Multisensory Climbing in the Magic Room

Matteo Secco(✉), Mattia Gianotti, Alessandro Colombo, and Franca Garzotto

Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci 32, Milano, Italy
{matteo.secco,mattia.gianotti,alessandro.colombo, franca.garzotto}@polimi.it

Abstract. Multisensory Environments have been focused on use cases centered on learning skills and cognitive rehabilitation, which limits physical exercise to be a means rather than an end. A novel solution to this problem comes from Sensorized Climbing Walls, which will allow UX designers to explore a previously unexplored interaction mode using the entire wall as an interactive surface and suggest physical activities with a clear and central physical rehabilitation goal. Research on Sensorized Climbing Walls to date has mainly focused on measurement for enhancing performance. Merging Sensorized Climbing Walls and Multisensory Environments, new opportunities arise to offer more playful experiences to better engage patients in otherwise strenuous exercise routines. The two technologies have proven valuable assets to support children with disabilities and offer complementary sets of stimuli. The development of this new integrated system will open up a new field of study for multisensory physical rehabilitation, Multisensory Environments, and climbing therapy.

Keywords: Multisensory Environment · Sensorized Climbing Wall · Technological aided physical exercise

1 Introduction

NeuroDevelopmental Disorder is a term covering several pathologies arising during children's development. The most common effects are connected to cognitive, social, and motor deficits [12]. Patients may find it difficult to complete even simple daily tasks, with significant impact on their lives and their families [7].

A MultiSensory Environment (MSE) is a dedicated indoor space combining various sensory experiences and motor interaction to promote motivation, interests, leisure, and relaxation . These practices are grounded on Sensory Integration Theory [13] and Embodied Cognition [10,16].

MSEs have proven effective for improving motion and equilibrium skills [9,11]. Using Nirvana [4] resulted in a significant improvement in the trunk motion test and in cognitive skills. FutureGYM [15] successfully introduced a synchronization of running motion in children. A different approach is to include

J. Abdelnour Nocera et al. (Eds.): INTERACT 2023, LNCS 14145, pp. 533–538, 2023.
https://doi.org/10.1007/978-3-031-42293-5_68

standardized physical practices in the MSE. Many sports have space requirements incompatible with MSEs, with climbing representing a rare exception.

Our aim is to combine the growing technologies of Sensorized Climbing Walls [1,14] and MSEs to achieve two very innovative goals: using the potential of multiple sensory stimuli to improve the overall experience of climbing for children and introducing an incredibly innovative interaction method for MSEs.

2 Magic Room and ACCEPT

Based on our state-of-the-art analysis, we believe there is significant potential for employing MSEs in the realm of physical rehabilitation, especially in creating a playful experience for enhancing motor coordination and equilibrium. To the best of our knowledge, existing interactive systems designed for physical rehabilitation are restricted to either floor-based or wall-based interaction. For instance, FUTUREGYM [15] and iGYM [8] employ floor projections to enrich the experience of traditional exercises or sports to improve the user's engagement and overall experience. However, the metrics derived from such experiences are coarse and fail to accurately gauge the compromised physical abilities of children.

On the contrary, several systems have adopted a different approach by utilizing a touch surface [5] or gestures (e.g. Nirvana [4]) to run exergames in the vertical space, with the objective of rehabilitating upper limb functionality. Although these systems offer numerous specialized exercises, they often lack an immersive aspect in the gaming and fail to facilitate collaboration, which is fundamental for the children's development.

Our MSE, described in the subsequent subsection, already leaverages floor projection to create playful virtual environments suitable for floor-based activities. Furthermore, it incorporates gesture-based interaction to enable upper-limb rehabilitation, and both these interaction methods are friendly to wheelchair users. Integration with a Sensorized Climbing Wall presents an immensely valuable compromise: by combining full-body tracking and measurement of the forces applied to each handhold we achieve precise mapping of user skills. Additionally, the integration of the projections and other components of the Magic Room enables us to generate a captivating gaming experience involving climbing activities for one or more users, fostering collaboration among children.

Among the vast amount of technological support for the training and rehabilitation of such skills, we have identified very promising potential support in the use of a climbing wall. *Vice versa*, the potential of the Magic Room immersive stimulation can support and improve the rehabilitative and training potential of a Sensorized Climbing Wall. For this reason, we propose the integration of an MSE, the Magic Room [6], and a Sensorized Climbing Wall, ACCEPT [2,3]

2.1 The Magic Room

The Magic Room (Fig. 1) is an interactive MSE that enables innovative, playful interventions for children. The Magic Room integrates digital worlds projected

on the wall and on the floor with a gamut of "smart" physical objects to enable tactile, auditory, and visual stimuli. The Magic Room is equipped with A) a frontal and B) a zenithal projector, C) an audio system, D) custom smart objects, E) a custom camera-based body tracker, F) soap bubble makers, G) a tablet for caregivers to control interaction flows, and H, I) smart lights, a PC orchestrates the system behavior. The interaction with the smart space uses gestures and body movements or the manipulation of the smart toys (Fig. 2).

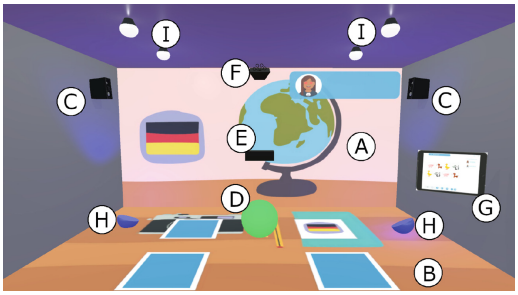

Fig. 1. The Magic Room's components

Fig. 2. The ACCEPT climbing wall

2.2 ACCEPT

ACCEPT is a climbing wall, approximately 3m wide and 2.5m high, equipped with triaxial force sensors measuring the magnitude and direction of forces applied to each hold. The wall allows the placement of standard climbing holds on a grid of attachment points, spaced according to typical children's anthropometric measurements. The sensors are hidden in the wall and invisible to the user.

The system reads synchronous force information from each sensor through a controller area network and serves it through an API, allowing a tablet application to show live the measured forces, visualize the data, store it, and associate it with a specific athlete. The app also stores the physical position and orientation of each sensor, so that forces from different sensors can be meaningfully composed.

3 Opportunities and Design

The integration of ACCEPT into the Magic Room environment would constitute the first example of a climbing wall within an Interactive Smart Space (ISS). The first level of integration will allow the Magic Room to access the data provided by ACCEPT, enabling the development of activities that react to the position of the user on the climbing wall and to the force vectors applied to each of the climbing holds. In a second integration phase, the wall could also be modified to act as an actuator by extending the ACCEPT system with different hardware elements like smart lights embedded into the holds. When not in use, the hold

attachments may be used for mounting Radio-Frequency IDentification (RFID) receivers on the vertical wall, robotic components to act as stimuli, and up to fully working interactive smart objects, all of which may be removed when not needed without permanently impacting the structure of the room itself.

This new technological advances open new design horizons for activities: the vertical dimension could be exploited, adding a variety of interactions in the narrations or developing entirely new challenges for the user. To our knowledge, at present time there exists no ISS or MSE that allows exploring the vertical space. Additionally, activities can be designed not only for cognitive training but also for physical training, widening the rehabilitation potential of the environment itself. Sessions with the ACCEPT system may also take advantage of the room's capabilities, exploiting it to create new stimuli and feedback and overall improve the engagement and user experience of its users. The following activities are an example of what could be achieved without additional setup.

Fig. 3. Silhouette game activity

Fig. 4. Cooperative climbing activity

3.1 Silhouette Game

In this activity (Fig. 3), after a narrative introduction the silhouette of a body is projected on the ACCEPT system, prompting the user with a position he/she should assume on the climbing wall. This may be a simple game objective, or be used to test the physical strength of the user in a predetermined position. Depending on the positioning of the climbing holds on the wall, the path the user will have to follow can be unique , or he/she can retain the freedom of choosing among multiple paths. As the user fits into the projected silhouette, the tracking system is able to detect the correct positioning and (optionally after a permanence time) provide the user with positive feedback for the accomplishment of the goal, e.g. by changing the color of the smart-lights. At this point, the room instructs the user to climb down the wall and the activity terminates.

3.2 Cooperative Climbing

This activity (Fig. 4) requires at least two users: one will be climbing on the ACCEPT wall, while the other will remain on the ground. The goal of the activity is to enhance cooperation and communication skills by having the user

on the ground direct the movements of the climber. The climber will start the activity with hands on two climbing holds and feet on the ground. On the floor a copy of the climbing wall will be projected, highlighting the next hold to be used according to some predefined sequence. The users on the ground will have to guide the climber's moves, communicating by voice. If the climber interacts with the correct hold the Magic Room will provide small feedback (through the smart lights only for example), while if the user moves into the wrong hold nothing will happen. The activity can be configured to have the sequence ends with the user on the ground again. After the entire sequence has been executed correctly, the activity is considered successfully completed and the Magic Room provides all the users a strong rewarding feedback.

4 The Call

MSEs have made strides in overcoming the limitations of cognitive rehabilitation, relegating physical rehabilitation to a secondary role. The incorporation of Sensorized Climbing Walls offers a unique opportunity to break free from this constraint: by exploring a novel interaction mode that utilizes the entire wall , we can propose physical exercises with explicit rehabilitation purposes. Prior research on Sensorized Climbing Walls has focused on enhancing performance measurement. Nonetheless, MSEs present an avenue to introduce more playful experiences, aiming to increase patient engagement during arduous exercise sessions. Our study seeks to address the following research questions:

1. Can MSEs provide a superior experience compared to traditional rehabilitation programs in terms of acceptability, engagement, and well-being?
2. Does the MSE experience yield measurable improvements in terms of rehabilitation outcome?

Answering the last question necessitates a comparison between rehabilitation outcomes in the MSE and those in a conventional therapy setting. To obtain scientifically valid conclusions, a considerable number of users are required. In the interim, we can monitor the effect of our solution on the overall well-being of the users. Our work paves the ground for a realm of multidisciplinary research, seamlessly integrating MSEs, multisensory cognitive rehabilitation, and physical rehabilitation through climbing. This integration presents a landscape of exciting challenges and unparalleled opportunities for groundbreaking innovation.

Acknowledgement. This project has been partially funded by project ActivE^3 "Everyone, Everywhere, Everyday" partially funded by Fondazione Cariplo and Regione Lombardia.

References

1. Amca, A.M., Vigouroux, L., Aritan, S., Berton, E.: Effect of hold depth and grip technique on maximal finger forces in rock climbing. J. Sports Sci. **30**(7), 669–677 (2012)

2. Colombo, A., et al.: Accept-a sensorized climbing wall for motor rehabilitation. In: Book of the 5th International Rock Climbing Research Congress, pp. 73–76 (2021)
3. Colombo, A., Maj, R., Canina, M., Fedeli, F., Dozio, N., Ferrise, F.: Design of a sensor network for the quantitative analysis of sport climbing. Frontiers in Sports and Active Living **5** (2023). https://doi.org/10.3389/fspor.2023.1114539, https://www.frontiersin.org/articles/10.3389/fspor.2023.1114539
4. De Luca, R., et al.: Effects of virtual reality-based training with bts-nirvana on functional recovery in stroke patients: preliminary considerations. Int. J. Neurosci. **128**(9) (2018)
5. Garcia-Hernandez, N., Huerta-Cervantes, K., Muñoz-Pepi, I., Parra-Vega, V.: Touch location and force sensing interactive system for upper limb motor rehabilitation. Multimed. Tools Appl. **81**(10), 14133–14152 (2022)
6. Garzotto, F., Beccaluva, E., Gianotti, M., Riccardi, F.: Interactive multisensory environments for primary school children. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–12. CHI '20, Association for Computing Machinery, New York, NY, USA (2020). https://doi.org/10.1145/3313831.3376343
7. Garzotto, F., Gelsomini, M., Gianotti, M., Riccardi, F.: Engaging children with neurodevelopmental disorder through multisensory interactive experiences in a smart space. Social Internet of Things, pp. 167–184 (2019)
8. Graf, R., et al.: Igym: An interactive floor projection system for inclusive exergame environments. In: Proceedings of the Annual Symposium on Computer-Human Interaction in Play, pp. 31–43 (2019)
9. Kristinsdottir, E.K., Baldursdottir, B.: Effect of multi-sensory balance training for unsteady elderly people: pilot study of the "reykjavik model." Disability and rehabilitation **36**(14), 1211–1218 (2014)
10. Macrine, S.L., Fugate, J.M.: Embodied cognition. In: Oxford Research Encyclopedia of Education (2020)
11. Moreira, N.B., Gonçalves, G., da Silva, T., Zanardini, F.E.H., Bento, P.C.B.: Multisensory exercise programme improves cognition and functionality in institutionalized older adults: A randomized control trial. Physiother. Res. Int. **23**(2), e1708 (2018)
12. Shams, L., Seitz, A.R.: Benefits of multisensory learning. Trends Cogn. Sci. **12**(11), 411–417 (2008)
13. Smith, M.C.: Sensory integration: Theory and practice. FA Davis (2019)
14. Stien, N., Saeterbakken, A.H., Hermans, E., Vereide, V.A., Olsen, E., Andersen, V.: Comparison of climbing-specific strength and endurance between lead and boulder climbers. PLoS ONE **14**(9), e0222529 (2019)
15. Takahashi, I., Oki, M., Bourreau, B., Kitahara, I., Suzuki, K.: Futuregym: a gymnasium with interactive floor projection for children with special needs. Int. J. Child-Comput. Interact. **15**, 37–47 (2018)
16. Wilson, M.: Six views of embodied cognition. Psych. Bull. Rev. **9**, 625–636 (2002)