	Learning theory, Barkley's Behavioural disinhibition theory and Brown's Model of ADHD
Intended health behaviour changes	Improvement in social interaction skills
Knowledge elements to be learned	Social skills
Behaviour change procedures or therapeutic procedures used	Awareness of the problems, intention to take actions, feedback on the actions, practicing the desired actions, repetition, and sustaining the desired behaviours
Clinical or parental support needed	Clinical support
Data are shared with parent or clinician	Yes
Type of game	Everyday life conditions

Table 1. *Cont.*

Social VR Characteristics	Description
Story	
Synopsis	A child has a series of tasks in Mass Transit Railway (MTR), Campus, Market and Restaurant conditions. In the MTR condition, the child needs to start from one destination to another. During their travelling, they must decide how to respond to different contingencies. In the Campus condition, they need to comply with the instruction of the teacher in the scenario. In the Market and Restaurant conditions, they need to purchase a number of items, in which they encounter different daily life interactions
How the story relates to targeted behaviour change	Through these scenarios, they learn to comply with rules, etiquette, manner, and properly communicate and interact with others. These improve their attention, initiative, inhibitive, emotional control, and self-control
Game components	
Player's game goals and objectives	Social interaction skills training
Rules	Restricted social skills training (20 min per session)
Game mechanics	MTR, Campus, and Market and Restaurant for social skills, social interaction, attention, initiative, inhibition, self-control and emotional control
Procedures to generalise or transfer outside of the game	Mainly help enhance social skills through real-life scenarios
Virtual environment	
Setting	The scenarios included MTR stations, Compartment, Classroom, Playground, Market, and Restaurant
Avatar	
Characteristics	The scenarios contain passer-by, teachers, classmate, sales, and waiters to interact with children
Abilities	Characters communicate and interact with the children through different events and incidents
Game platform(s) needed to play the game	Unity real-time development platform
Sensors used	Oculus Quest 2
Estimated play time	1–2 h

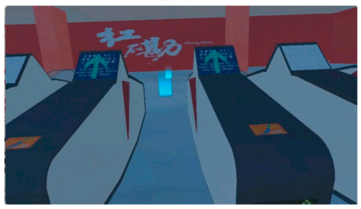
2.2. Theoretical Background

The design of Social VR is theoretically driven by learning theory, Barkley's model [24] and Brown's model [25]. Learning theory depicts the conditions and processes during learning, providing models for developing instructions that facilitate better learning [26]. The theory explains how people understand and integrate information into mental models that generate new knowledge, what motivates people to learn and what environments promote or hinder learning [27]. Therefore, to provide appropriate training for enhancing social interaction skills in children with ADHD, the design of Social VR should consider the features of ADHD. Barkley's model is based on the idea that the inability to inhibit is at the root of the problems experienced by people with ADHD, and inhibition is indispensable for four efficient functions, namely (1) nonverbal working memory, (2) verbal working memory, (3) self-regulation of affect/motivation/arousal, and (4) reconstitution (generativity and planning). In Brown's model, six separate clusters were categorised to describe cognitive impairments in individuals with ADHD, including (1) activation, (2) focus, (3) effort, (4) emotion, (5) memory and (6) action. Although the emphases of these models are distinct, a comprehensive understanding of ADHD thus needs to consider the multiple factors that may contribute to ADHD-related symptoms.

In view of the inhibition behaviours and executive impairment among children with ADHD, creating a concentrated, organised and productive environment is essential in children's learning process [28]. An immersive, realistic and interactive environment can be provided by VR to engage and motivate children to learn [29]. In this usability

study, the Social VR prototype had three conditions, including (1) MTR; (2) Campus; and (3) Market and Restaurant, which cultivate children's manners and etiquette in different circumstances. Each condition specifically focuses on social interaction skills, initiation, inhibition, self-control and emotional control (Table 2). The participants need to interact with different characteristics (e.g., passengers, teachers, classmates, sales and waiters) in the three conditions so as to complete a series of tasks. Immediate feedback is provided to indicate the correctness of the responses of the participants. Furthermore, these three conditions contain scenarios that are familiar to participants, increasing the ecological validity of the scenarios and facilitating the transfer of acquired abilities to daily life activities [30]. These three scenarios offer a structured and predictable setting, which can be beneficial for children with ADHD who often thrive in environments with clear routines and expectations [30]. The controlled nature of the VR environment allowed our research team to create scenarios that provide specific social challenges while ensuring a manageable and controlled experience for the participants. Due to the high degree of control over familiar scenes, VR creates real-life scenarios that are more engaging and motivating than traditional methods [30]. Compared with conventional learning, VR can provide children with a safer and more effective learning environment, allowing them the experience situations that may be difficult to handle in the real world [31]. Children can recognise their own problems and develop different abilities in these environments, helping them to better control their behaviours in real life.

Table 2. Description of each condition.

Condition	Target	Description	Interaction	Instant Feedback
MTR 	Social interaction Attention Initiation Inhibition	Participants take the MTR to the destinations required by the instructions. Participants are required to abide by MTR etiquette and manners during the ride. Various passengers and strangers ask the participants for help. Multiple activities take place inside the compartment, training participants' attention, initiative, and inhibition.	• Pointing and clicking on multiple-choice questions • Speaking with avatars • Grabbing objects in some tasks	• An RA acts as an avatar to guide the participants. • Multiple-choice questions: Select the correct choices and the colour of the option turns green. Select the wrong choice and the colour of the option turns red.
Campus 	Social interaction Attention Initiation Inhibition	Participants follow the instructions of the teacher and complete each task accordingly. The participants interact with the classmates and teachers. Participants encounter several incidents in the classroom and playground to train their attention, initiation, and inhibition.	• Speaking with teachers, classmates and staff • Grabbing objects in some tasks	• An RA acts as an avatar to guide the participants.
Market & Restaurant 	Social interaction Attention Inhibition Working memory	Participants purchase some items at the market and buy takeaway food at the restaurant according to the instructions. Participants interact with the salespeople and waiters.	• Grabbing items • Moving objects • Speaking with sales and waiters	• The items are obtained and the items on the list are deleted. • An RA acts as an avatar to guide the participants.

Note. RA: research assistant.

The virtual reality development engineers created the scenarios using the Unity platform software based on the above requirements. The initial version of the Social VR prototype was iteratively tested to detect all bugs and areas for improvement throughout the development process. In addition to enhancing the social interaction skills of children with ADHD, the social VR is designed to prevent all discomfort and symptoms of motion sickness. Children with ADHD were recruited to collect feedback on their interactions with the prototype to validate the prototype. Modifications to the initial version were made based on suggestions for its usability, such as ease of use, authenticity, satisfaction, and adverse effects (e.g., motion sickness), from users who participated in testing the initial version. The modification included optimising the frame rate to provide smooth and fluid visuals, reducing the latency between head movement and visual updates in the VR environment and limiting the field of view changes, especially during scene transitions or when the user is moving.

The aim of Social VR was to assist children with ADHD in acquiring the knowledge and skills related to social interaction. Immersive virtual environments were utilised in the education setting to make the learning process more engaging and motivating [32]. Considering the features and intention, Social VR is defined as a gamification-based intervention [33].

3. Methods

3.1. Sample and Procedure

Participants were recruited in April and May 2023 through advertisements in the community centres. Interested guardians were contacted via WhatsApp and then assessed for eligibility through a brief phone screening. Eligible participants and their guardians were invited to attend one single session and guardians provided written informed consent. Participants in this usability study tested the initial version of Social VR. Before the test, participants wore head-mounted displays (HMD) to watch a 3 min video downloaded from YouTube to see whether they felt uncomfortable. The Oculus Quest 2 was employed as the HMD and two touch controllers were utilised. Participants were eligible to play Social VR if there was no discomfort.

The inclusion criteria were as follows: (1) 6 to 12 years of age; (2) assigned a diagnosis of ADHD by a mental health professional; (3) competency in reading Chinese and listening and speaking Cantonese; (4) written informed consent provided by the guardians of the participants. Exclusion criteria were as follows: (1) with an IQ lower than 85; (2) with severe physical or learning disabilities. Ethics approval was obtained from the Institutional Review Board of The Hong Kong Polytechnic University (HSEARS20221221003). Written informed consent was obtained from the guardians of the participants.

The participants attended three sessions per day. Each session lasted about 15 to 20 min subject to the physical condition and emotion of the participants. All participants followed the same sequence of each session, namely MTR, Campus and Market and Restaurant. The fixed order was to ensure a standardised experience for all participants. Prior to the first session, the demographic information of the participants was collected. After the third VR intervention session, the participants were required to complete a self-administered questionnaire regarding the participants' experiences with Social VR, satisfaction, and motion sickness. A research assistant assisted and guided the participants throughout the process. Figure 2a shows the equipment used for Social VR. Figure 2b demonstrates the participant playing Social VR.

(**a**) (**b**)

Figure 2. (**a**) Meta Quest 2 headset with an adjustable head strap and touch controller; (**b**) Social VR intervention.

3.2. Measures

Demographic information, including age, gender, ADHD subtypes, medication, type of school, glasses worn, and previous VR experience, was collected. Regarding the mechanics of Social VR, six questions adapted from the usability study of Rodrigo-Yanguas et al. [34] testing a virtual reality serious video game were used in this study. Each question uses a 10-point Likert scale, with higher scores indicating greater agreement. The questions were validated by Lewis [35], yielding a reliability coefficient (α) ranging from 0.91 to 0.96.

- Mechanics of the Social VR
    1. Was the Social VR interesting? (Interesting)
    2. Did you find it easy to understand the instructions in the scenarios? (Instruction)
    3. Did you find each scenario easy to start? (Easy to start)
    4. Did you find the headset and controllers easy to use? (Control)
    5. Has your understanding of the scenario become better as the situations change? (Understand after change)
    6. How would you rate the visual graphics? (Graphics)

Regarding the satisfaction and motion sickness of the participants with the testing of Social VR, eight questions adapted from the study of Rodrigo-Yanguas et al. [34] were used. The questions related to satisfaction were measured by three-point scales (yes/neutral/no) and motion sickness was a yes or no question. The questions were validated by Sevinc [36], yielding a reliability coefficient (α) ranging from 0.85 to 0.95.

Satisfaction:

- Did you enjoy the experience?
- Do you want to repeat it?
- Did the experience feel real to you?
- Was the sound quality satisfactory?
- Did you find it easy to understand the activity?
- Do you think it is good overall?

Motion sickness:

- Did you feel dizzy when playing Social VR?
- Did you experience motion sickness while playing Social VR?

3.3. Statistical Analysis

Statistical analysis was performed in SPSS 26.0. Demographic data were summarised as frequencies and percentages for categorical variables and mean and standard deviation for continuous variables. ADHD sub-type differences at baseline were compared using the chi-square test for categorical variables. The results of the mechanics of the conditions in Social VR were demonstrated in percentages in a cluster bar chart. The effects of the mechanics among the three conditions on the ADHD sub-type were analysed using *f*-test. The satisfaction and motion sickness were summarised as frequencies and percentages.

4. Results

4.1. Sample Characteristics

Twenty-five children met the eligibility criteria after screening for eligibility. The demographic information of the participants is demonstrated in Table 3.

Table 3. Demographic information of the participants in terms of different ADHD subtypes.

	All Subtypes (N = 25)	**Participants with a Combined Subtype (17; 68.0%)**	**Participants with an Inattentive Subtype (6; 24.0%)**	**Participants with a Hyperactive–Impulsive Subtype (2; 8.0%)**	***p* Value**
Age (years), mean (SD)	8.72 (2.01)	9.12 (1.96)	7.67 (2.25)	8.5 (0.71)	0.488
Gender, n (%)					0.007
Male	19 (76.0)	16 (94.2)	2 (33.3%)	1 (50.0)	
Female	6 (24.0)	1 (5.88)	4 (66.7%)	1 (50.0)	
Medication, n (%)					0.918
Yes	14 (56.0)	10 (58.8)	3 (50.0)	1 (50.0)	
No	11 (44.0)	7 (41.2)	3 (50.0)	1 (50.0)	
Type of school					-
Mainstream school	25 (100.0)	17 (100.0)	6 (100.0)	2 (100.0)	
Glasses worn, n (%)					0.714
Yes	5 (20.0)	4 (23.5)	1 (16.7)	0	
No	20 (80.0)	13 (76.5)	5 (83.3)	2 (100.0)	
Previous VR experience, n (%)					0.783
Yes	1 (4.0)	1 (6.8)	0 (0.0)	0 (0.0)	
No	24 (96.0)	16 (94.2)	6 (100.0)	2 (100.0)	

Most of the participants were boys (76.0%). A total of 68.0% of the participants had a combination type, 24.0% of the participants had an inattentive type, and 8.0% of the participants had a hyperactive–impulsive type of disorder. More than half of the participants (56.0%) took medication. Most of the participants (80.0%) did not wear glasses. Only one participant had the experience of using VR. The demographic characteristic of the participants was well balanced, except for gender. ADHD is often diagnosed at a higher rate in males than in females [37], possibly contributing to a significant effect on gender.

4.2. Usability

Figure 3 demonstrates the percentages of the participants who liked each condition. Regarding the level of interest, MTR, Campus and Market and Restaurant environments showed 91.2%, 71.2%, and 81.2%, satisfaction respectively. For easy-to-understand instructions, all conditions had a satisfaction level of 90% and above. The percentages of easy start of MTR, Campus and Market and Restaurant were 93.6%, 94.0% and 85.2%, respectively. The controls of MTR (96.0%) and Campus (96.8%) were easy to use; only Market and Restaurant gained less than 80.0% of satisfaction. All participants found each condition understandable after changes. The aesthetic appeal of the graphics of MTR and Market and Restaurant was valued at more than 90.0%, and that of Campus was at 81.2%. Table 4 displays the results of the f-test examining the differences in the mechanics of

three conditions among the three ADHD subtypes of participants. Only the instruction perspective of the condition of Market and Restaurant demonstrated a significant difference among the three ADHD subtype groups ($p = 0.04 < 0.05$). The value of the ADHD subtypes of hyperactive–impulsive rating in the instruction of Market and Restaurant was 10, that of the ADHD combined subtype was 9.59, and that of the inattentive subtype was 9.33. Other mechanics perspectives across the three conditions in Social VR had no significant effects among the three ADHD subtype groups, indicating that these mechanics in Social VR are applicable to the three ADHD subtype groups.

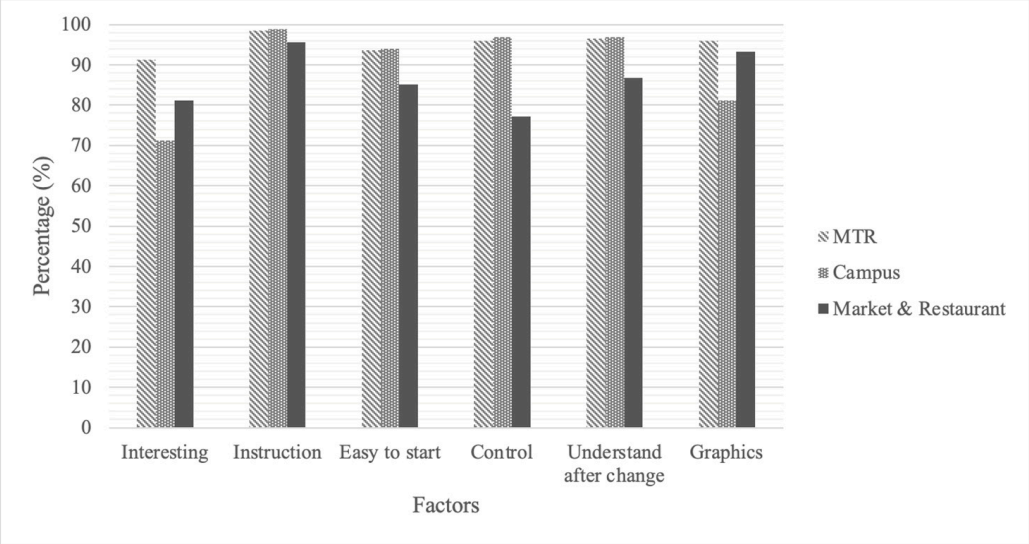


Figure 3. Results of specific questions about the mechanics of each condition (N = 25).

Table 4. The results of the differences in the mechanics of three conditions among the three ADHD subtypes of participants. Combined subtype (N = 17); hyperactive–impulsive subtype (N = 2); inattentive subtype (N = 6).

Condition	Mechanics	ADHD Subtypes	Mean	S.D.	Between Groups		
					df	F	*p*
MTR	Interesting	Combined	9.12	0.485	1	0.083	0.776
		HI	9.00	0.000			
		Inattention	9.17	0.408			
	Instruction	Combined	9.88	0.332	1	0.660	0.425
		HI	10.00	0.000			
		Inattention	9.67	0.516			
	Easy to start	Combined	9.35	0.493	1	0.532	0.473
		HI	9.50	0.707			
		Inattention	9.33	0.816			
	Control	Combined	9.59	0.507	1	0.226	0.639
		HI	9.50	0.707			
		Inattention	9.67	0.516			
	Understand after change	Combined	9.65	0.493	1	2.793	0.108
		HI	9.50	0.707			
		Inattention	9.67	0.516			
	Graphics	Combined	9.71	0.470	1	0.100	0.755
		HI	9.50	0.707			
		Inattention	9.33	0.516			
Campus	Interesting	Combined	7.06	1.249	1	2.812	0.107
		HI	8.00	1.414			
		Inattention	7.00	0.894			

Table 4. *Cont.*

Condition	Mechanics	ADHD Subtypes	Mean	S.D.	Between Groups df	F	p
Market and Restaurant	Instruction	Combined	9.94	0.243	1	0.146	0.706
		HI	10.00	0.000			
		Inattention	9.67	0.516			
	Easy to start	Combined	9.29	0.470	1	0.100	0.755
		HI	9.00	0.000			
		Inattention	9.83	0.408			
	Control	Combined	9.59	0.507	1	0.159	0.694
		HI	9.50	0.707			
		Inattention	10.00	0.000			
	Understand after change	Combined	9.59	0.507	1	0.159	0.694
		HI	9.50	0.707			
		Inattention	10.00	0.000			
	Graphics	Combined	8.29	0.920	1	0.021	0.887
		HI	8.50	0.707			
		Inattention	7.50	0.548			
	Interesting	Combined	8.18	0.529	1	0.202	0.658
		HI	8.50	0.707			
		Inattention	7.83	0.753			
	Instruction	Combined	9.59	0.795	1	4.679	0.041 *
		HI	10.00	0.000			
		Inattention	9.33	0.816			
	Easy to start	Combined	8.41	0.795	1	0.107	0.747
		HI	9.50	0.707			
		Inattention	8.50	1.049			
	Control	Combined	7.82	0.728	1	0.002	0.963
		HI	7.50	0.707			
		Inattention	7.50	0.548			
	Understand after change	Combined	8.76	0.437	1	0.187	0.669
		HI	8.50	0.707			
		Inattention	8.50	0.548			
	Graphics	Combined	9.41	0.507	1	1.609	0.217
		HI	9.50	0.707			
		Inattention	9.00	0.000			

* $p < 0.05$. Note. HI = hyperactive–impulsive; S.D. = standard deviation.

Table 5 shows the percentages of participants' experiences with Social VR. All participants were satisfied with the use of Social VR, including a high level of enjoyment, willingness to repeat, feeling real, and good visual and auditory effects. Regarding motion sickness, no participants reported dizziness and discomfort during and after playing Social VR.

Table 5. The satisfaction and motion sickness of the participants after testing Social VR (N = 25).

Factors of Satisfaction	Experience (Yes), *n* (%)	Experience (Neutral), *n* (%)
Enjoy the experience	25 (100.0%)	0 (0.0%)
Want to repeat it	25 (100.0%)	0 (0.0%)
Feel real	22 (88.0%)	3 (12.0%)
Sound	20 (80.0%)	5 (20.0%)
Easy to understand	25 (100.0%)	0 (0.0%)
Feeling	25 (100.0%)	0 (0.0%)
Motion sickness	**No, n (%)**	
Dizziness	25 (100.0%)	
Motion sickness	25 (100.0%)	

5. Discussion

This study extends existing knowledge about the potential of using Social VR to provide psychological and psychiatric therapy for children with ADHD. Clinical activity and tolerable side effects of VR-based interventions must be demonstrated before the Social VR interventions can be incorporated into multimodal treatments for ADHD. Three VR scenarios were created using the Unity platform. All participants enjoyed playing Social VR and were satisfied with the visual and auditory effects of Social VR. Although inferential statistics have not yet been provided for this development and usability study, given the increasing number of newly diagnosed ADHD [38], there is an urgent need to use an effective approach (i.e., VR) to treat children with ADHD [18,30,39].

The results of this study show that the Social VR is generally interesting, understandable, easy to pick up, easy to use and control, and has beautiful visual graphics. Nevertheless, there were some differences between each condition, possibly suggesting that improvements are needed to certain components of Social VR. Comparing the three conditions in Social VR, namely MTR, Campus and Market and Restaurant, MTR is the most interesting, while Campus is not so interesting. The reason may be that some participants said they did not like being in the classroom because they did not like going to school [40]. Regarding easy-to-understand instructions, Market and Restaurant had a relatively lower rating than the other conditions. A possible explanation for this might be that the instructions in the MTR and Campus environments were played by voice and displayed in the text but in the Market and Restaurant environment, the instructions were displayed in text and pictures only. Participants' attention to the instruction might have been reduced if there were no spoken instructions to play. The result was compared to the findings of Chen [41], who asserted that the listen-to-read group outperformed the read-only group in recognising the form and meaning of vocabulary. In terms of ease of control, the control of Markets and Restaurants environment seemed to be not easy to use compared with that of MTR and Campus. The possible reason for this is that this condition requires more movements, such as grasping, crouching, and looking up and down while searching for the items they need to purchase than the other two conditions. Regarding the result of the Markets and Restaurants environment having the lowest rating in understanding the scenario better as the situations changed, this is likely to be related to the absence of spoken instructions in this condition. Further evaluation is needed to identify the reasons. The Campus condition received the lowest scores in terms of graphics quality. This is likely because some participants found the school to be uninteresting and dull. This finding seems to be consistent with the study of Classi et al. [42], stating that school avoidance was common in ADHD due to fear of academic demands, peer rejection or anxiety.

Regarding the differences in the mechanics in the three conditions of Social VR among the three ADHD subtypes, only the assertion that it is "easy to understand the instructions in the scenarios" in Market and Restaurant had a significant effect among the three ADHD subtype groups. This may imply that the three ADHD subtypes may have different levels of understanding of Market and Restaurant instructions, with participants in the hyperactive–impulsive subtype having the highest comprehension of instructions compared to the combined ADHD subtype and inattention subtype groups. The inattention subtype groups had the lowest level of comprehension of instructions in the Market and Restaurant condition. This finding may be due to the absence of spoken instructions in the Market and Restaurant condition, possibly affecting the comprehension of instructions among the participants with the inattentive subtype. More research needs to be conducted to evaluate such differences.

As for overall satisfaction, all participants liked Social VR because they found it fun and engaging and would like to repeat it. The participants found the conditions easy to navigate and interact with. Of the six factors related to satisfaction, the sound of Social VR appears to be the least satisfying. No participants experienced discomfort or motion sickness because we limited the duration of each session to 20 min, used teleport

instead of walking in the virtual environment, and utilised adjustable and protective head strap support.

This development and usability study contained several limitations. First, the small sample size of the study may have affected the generalisability of the results and may not have been representative of all related users, though random sampling was adopted in this study to ensure a diverse sample. Thus, results and interpretation should be considered with caution, and a larger sample size and diverse target populations are recommended to be adopted in future studies. Second, this study mainly focused on the specific aspects of the Social VR, although overall satisfaction was included. Therefore, a broader range of needs and preferences, such as factors affecting distraction within social VR, can be captured in further studies. Third, participants may not have been able to effectively express their thoughts and experiences and completely provide comprehensive feedback due to the limited time and environmental setting. Therefore, future research (i.e., pilot study) will take more objective measures to determine participants' understanding and experience of the intervention.

6. Conclusions

VR has emerged as a promising technology for use in psychological and psychiatric therapy due to its ability to provide patients with a safe and controlled environment, surpassing traditional therapeutic approaches for mental disorders. This study set out to outline the development process of a VR-based social skills intervention designed for children with ADHD and to evaluate these children's experience with Social VR in terms of its mechanics, satisfaction, and motion sickness. The findings of this study showed that the implementation of Social VR yielded a program that was not only enjoyable and engaging but also ensured a safe environment for the participants. However, it was observed that adjustments might be necessary in the delivery of instruction within the Market and Restaurant condition to ensure compatibility with all subtypes of ADHD. Following these adjustments, the overall results strongly indicate the feasibility of conducting a pilot trial to evaluate the preliminary efficacy of Social VR in children with ADHD. The outcomes hold significant implications for the application of virtual reality in assisting individuals with neurodevelopmental disorders, particularly ADHD. This research contributes to the growing understanding of the potential benefits and feasibility of employing virtual reality in the context of neurodevelopmental disorders.

Author Contributions: Conceptualization, K.-P.W.; methodology, K.-P.W.; software, K.-P.W. and J.Q.; validation, K.-P.W. and J.Q.; formal analysis, K.-P.W.; investigation, K.-P.W.; resources, K.-P.W. and J.Q.; data curation, K.-P.W. and B.Z.; writing—original draft preparation, K.-P.W.; writing—review and editing, K.-P.W. and B.Z.; visualization, K.-P.W. and B.Z.; supervision, J.Q.; project administration, K.-P.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of The Hong Kong Polytechnic University (HSEARS20221221003).

Informed Consent Statement: Informed consent was obtained from all subjects' guardians involved in the study. Written informed consent was obtained from the patients' guardians to publish this paper.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical restrictions.

Acknowledgments: We thank all the children and parents for their participation in this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Biele, G.; Overgaard, K.R.; Friis, S.; Zeiner, P.; Aase, H. Cognitive, emotional, and social functioning of preschoolers with attention deficit hyperactivity problems. *BMC Psychiatry* **2022**, *22*, 78. [CrossRef]
2. McDonald, K.L.; Wang, J.; Menzer, M.M.; Rubin, K.H.; Booth-LaForce, C. Prosocial behavior moderates the effects of aggression on young adolescents' friendships. *Int. J. Dev. Sci.* **2011**, *5*, 127–137. [CrossRef] [PubMed]
3. Carpenter Rich, E.; Loo, S.K.; Yang, M.; Dang, J.; Smalley, S.L. Social functioning difficulties in ADHD: Association with PDD risk. *Clin. Child Psychol. Psychiatry* **2009**, *14*, 329–344. [CrossRef] [PubMed]
4. Glenn, D.E.; Michalska, K.J.; Lee, S.S. Social skills moderate the time-varying association between aggression and peer rejection among children with and without ADHD. *Aggress. Behav.* **2021**, *47*, 659–671. [PubMed]
5. Nelson, J.M.; Gregg, N. Depression and anxiety among transitioning adolescents and college students with ADHD, dyslexia, or comorbid ADHD/dyslexia. *J. Atten. Disord.* **2012**, *16*, 244–254. [CrossRef]
6. Yang, H.-N.; Tai, Y.-M.; Yang, L.-K.; Gau, S.S.-F. Prediction of childhood ADHD symptoms to quality of life in young adults: Adult ADHD and anxiety/depression as mediators. *Res. Dev. Disabil.* **2013**, *34*, 3168–3181. [CrossRef]
7. Adler, L.D.; Nierenberg, A.A. Review of medication adherence in children and adults with ADHD. *Postgrad. Med.* **2010**, *122*, 184–191. [CrossRef]
8. Handelman, K.; Sumiya, F. tolerance to stimulant medication for attention deficit hyperactivity disorder: Literature review and case report. *Brain Sci.* **2022**, *12*, 959. [CrossRef]
9. Childress, A.C.; Komolova, M.; Sallee, F.R. An update on the pharmacokinetic considerations in the treatment of ADHD with long-acting methylphenidate and amphetamine formulations. *Expert Opin. Drug Metab. Toxicol.* **2019**, *15*, 937–974. [CrossRef]
10. van de Loo-Neus, G.H.H.; Rommelse, N.; Buitelaar, J.K. To stop or not to stop? How long should medication treatment of attention-deficit hyperactivity disorder be extended? *Eur. Neuropsychopharmacol.* **2011**, *21*, 584–599. [CrossRef]
11. Storebø, O.J.; Elmose Andersen, M.; Skoog, M.; Joost Hansen, S.; Simonsen, E.; Pedersen, N.; Tendal, B.; Callesen, H.E.; Faltinsen, E.; Gluud, C. Social skills training for attention deficit hyperactivity disorder (ADHD) in children aged 5 to 18 years. *Cochrane Database Syst. Rev.* **2019**, *6*, CD008223. [CrossRef] [PubMed]
12. Mikami, A.Y.; Smit, S.; Khalis, A. Social Skills Training and ADHD—What Works? *Curr. Psychiatry Rep.* **2017**, *19*, 93. [CrossRef] [PubMed]
13. Willis, D.; Siceloff, E.R.; Morse, M.; Neger, E.; Flory, K. Stand-alone social skills training for youth with ADHD: A systematic review. *Clin. Child. Fam. Psychol. Rev.* **2019**, *22*, 348–366. [PubMed]
14. Bashiri, A.; Ghazisaeedi, M.; Shahmoradi, L. The opportunities of virtual reality in the rehabilitation of children with attention deficit hyperactivity disorder: A literature review. *Korean J. Pediatr.* **2017**, *60*, 337–343. [CrossRef] [PubMed]
15. Corrigan, N.; Păsărelu, C.R.; Voinescu, A. Immersive virtual reality for improving cognitive deficits in children with ADHD: A systematic review and meta-analysis. *Virtual Real.* **2023**, *18*, 1–20. [CrossRef]
16. Li, L.; Yu, F.; Shi, D.; Shi, J.; Tian, Z.; Yang, J.; Wang, X.; Jiang, Q. Application of virtual reality technology in clinical medicine. *Am. J. Transl. Res.* **2017**, *9*, 3867–3880.
17. Adabla, S.; Nabors, L.; Hamblin, K. A scoping review of virtual reality interventions for youth with attention-deficit/hyperactivity disorder. *Adv. Neurodev. Disord.* **2021**, *5*, 304–315. [CrossRef]
18. Parsons, T.D.; Duffield, T.; Asbee, J.A. Comparison of virtual reality classroom continuous performance tests to traditional continuous performance tests in delineating ADHD: A meta-analysis. *Neuropsychol. Rev.* **2019**, *29*, 338–356. [CrossRef]
19. Romero-Ayuso, D.; Toledano-González, A.; Rodríguez-Martínez, M.D.C.; Arroyo-Castillo, P.; Triviño-Juárez, J.M.; González, P.; Ariza-Vega, P.; González, A.D.P.; Segura-Fragoso, A. Effectiveness of virtual reality-based interventions for children and adolescents with ADHD: A systematic review and meta-analysis. *Children* **2021**, *8*, 70. [CrossRef]
20. Dechsling, A.; Orm, S.; Kalandadze, T.; Sütterlin, S.; Øien, R.A.; Shic, F.; Nordahl-Hansen, A. Virtual and augmented reality in social skills interventions for individuals with autism spectrum disorder: A scoping review. *J. Autism Dev. Disord.* **2022**, *52*, 4692–4707. [CrossRef]
21. Ke, F.; Moon, J.; Sokolikj, Z. Virtual reality–based social skills training for children with autism spectrum disorder. *J. Spec. Educ. Technol.* **2022**, *37*, 49–62. [CrossRef]
22. Montoya-Rodríguez, M.M.; de Souza Franco, V.; Tomás Llerena, C.; Molina Cobos, F.J.; Pizzarossa, S.; García, A.C.; Martínez-Valderrey, V. Virtual reality and augmented reality as strategies for teaching social skills to individuals with intellectual disability: A systematic review. *J. Intellect. Disabil.* **2022**. [CrossRef] [PubMed]
23. Baranowski, T. Descriptions for articles introducing a new game for health. *Games Health J.* **2014**, *3*, 55–56. [CrossRef] [PubMed]
24. Barkley, R.A. Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychol. Bull.* **1997**, *121*, 65–94. [CrossRef] [PubMed]
25. Brown, T.E. ADD/ADHD and impaired executive function in clinical practice. *Curr. Psychiatry Rep.* **2008**, *10*, 407–411. [CrossRef] [PubMed]
26. Sherlin, L.H.; Arns, M.; Lubar, J.; Heinrich, H.; Kerson, C.; Strehl, U.; Sterman, M.B. neurofeedback and basic learning theory: Implications for research and practice. *J. Neurother.* **2011**, *15*, 292–304. [CrossRef]
27. Ziegler, S.; Pedersen, M.L.; Mowinckel, A.M.; Biele, G. Modelling ADHD: A review of ADHD theories through their predictions for computational models of decision-making and reinforcement learning. *Neurosci. Biobehav. Rev.* **2016**, *71*, 633–656. [CrossRef]
28. Xin, Y. Influence of learning engagement on learning effect under a virtual reality (VR) environment. *Int. J. Emerg. Technol. Learn.* **2022**, *17*, 226–237. [CrossRef]

29. Cardona-Reyes, H.; Ortiz-Aguinaga, G.; Barba-Gonzalez, M.L.; Muñoz-Arteaga, J. User-centered virtual reality environments to support the educational needs of children with ADHD in the COVID-19 pandemic. *IEEE Rev. Iberoam. Tecnol. Aprendiz.* **2021**, *16*, 400–409. [CrossRef]
30. Zangiacomi, A.; Flori, V.; Greci, L.; Scaglione, A.; Arlati, S.; Bernardelli, G. An immersive virtual reality-based application for treating ADHD: A remote evaluation of acceptance and usability. *Digit. Health* **2022**, *8*, 205520762211432. [CrossRef]
31. Parsons, T.D.; Bowerly, T.; Buckwalter, J.G.; Rizzo, A.A. A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. *Child. Neuropsychol.* **2007**, *13*, 363–381. [CrossRef] [PubMed]
32. Johnson, D.; Deterding, S.; Kuhn, K.-A.; Staneva, A.; Stoyanov, S.; Hides, L. Gamification for health and wellbeing: A systematic review of the literature. *Internet Interv.* **2016**, *6*, 89–106. [CrossRef] [PubMed]
33. Gentry, S.; L'Estrade Ehrstrom, B.; Gauthier, A.; Alvarez, J.; Wortley, D.; van Rijswijk, J.; Car, J.; Lilienthal, A.; Tudor Car, L.; Nikolaou, C.K.; et al. Serious gaming and gamification interventions for health professional education. *Cochrane Database Syst. Rev.* **2018**, *2018*, CD012209. [CrossRef]
34. Rodrigo-Yanguas, M.; Martin-Moratinos, M.; Menendez-Garcia, A.; Gonzalez-Tardon, C.; Royuela, A.; Blasco-Fontecilla, H. A virtual reality game (The Secret Trail of Moon) for treating attention-deficit/hyperactivity disorder: Development and usability study. *JMIR Serious Games* **2021**, *9*, e26824. [CrossRef] [PubMed]
35. Lewis, J.R. IBM Computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use. *Int. J. Hum-Comput. Interact.* **1995**, *7*, 57–78. [CrossRef]
36. Sevinc, V.; Berkman, M.I. Psychometric evaluation of simulator sickness questionnaire and its variants as a measure of cybersickness in consumer virtual environments. *Appl. Ergon.* **2020**, *82*, 102958. [CrossRef] [PubMed]
37. Andersen, S.L.; Teicher, M.H. Sex differences in dopamine receptors and their relevance to ADHD. *Neurosci. Biobehav. Rev.* **2000**, *24*, 137–141. [CrossRef]
38. Retz, W.; Ginsberg, Y.; Turner, D.; Barra, S.; Retz-Junginger, P.; Larsson, H.; Asherson, P. Attention-Deficit/Hyperactivity Disorder (ADHD), antisociality and delinquent behavior over the lifespan. *Neurosci. Biobehav. Rev.* **2021**, *120*, 236–248. [CrossRef]
39. Seesjärvi, E.; Puhakka, J.; Aronen, E.T.; Lipsanen, J.; Mannerkoski, M.; Hering, A.; Zuber, S.; Kliegel, M.; Laine, M.; Salmi, J. Quantifying ADHD symptoms in open-ended everyday life contexts with a new virtual reality task. *J. Atten. Disord.* **2021**, *26*, 1394–1411. [CrossRef]
40. Golubchik, P.; Golubchik, L.; Sever, J.M.; Weizman, A. The beneficial effect of methylphenidate in ADHD with comorbid separation anxiety. *Int. Clin. Psychopharmacol.* **2014**, *29*, 274–278. [CrossRef]
41. Chen, Y. Comparing incidental vocabulary learning from reading-only and reading-while-listening. *System* **2021**, *97*, 102442. [CrossRef]
42. Classi, P.; Milton, D.; Ward, S.; Sarsour, K.; Johnston, J. Social and emotional difficulties in children with ADHD and the impact on school attendance and healthcare utilization. *Child Adolesc. Psychiatry Ment. Health* **2012**, *6*, 33. [CrossRef] [PubMed]