Design to Assist Better Childhood for the Lower Limb Disabled through VR Application: The Climbing on Adventure Island

Jiajing Huang, Chengyuan Chen, Muge Li, Lanxin Hui, Yunping Yang, Jiazhen Li

Department of Industrial Design, Guangdong University of Technology

1.Problem Statement/Research Question and Background

Disabled children with lower limb dysfunction have a lower level of participation in sports than healthy children due to difficulties in performing certain activities and sub-health problems related to diagnosis. This has a negative impact on their growth and self-development. In terms of psychology and physiology, its effects include decline in health levels, lack of motor coordination, impaired self-esteem and decreased quality of life [1].

In recent years, technologies such as virtual reality (VR) have been widely used in exercise rehabilitation, psychological therapy and other fields for the disabled. Lange et al. proposed to combine task-specific training with VR games to enhance traditional rehabilitation interventions by extending the exercise participation of the disabled [2]. The study of Fralish et al. showed that VR programs are beneficial for the disabled in ameliorating the physical flexibility and mental health [3]. These merits brought by VR applications stand a higher value for people in their childhood, since they are sensitive to the external stimulates, and willing to explore the fields that people without disability taken part in.

Thus, we decided to design a virtual sports experience application to assist better childhood for the lower limb disabled. The application is deigned as a game since the prospective users are youngers. However, it not only stays at the entertainment perspective, but also pretends to provide substantial help for disabled children from the psychological and physical perspectives. In psychology, it enables children with lower limb dysfunction to obtain sports experiences similar to those of other children, makes it possible for them to experience the feelings of other children, feel the freedom and happiness brought by exercise, obtain spiritual comfort, and regain self-confidence. These experiences via VR and associated multimodal interactions are of remarkable significance to children who have difficulties in moving. In physiology, immersive sports participation can arouse the enthusiasm of disabled children to exercise, avoiding the decline or even loss of sports ability, as well as improving the corresponding physical health. In addition, compared with actual outdoor sports, sports within virtual reality may significantly reduce the possibility of injury caused by accidental hazards. Thus, there is a need of designing that may assist better childhood for people with lower limb disabilities by extending their

exercise experience in the virtual environment.

2.Methods/Approach/Solution Considered

Our team proposed to realize the above-mentioned design with three different approaches: motion sensing interaction, augmented reality (AR) and VR.

First, we planned to use motion sensing technology to capture the upper limb movements of children with lower limb disabilities so that they can participate in the virtual table tennis through TV screen, and experience the happiness brought by sports. As this virtual game of table tennis requires users to move within a certain range, which is difficult for children with lower limb disabilities, and the motion sensing interactive only relying on the TV screen has a weak sense of immersion, reducing the sports experience greatly. Thus, we decided to seek more suitable sports experience game for children with lower limb disabilities.

The next solutions we considered are VR and AR. The ultimate purpose of our design is to provide sports experience close to the real-world ones for disabled children. The application is supposed to empowers them to participate in virtual sports, to gain the sense of achievement and pleasure brought by sports like other children after overcoming challenges and difficulties in sports, to exercise their will and consolidate self-confidence. In addition to designing virtual environment, AR needs to consider the setting of the external physical environment by using the simultaneous localization and mapping (SLAM) technology. Due to the high technical difficulty and development cost of the AR scheme, our team decided to tackle the challenge by developing a VR application with less difficulty and stronger immersion.

After determining the primary approach, we decided to design a sports experience VR application simulating rock climbing and give it an interesting story background based on the physiological characteristics and educational needs of children with lower limb disabilities. This application enables lower limb disabled children to participate in virtual rock climbing using their upper limb functions, exercise their physical function, and experience the feeling and happiness brought by the activities. At the same time, they can learn the relevant knowledge involved in the story, which makes the exercise and rehabilitation more entertaining.

3.Description of Final Approach and Design

The rock-climbing experience game using VR technology focused on addressing the issues of limited sports participation, as well as restricted physical and psychological development of children with lower limb disabilities. We developed a novel floating island game environment, set up an interesting story background of rescuing the islander, and incorporated historical knowledge related to world famous architecture (e.g. the Leaning Tower of Pisa, and Roman Colosseum) to make it fun and educational. Disabled children wear HTC Vive glasses when

playing, enter the immersive virtual environment, complete the architectural climbing task with the transient and grasping functions of the gamepad, and get the trophy. The trophy can be collected to rescue the islander. During the game experience, disabled children not only exercise their physical functions, gain the courage to overcome difficulties and the joy of success, but also learn relevant knowledge involved in the historical stories.

The level design followed the principle from easy to difficult and from low to high, so that disabled children can overcome their inner fear and temper their personal will in the process of constantly challenging themselves. We set obstacles such as moving gears to increase the difficulty of climbing, so that disabled children can constantly improve their reaction and thinking ability in the process of coping with obstacles. In environmental scene design, we provided users with rich experience through different virtual environment (such as the Leaning Tower of Pisa, and Roman Colosseum) and climbing scene (rock climb, horizontal bar climb, and ladder climb). We set up virtual historical figures and vivid historical stories at the top of the buildings to carry out science popularization of world-famous architecture knowledge. In terms of interaction design, we created drone guides and signposts to provide users with route guidance, and provided instant interactive feedback in the form of rock climbing point color changing and audio hints.
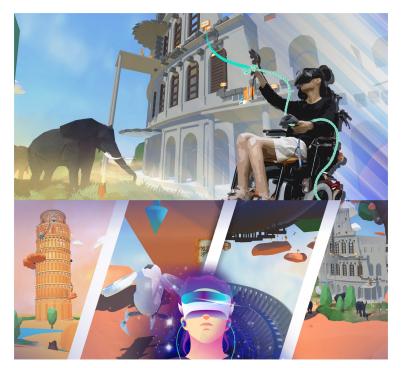

Figure1. The concept and details of the the rock-climbing experience game

4.Outcome

An early but with full function version of the game application had been developed. Due to the Cov-19, disabled children were not easy to be invited as subjects to evaluate our design. In order

to verify the impact of our solution, we invited 10 normal college students (7 male and 3 female) from our school to participant to the pilot study. After the subjects completed designed procedure, their emotions were measured using a questionnaire, and they were interviewed to reveal un-covered challenges. The experiment was carried out in a quiet laboratory. During the experiment, the subjects were asked to sit on the chair while keeping their lower limbs as still as possible, and wearing HTC Vive glasses plus holding the HTC Vive gamepad with hands.

According to the PAD model emotion evaluation simplified scale, we defined our questionnaire as those in [4]. The data of the PAD model emotion evaluation simplified scale was calculated using:

$$P = (V_1 - V_4 + V_7 - V_{10})/4 \qquad (1)$$
$$A = (-V_2 + V_5 - V_8 + V_{11})/4 \qquad (2)$$
$$D = (V_3 - V_6 + V_9 - V_{12})/4 \qquad (3)$$

as defined in [4]. The experimental evaluation results showed that the mean P value of the 10 subjects was +2.25, proving that users had smooth thinking during the game, could choose the most effective method to complete the experimental task with a high degree of pleasure. The mean A value was +1.75, indicating that the game is attractive, and the subjects generally found it novel and interesting. The mean D value is +0.675, demonstrating that for the subjects, the game has low cognitive load and learning cost, high ease of use, and can be controlled. These results were further verified by the the interviews of the 10 subjects, most of whom found the game novel and fun, moderately difficult, and although they felt tired due to the physical exertion of their upper limbs, they had a sense of achievement and still wanted more. In addition, the subjects reported slight sweating and upper limbs soreness after the experiment, proving that the game could greatly increase upper limb motor participation and active body function.

Table1. The results of the PAD model emotion evaluation for 10 subjects

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	mean
V_1	3	1	4	3	-2	4	3	3	0	4	-
V_2	-3	-3	2	-3	-2	-4	0	-4	3	-4	-
V_3	2	3	4	4	2	-3	2	2	3	4	-
V_4	-3	-3	0	-2	-2	-1	-2	-4	-3	-4	-
V_5	3	3	2	2	0	4	4	-1	0	4	-
V_6	-2	-3	-2	3	0	-1	-1	1	-2	-4	-
V_7	3	-1	4	2	2	2	1	4	-4	4	-
V_8	-3	0	4	2	-3	-4	-1	-2	2	-4	-
V_9	2	1	4	-3	0	-3	2	-2	-3	4	-
V_{10}	-3	-2	-3	-2	-2	-4	-2	-4	0	-4	-
V_{11}	3	0	2	4	2	3	2	4	-2	4	-
V_{12}	3	-1	0	2	0	3	0	3	3	-4	-
P	3	1.25	2.75	2.25	1	2.75	2	3.75	-0.25	4	2.25
A	3	1.5	-0.5	1.75	1.75	3.75	1.75	2.25	-1.75	4	1.75

| D | 0.75 | 2 | 2.5 | -1 | 0.5 | -2 | 1.25 | -1 | -0.25 | 4 | 0.675 |

Figure2. The pilot study

According to our pilot study, a number of problems stand after interviewing the subjects: there is no end point and progress display, which makes users feel confused; there is no archiving function, users will lose patience after multiple failure; the level line is long, easy to fatigue; rocks sizes, distances and sound feedback settings are not appropriate, etc. We plan to address these problem and turn them into improvement key points in the next iteration of our design.

5.Cost

We used VRTK3.2.1 and SteamVR2.1.0 software development kit (SDK) to develop games in Unity environment with open source code, reducing programming difficulty and development cost. The initial operating costs mainly include equipment (10 sets) costs, art (graphic design, 3D model, and animation sound) costs, development (programming code, and game special effects) costs, and platform operating costs, about 105,000 RMB (16,000 USD), of which equipment costs account for about 67%, art and development costs account for about 28%, and platform operating costs account for about 5%. In our case, the hardware was supported by our school and supervisors. And the art, design and developments workloads are handled by team members. Note that the technology involved are not of the frontier in computer science and AI which means the college students with professional skills may be qualified. Thus, if the assistive application is developed by school, the cost would be very limited.

The main customers of The Climbing on Adventure Island will be hospitals, clinics, family with kids of lower limb disabled, and possibly schools with special education programs. Depending on the use scenario, the game can be used in different ways, as an assistive rehabilitation tool in hospitals and clinics or a curriculum teaching tool in special schools. If the buyer have VR equipment ready, the application would be very affordable.

6.Significance

After the early but with full function version pilot study, it was demonstrated that The Climbing on Adventure Island have a positive physiological and psychological impact on aimed users. We believe that this climbing experience VR game can assist overcome the problems of low sports participation and limited physiological and psychological development of children with lower limb disabilities.

Our design may assist better childhood for the aimed subjects in multiple perspectives. In psychology, it enables children with lower limb dysfunction to have a similar sports experience as healthy children, makes it possible for them to experience the feelings of able-bodied children, feel the freedom and happiness brought by sports, gain spiritual comfort and regain self-confidence. In physiology, it arouse the enthusiasm of disabled children to exercise through immersive sports. It can exercise physical coordination of children, improve their physical health of children, avoid the decline or even loss of motor ability, and greatly reduce the possibility of accidental danger in actual outdoor sports, avoiding physical damage to disabled children.

Reference

[1] Sayed Ahmed, B., Lamy, M., Cameron, D., Artero, L., Ramdial, S., Leineweber, M., & Andrysek, J. (2018). Factors impacting participation in sports for children with limb absence: a qualitative study. Disability and rehabilitation, 40(12), 1393-1400.

[2] Lange, B. S., Requejo, P., Flynn, S. M., Rizzo, A. A., Valero-Cuevas, F. J., Baker, L., & Winstein, C. (2010). The potential of virtual reality and gaming to assist successful aging with disability. Physical Medicine and Rehabilitation Clinics, 21(2), 339-356.

[3] Fralish, B., Nickels, M., & Garcia, J. (2018). Improved physiology and psychosocial well-being for individuals with physical disabilities through virtual reality immersion: a case study. Journal of Developmental and Physical Disabilities, 30(6), 771-782.

[4] Li Deng, Bo Chen, Xiyue Pang, Rong Wen, & Bingyu Xie. (2018). The Application of EEG Technology in the Emotional Design of Cultural Creative Products. Journal of Graphics, 39(2), 327-332.