

SHORT COMMUNICATION

DO YOUTHS WITH NEUROMOTOR DISORDER AND THEIR THERAPISTS PREFER A MIXED OR VIRTUAL REALITY HEAD-MOUNTED DISPLAY?

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Objective: To evaluate the usability of 2 head-mounted displays in youths undergoing neurorehabilitation; a mixed reality head-mounted display and a virtual reality head-mounted display.

Design: Observational cross-sectional study.

Patients: Thirteen youths (age range 7.8–16.5 years) with neuromotor disorder.

Methods: Youths wore a mixed reality or a virtual reality head-mounted display while being verbally guided through a scene with virtual objects. Differences between the 2 systems, regarding usability, user experience, and acceptability, were evaluated using standardized questions for the youths and their therapists. System preferences and symptoms of cybersickness were noted.

Results: Both head-mounted displays were easy to mount and adjust to the children's heads, but the mixed reality system was unstable in 40% of the youths. Participants stated that they could move naturally with both devices. Object appearance scored higher with the virtual reality system, while therapists rated youths' movement execution and needed additional support in favour of the mixed reality system. Most youths preferred the virtual reality device, mainly due to the more distinct appearance of objects and the objects' richer colours. Therapists' preferences were balanced. Two children reported minimal signs of cybersickness.

Conclusion: Youths and therapists accepted both systems well, with advantages regarding usability, user experience, and preference for the virtual reality, and acceptability for the mixed reality head-mounted display.

Key words: rehabilitation; paediatric; feasibility study; virtual reality.

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LAY ABSTRACT

Many essential walking activities in daily life, such as crossing a street or stepping over an obstacle, can be challenging or tedious to practice in conventional rehabilitation settings. Extended reality applications can create a safe and attractive training environment; therefore we evaluated the usability of 2 head-mounted displays in children and adolescents with a neuromotor impairment. Thirteen youths used a mixed and a virtual reality head-mounted display and were verbally guided through a scene with virtual objects. Both headsets were easy to mount and adjust to the children's heads, but the mixed reality device was unstable in 40% of the youths. Most youths preferred the virtual reality device, mainly due to the more distinct appearance of objects. Therapists' preferences were balanced. Two children reported minimal signs of cybersickness. This study demonstrates the usability of head-mounted displays for youths undergoing rehabilitation, offering exciting possibilities for therapy and training in this field.

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Paediatric neurorehabilitation has shifted from improving body structures and functions towards promoting activities and participation (1, 2), and meaningful goals are defined by the rehabilitation team and the family together (3). Regarding walking, activities involving obstacles, public areas, and moving in a group are perceived as particularly meaningful by the families (manuscript submitted). However, therapies usually take place in a therapeutic environment, where these mentioned priorities can be practiced only to a limited extent.

Use of extended reality (XR) applications could be a solution to this problem. XR is an umbrella term describing immersive technologies that merge the physical and virtual worlds. These technologies extend the reality that we experience, either by integrating computer-generated objects in the physical world (mixed reality; MR), or by replicating an environment that simulates a physical presence in the virtual world, thus creating a fully immersive experience (virtual reality; VR) (4, 5). As XR systems have become more affordable in recent years, these technologies have become increasingly popular in the rehabilitation sector (5).

XR could be a promising extension for paediatric gait rehabilitation. By presenting virtual scenes to the child, the training of challenging, hazardous, or tedious walking activities could take place in a safe, yet attractive, environment. Individual adjustments would enable training tailored to the child's capabilities. The resemblance to computer games and the applications' playful characteristics might help to enhance children's active participation without being focused on the walking task (6). To date, studies that have reported promising results for therapeutic gait interventions with VR in children have mostly employed commercially available (video-)game systems, such as the Nintendo Wii (Nintendo, Kyoto, Japan) or Xbox Kinect (Microsoft, Redmond, USA) (7–9). These games are usually presented on 2-dimensional screens or as floor-projections, and lack essential aspects of VR, such as immersion, interaction, sensorimotor contingencies, and illusions (10).

Head-mounted displays (HMDs) provide a stereoscopic 3D-view, and many of these applications are mobile, which is especially advantageous for training walking activities (10). However, only a few studies have evaluated the feasibility and acceptability of HMDs in paediatric patients (11–14). Of these, only one study has pilot-tested the usability of a VR-HMD in a clinical setting, with 4 children with neuromotor impairment (14). Usability testing is crucial when implementing new health-related VR applications (15). Therefore, the aim of this study was to investigate the usability, user experience, and acceptability of 2 commercially available XR-HMDs in children undergoing inpatient neurorehabilitation. The results of this study should provide insight into whether XR is a suitable technology for paediatric neurorehabilitation and, if so, whether MR or VR is more appropriate for a mobile application in this patient population.

METHODS

This cross-sectional study was performed in the Swiss Children's Rehab (SCR) of the University Children's Hospital Zurich. Clarification of responsibility by the ethics committee of Canton

Zurich confirmed that approval was not needed (Req-2019-01161). Written informed consent was obtained from the legal representatives and the participating children and adolescents.

Study sample

Children and adolescents aged 6–18 years undergoing inpatient rehabilitation at the SCR who could walk with or without walking devices were eligible. The participants were selected on purpose to cover a broad range of ages, diagnoses, mobility levels, visual acuity levels, and cognitive and motor abilities to test the HMDs on a heterogeneous group. Exclusion criteria were: inability to follow verbal instructions, uncorrectable severe visual impairment, and history of seizures or taking anticonvulsant medication.

Procedures

The virtual test scene was developed in Unity (Unity Technologies, San Francisco, CA, USA) and consisted of several non-interactive objects that were placed in a 4×8-m area on the floor and in the air within a wide indoor room. The surface was even and there were no items with which to collide (**Fig. 1**). The children tested 1 MR-HMD, the Magic Leap 1 (Magic Leap,

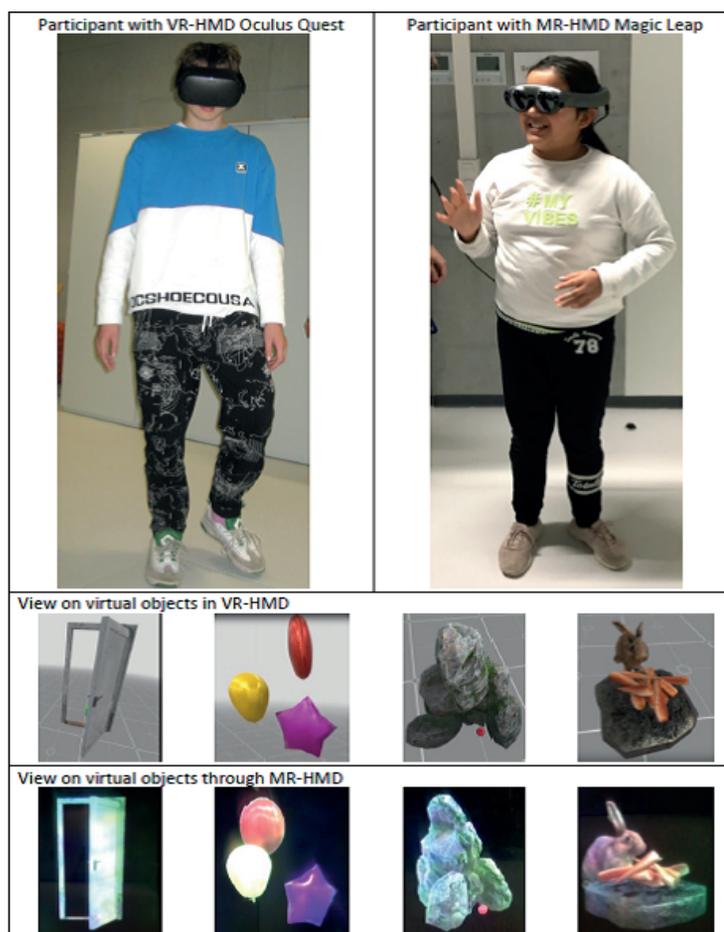


Fig. 1. Participants with extended reality-head-mounted displays (XR-HMDs), view on virtual test scene, and examples of virtual objects (view through XR-HMD). Note: the background through the mixed reality head-mounted display (MR-HMD) is usually not black, but shows the actual environment. Permission has been given to publish the photo from the patients.

Plantation, USA), and 1 VR-HMD, the Oculus Quest 1 (Facebook Technologies, Menlo Park, USA). Whilst wearing the MR-HMD, the room light was dimmed to increase the visual contrast of the virtual objects, which the participants saw embedded in the real environment of the test room. With the VR-HMD, the objects were situated in an empty virtual room with a grey floor featuring a white grid. Half of the participants tested the VR-HMD first, the others started with the MR-HMD. After the investigator had adjusted the HMD to the participants' heads and checked its optimal positioning, the children could explore the environment and perform short tasks that were verbally instructed by the investigator to ensure that the children were aware of all existing virtual objects. The objects' arrangement and the tasks should animate the participants to perform various movements, such as bending down or directing the head towards the ceiling. The tests lasted 5–10 min per HMD. A physiotherapist accompanied the participant to ensure safety and provide assistance if necessary.

Following each test, the investigator interviewed the participants using standardized questions and a visual analogue scale. Questions covered the comfort of the HMD, the participant's visual perception of the virtual objects, degree of immersion, and fun experienced while wearing the device. The detailed questions are presented in Fig. 2. Potential adverse events and symptoms of cybersickness were recorded using the Virtual Reality Sickness Questionnaire (VRSQ; 16).

To describe the participant's functional mobility in everyday life, the Gillette Functional Assessment Questionnaire walking scale (FAQ) and the Functional Mobility Scale (FMS) were rated by the physiotherapist (17). The FAQ quantifies a range of walking abilities in daily life, while the FMS complements the

information by assessing the assistive device used over 5, 50, and 500 m. In addition, the physiotherapist and the investigator answered short questionnaires on a 5-point Likert scale. While the therapist assessed aspects regarding the HMD's acceptability as a therapeutic tool for the child (movement quality, level of additional support, use of walking aids), the investigator judged the HMDs' adjustability and stability on the child's head (see Fig. 2).

Data analysis

Participants' characteristics are presented using descriptive statistics. Responses from the questionnaires, and potential differences between the 2 HMDs, are illustrated with frequencies, medians, and interquartile ranges (IQR). Because of the limited sample size and the heterogeneous study sample, effect sizes were calculated based on the z values of the non-parametric Wilcoxon rank sum tests and interpreted as $r > 0.1$ small, $r > 0.3$ moderate, and $r > 0.5$ large effect (18).

RESULTS

Thirteen children with a median age of 12.3 years (IQR 4.8) tested the 2 HMDs. All but one patient (ID8) could walk outdoors, at least for short distances ($FAQ \geq 6$). While 7 children walked independently over all distances without an assistive device ($FMS \geq 5$), 6 used walkers, crutches or needed supervision. Further characteristics are presented in Table I.

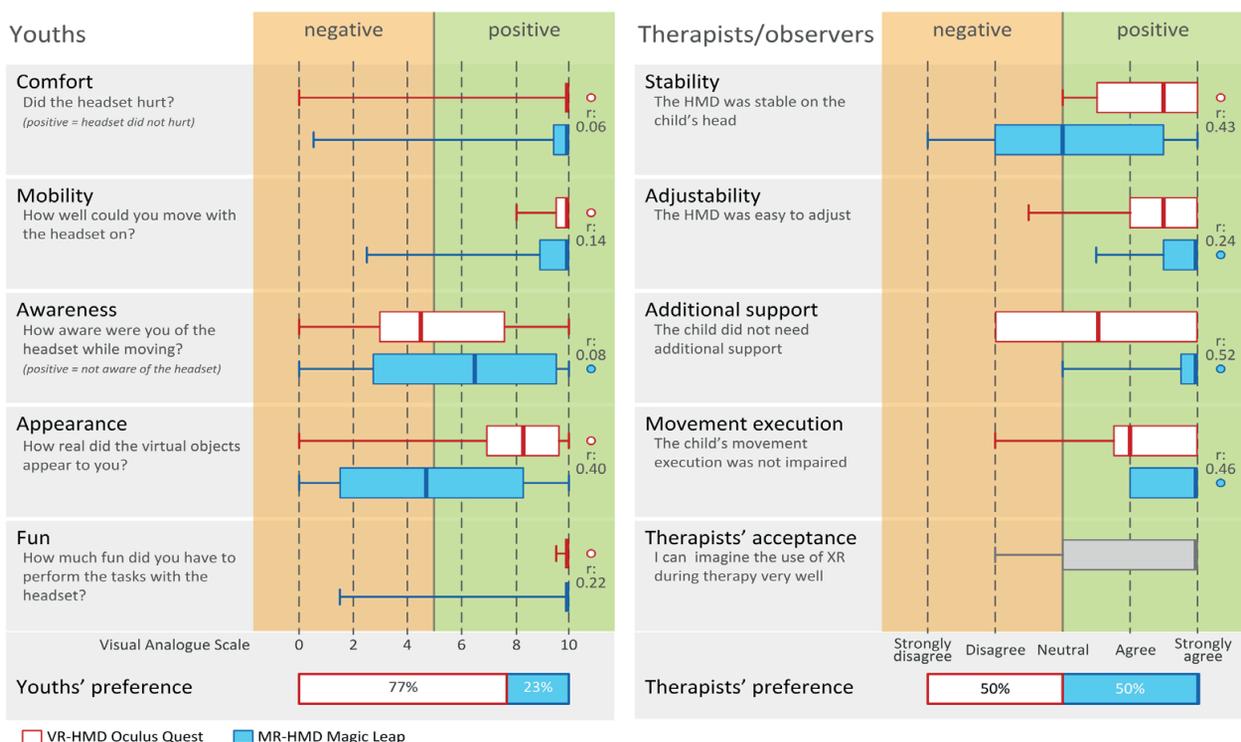


Fig. 2. Youths', therapists' and observers' ratings and effect sizes of various parameters regarding usability, user experience, and acceptability of the head-mounted displays (HMDs). Horizontal boxplots representing the median score (bold vertical line) and the interquartile range (box). The whiskers represent the minimum (left) and maximum (right) values. r: effect size, the position and colour of the circle indicates the effect's direction in favour of the virtual reality head-mounted display (VR-HMD) or the mixed reality head-mounted display (MR-HMD): $r > 0.1$ small, $r > 0.3$ moderate, and $r > 0.5$ large effect (18).

Table I. Descriptive characteristics of the study participants ($n = 13$)

| Participant | Sex | Age, years | Height, cm | Head circumference, cm | Diagnosis | Glasses | FMS | FAQ | Preference |
|-------------|-----|------------|------------|------------------------|---|---------|-------|-----|------------|
| 1 | F | 9.9 | 139 | 54.5 | TBI | Yes | 6/6/6 | 10 | MR |
| 2 | M | 10.1 | 129 | 50 | Unilateral spastic CP (I), post lower limb surgery | Yes | 4/2/1 | 6 | MR |
| 3 | M | 16.0 | 180 | 55 | Stroke | No | 6/6/6 | 10 | MR |
| 4 | F | 7.8 | 134 | 52.5 | Rhabdomyolysis | No | 4/4/4 | 6 | VR |
| 5 | M | 12.5 | 156.5 | 53 | Meningomyelocele | Yes | 3/3/3 | 7 | VR |
| 6 | F | 13.3 | 149.5 | 54 | Bilateral PFFD | Yes | 3/3/1 | 6 | VR |
| 7 | M | 16.5 | 185 | 56 | Unilateral spastic CP (I) | No | 6/6/6 | 10 | VR |
| 8 | F | 14.9 | 166 | 59 | CIDP | Yes | 1/1/1 | 4 | VR |
| 9 | M | 11.1 | 146 | 54 | Hypoxic ischaemic encephalopathy | No | 6/6/6 | 9 | VR |
| 10 | M | 12.3 | 152 | 50.5 | Bilateral spastic CP (II) | Yes | 5/5/5 | 8 | VR |
| 11 | F | 12.0 | 150 | 54 | TBI | No | 6/6/6 | 10 | VR |
| 12 | F | 15.5 | 169.5 | 54 | Scoliosis correction with spondylodesis T1-L4 | Yes | 5/5/5 | 7 | VR |
| 13 | M | 8.8 | 137 | 48 | Unilateral spastic CP (II), post lower limb surgery | No | 5/4/4 | 7 | VR |

*In children diagnosed with CP, the Gross Motor Classification System is given in parentheses. F: female; M: male; TBI: traumatic brain injury; CP: cerebral palsy; PFFD: proximal femoral focal deficiency; CIDP: chronic inflammatory demyelinating polyradiculoneuropathy; FMS: Functional Mobility Scale 5/50/500 m (17); FAQ: Gillette Functional Assessment Questionnaire – walking scale (17), MR: mixed reality; VR: virtual reality.

During testing, 12 children were supervised by their physiotherapist. While it would have been possible to wear glasses under the VR-HMD, most of the 7 children wearing glasses tested the HMDs without their glasses. None of them had any problems recognizing the objects or moving around. Concerning the VRSQ, 1 child (ID11) reported minimal dizziness during the VR-session, and 1 adolescent (ID6) had a minor headache directly afterwards. The same adolescent mentioned slight difficulties with visual acuity after using the MR-HMD, which resolved within 1 min. Apart from that, no side-effects occurred.

Ratings regarding the HMDs' usability, user experience, acceptability, and corresponding effect sizes are shown in Fig. 2.

Usability

Both HMDs were easy to mount and adjust to the children's heads, but the MR-HMD was unstable and slipped around on the head of 5 participants when they moved ($r=0.41$).

User experience

Participants reported tremendous fun with both systems. Although they tended to be aware of wearing the HMDs, they stated that the devices did not hurt and that they could move naturally while wearing them. Object appearance scored higher with the VR than with the MR system ($r=0.4$). Five youths reported that the small field of view of the MR-HMD was annoying because they could not entirely see close objects without constantly moving their head. Three participants found it somewhat strange not to see their own body when wearing the VR-HMD.

Acceptability

According to the therapists, the MR-HMD did not affect children's movement execution, while the VR-HMD might have influenced the movements of 3 children ($r=0.46$). Moreover, the required level of additional

support was rated higher in some children with the VR-HMD ($r=0.52$). This support consisted mainly of close supervision, as some therapists were not sure how safe the child would be moving with the VR device. Therapists' general acceptance of XR in therapy was high. For only 2 children did the therapists consider XR applications not a clinically useful addition to conventional physiotherapy.

Preferences

Ten participants favoured the VR-HMD, mainly due to the objects' more distinct appearance and richer colours, the broader field of view, and higher immersion. Visibility of their own body and the real environment was the reason for preferring the MR-HMD in the remaining 3 participants.

Therapists' preferences between VR-HMD and MR-HMD for their patients were balanced. Reasons supporting the use of the MR-HMD were: safer walking, no additional support needed, better orientation in space, and closer to reality. Reasons for supporting the use of the VR-HMD were: higher enthusiasm, motivation and immersion, less distraction, more courageous and versatile movements, and the large field of view without constantly having to move the head.

DISCUSSION

This study assessed the suitability of an MR-HMD and a VR-HMD application as a training tool for everyday life walking activities in children undergoing inpatient neuro-rehabilitation. While both devices were well accepted by the patients and their therapists, the VR-HMD scored higher regarding aspects of usability and user experience and was preferred by the majority of the youths, whereas therapists' acceptability ratings favoured the MR-HMD.

Although most HMD manufacturers do not recommend using their product before the age of 12 or 13 years, these recommendations are not based on empirical evidence (19). While we know of no other study in the paediatric field that has involved MR-HMDs, limited research exists on the feasibility of VR-HMDs, all of which supports our findings:

a recent study evaluated 3 different VR-HMDs in children with autism. The 6- to 16-year-olds reported the HMDs as enjoyable, physically and visually comfortable, easy to use, and exciting (6). Children with upper limb injuries undergoing one therapy session with a VR-HMD reported that they enjoyed this session more, and that movement was easier and less painful than in their usual therapy sessions. Their therapists perceived VR-HMD as useful and adaptable to individual patient's needs (11). Two youth with spina bifida performing a 4-week home exercise programme using a VR-HMD expressed high levels of enjoyment over the whole training period (13). Otherwise, VR-HMDs were used primarily as a tool for pain distraction, assessment, cognitive training, measurement (e.g. attention pattern, performance on cognitive tasks), or education (12, 14, 20, 21).

The current study has several limitations. The study sample was small, thus precluding statistical analyses and generalizations. Only one example of a VR-HMD and an MR-HMD were tested. Children wore each HMD for only 5–10 min, and interactions with virtual objects were impossible. Nevertheless, this study showed that the acceptance towards XR-HMDs was very high from both children and therapists, with advantages regarding the usability, user experience, and preference for the VR-HMD. We found this superiority quite surprising, as patients with neuromotor disorder may often exhibit sensory impairments and rely more on visual feedback, which is precluded by the VR-HMD.

Future research should integrate the possibility of interacting with the virtual world and a virtual representation of body parts in VR, as such features contribute strongly to an improved XR experience (10). Further studies could also objectify whether children's movement quality while wearing XR-HMDs is comparable to their movements in everyday life, whether potential skill acquisitions in XR are transferred to the real world, and the influence of XR-HMDs on children's motivation in therapy.

This study demonstrates the usability, user experience, and acceptability of XR-HMDs in paediatric neurorehabilitation, which offers promising options for therapy and training of everyday life activities within a therapeutic setting.

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The authors have no conflicts of interest to declare.

REFERENCES

1. Law M, Darrah J. Emerging therapy approaches: an emphasis on function. *J Child Neurol* 2014; 29: 1101–1107.
2. Rosenbaum P, Gorter JW. The "F-words" in childhood disability: I swear this is how we should think. *Child Care Health Dev* 2012; 38: 457–463.
3. Rast FM, Labruyère R. ICF mobility and self-care goals of children in inpatient rehabilitation. *Dev Med Child Neurol* 2020; 62: 483–488.
4. Giglioli IAC, Bermejo Vidal C, Alcañiz Raya M. A virtual versus an augmented reality cooking task based-tools: a behavioral and physiological study on the assessment of executive functions. *Front Psychol* 2019; 10: 1–12.
5. Cipresso P, Giglioli IAC, Raya MA, Riva G. The past, present, and future of virtual and augmented reality research: a network and cluster analysis of the literature. *Front Psychol* 2018; 9: 1–20.
6. Newbutt N, Bradley R, Conley I. Using virtual reality head-mounted displays in schools with autistic children: views, experiences, and future directions. *Cyberpsychology, Behav Soc Netw* 2020; 23: 23–33.
7. Ravi DK, Kumar N, Singhi P. Effectiveness of virtual reality rehabilitation for children and adolescents with cerebral palsy: an updated evidence-based systematic review. *Physiother (UK). The Chartered Society of Physiotherapy* 2017; 103: 245–258.
8. Chen Y, Fanchiang HD, Howard A. Effectiveness of virtual reality in children with cerebral palsy: a systematic review and meta-analysis of randomized controlled trials. *J Phys Ther* 2018; 98: 63–77.
9. Rutkowski S, Kiper P, Cacciante L, Cieślík B, Mazurek J, Turolla A, et al. Use of virtual reality-based training in different fields of rehabilitation: A systematic review and meta-analysis. *J Rehabil Med* 2020; 52: jrm00121.
10. Perez-Marcos D. Virtual reality experiences, embodiment, videogames and their dimensions in neurorehabilitation. *J Neuroeng Rehabil* 2018; 15: 1–8.
11. Phelan I, Furness PJ, Dunn HD, Carrion-Plaza A, Matsangidou M, Dimitri P, et al. Immersive virtual reality in children with upper limb injuries: findings from a feasibility study. *J Pediatr Rehabil Med*. 2021; 14: 401–414.
12. Tennant M, McGillivray J, Youssef GJ, McCarthy MC, Clark TJ. Feasibility, acceptability, and clinical implementation of an immersive virtual reality intervention to address psychological well-being in children and adolescents with cancer. *J Pediatr Oncol Nurs* 2020; 37: 265–277.
13. Lai B, Davis D, Narasaki-Jara M, Hopson B, Powell D, Gowey M, et al. Feasibility of a commercially available virtual reality system to achieve exercise guidelines in youth with spina bifida: mixed methods case study. *JMIR Serious Games* 2020; 8: e20667.
14. Shen J, Xiang H, Luna J, Grishchenko A, Patterson J, Strouse RV, et al. Virtual reality-based executive function rehabilitation system for children with traumatic brain injury: design and usability study. *JMIR Serious Games* 2020; 8: e16947.
15. Zhang T, Booth R, Royce JL, Chan R, Yeung A, Gratzer D, et al. A primer on usability assessment approaches for health-related applications of virtual reality. *JMIR Serious Games* 2020; 8: e18153.
16. Kim HK, Park J, Choi Y, Choe M. Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment. *Appl Ergon* 2018; 69: 66–73.
17. Ammann-Reiffer C, Bastiaenen CHG, Klöti C, van Hedel HJA. Concurrent validity of two gait performance measures in children with neuromotor disorders. *Phys Occup Ther Pediatr* 2019; 39: 181–192.
18. Fritz CO, Morris PE, Richler JJ. Effect size estimates: current use, calculations, and interpretation. *J Exp Psychol Gen* 2012; 141: 2–18.
19. Aubrey JS, Robb MB, Bailey J, Bailenson J. *Virtual reality 101: what you need to know about kids and VR*. San Francisco: Common Sense; 2018.
20. Morrongiello BA, Seasons M, McAuley K, Koutsoulianos S. Child pedestrian behaviors: Influence of peer social norms and correspondence between self-reports and crossing behaviors. *J Safety Res Elsevier Ltd and National Safety Council*; 2019; 68: 197–201.
21. Bailey JO, Bailenson JN. Immersive virtual reality and the developing child. In: Blumberg FC, Brooks PJ, editors. *Cognitive development in digital contexts*. San Diego: Elsevier Inc.; 2018, p. 181–200.