“Wii-Hab” in critically ill children: A pilot trial

Farah Abdulsatar, Rachel G. Walker, Brian W. Timmons and Karen Choong

Child Health and Exercise Medicine Program, McMaster University, Hamilton, ON, Canada
Department of Pediatrics, McMaster University, Hamilton, ON, Canada
Department of Critical Care, McMaster University, Hamilton, ON, Canada
Department of Clinical Epidemiology and Biostatistics, McMaster University, Hamilton, ON, Canada

Accepted 5 November 2013

Abstract.

PURPOSE: To evaluate the safety and feasibility of virtual reality (VR) exercise as a novel acute rehabilitation intervention in a Pediatric Critical Care Unit (PCCU) setting.

METHODS: Children aged 3–18 years with an anticipated PCCU stay > 48 hours, and baseline normal to moderate cognitive and functional disability were eligible. Exclusion criteria included: anticipated death, physical inability, or a contraindication to mobilization. Nintendo Wii Boxing was prescribed for a minimum of 10 minutes twice a day for 2 days. Primary outcomes were feasibility and safety.

RESULTS: Of 21 eligible patients, 12 (57.1%) were enrolled and 8 completed the study. 41.7% (5/12) were males, and the median age was 11 (3, 16) years. Four of the 8 participants who received the intervention were mechanically ventilated during Wii play. Participants used the Wii a median of 2 times (1, 5) over the 2-day intervention period, for a median total duration of 54.5 (15, 224) minutes. There were no adverse events attributable to the intervention. Upper limb activity during Wii was significantly greater than the average daily activity (p = 0.049). Grip strength did not change significantly from baseline (p = 0.20).

CONCLUSION: While the results of this pilot trial suggest that VR exercise may be safely applied in a subset of critically ill children, we observed several threats to its feasibility in this population.

Keywords: Pediatrics, critical care, acute rehabilitation, virtual reality gaming

1. Introduction

Patients with critical illness are often bed-ridden for prolonged periods of time due to perceived comfort, safety, and maintenance of cardiorespiratory stability. As a result, immobility and deep sedation are common prescriptions in pediatric critical care units (PCCU) [1]. The care of these patients has primarily been focused on resuscitation and reversal of acute organ failure, with little attention paid to the prevention of weakness and neuromuscular dysfunction, and enhancement of recovery during critical illness [2]. Intensive Care Unit-acquired weakness (ICU-AW) is a common and important sequelae of prolonged bedrest and immobility in the critically ill population. Affecting up to 60% of critically ill adults [3,4], ICU-AW contributes to significant morbidity, hospital length of stay, and mortality, and adversely affects the long-term functional outcomes and quality-of-life in survivors of critical illness and their caregivers [5–7]. While the evidence in pediatrics is limited, ICU-AW has also been linked to mechanical ventilator dependence, prolonged hospitalization, and persistent neuromuscular weakness in this population [7]. Prolonged immobility and ICU-AW have been implicated as risk factors for
poor neurocognitive and functional recovery in these children [8].

Accumulating evidence suggests that acute rehabilitation implemented while still in the ICU in critically ill adults is safe, feasible, cost effective, and improves short-term patient outcomes [9–11]. In contrast, there is a paucity of this research in pediatrics. While immobilization has been implicated as an important contributing factor to morbidity and adverse functional, cognitive, and quality-of-life outcomes, the safety and efficacy of acute rehabilitation has yet to be systematically evaluated in critically ill children. Furthermore, there are numerous actual and perceived challenges to applying rehabilitation interventions in the PCCU environment given the nature of underlying illnesses and diversity in functional and cognitive abilities [12]. Hence, novel approaches to enhance physical activity in this population need to be evaluated. Current evidence suggests that interactive virtual reality (VR) exercise results in physiological and energy expenditure responses similar to traditional forms of physical activity [13]. Furthermore, this modality of promoting physical activity is popular amongst children and their peers, and can elicit better compliance than traditional, structured exercise [14]. We therefore hypothesized that VR exercise may be a novel method of complementing rehabilitation in the PCCU setting. The primary objective of this pilot trial was to evaluate the feasibility and safety of VR exercise as a means of acute rehabilitation in critically ill children.

2. Methods

2.1. Study design and participants

This prospective clinical trial was approved by the Hamilton Health Sciences/Faculty of Health Sciences Research Ethics Board and conducted in the PCCU at McMaster Children’s Hospital. Consecutive patients aged 3 to 18 years admitted to the PCCU with an anticipated length of stay of greater than 48 hours were eligible. Exclusion criteria were as follows: anticipated death or withholding life-sustaining therapy, physical inability to mobilize (e.g. secondary to upper limb surgery), cardio-respiratory instability, language barrier, and inability to comprehend instructions or perform the intervention (i.e. deep sedation, and/or severe cognitive or functional disability, as defined by poor pediatric overall performance (POPC) and pediatric cerebral performance (PCPC) category scores of ≥ 4) [15]. Informed consent and assent where appropriate were obtained prior to patient enrolment. The primary outcomes of interest were feasibility and safety. Feasibility was defined as the ability to enroll participants over an 8-month study period, implement the intervention and study procedures, and adhere to the research protocol. Safety was evaluated by the adverse event rate (defined below). Secondary outcomes included upper limb activity during the intervention compared to the rest of the day, muscle strength during the study period, and caregiver and participant satisfaction with the intervention. Hand-grip strength is a recommended objective tool for screening and monitoring ICU-AW in adults, but has not been validated in critically ill children [16]. We therefore assessed the feasibility of conducting this measurement in the population.

2.2. Study intervention

Nintendo Wii™ Boxing (hereafter referred to as Wii™) was the specific VR intervention chosen for this trial. Wii™ Boxing encourages antigravity-movement of the upper limbs, requires minimal manual dexterity, and can be used in a recumbent position, making it suitable for our target population. One of the investigators (FA) set up the Wii™ for each participant at each intervention period, and instructed the caregivers on its use. The schema for the study period and measurements are outlined in Fig. 1. Following enrollment, each participant was prescribed Wii™ play for a minimum of 10 minutes, twice a day for a maximum of two days. However, participants were allowed to play longer and/or more frequently if they desired. For voluntary Wii™-play times outside of the prescribed intervention periods, the participant had the option of playing other game choices from the Wii™ Sport pack. Caregivers were asked to record the frequency and duration of each Wii™ play period in an activity diary.

2.3. Measurements

In order to compare upper-limb activity during the short intervention period to non-intervention periods during the rest of the day, we measured upper-limb movement using accelerometers, a validated method for measuring physical activity in children [17]. We attached Actigraph GT3X accelerometers to both wrists of each participant to measure upper-limb movement over the entire study period. Activity counts were recorded in 3-s sampling intervals (i.e., epochs; time
period over which activity counts recorded by the accelerometer are summed) and data were downloaded and processed at the end of the study period according to standard procedures previously described by our group [18]. Rather than transforming activity counts into energy expenditure, we reported raw counts as an indication of upper-limb movement. Hand-grip strength was measured by the investigator (FA) at baseline and daily during the study period, using the Grip-A Dynamometer™ or the Martin Vigorimeter as appropriate for patient size [19].

Baseline demographic data and patient outcomes were collected on standardized case report forms by the investigators (FA, RGW). Severity of illness was measured using validated pediatric scoring tools (the Pediatric risk of mortality (PRISM III)) [20]. The Pediatric logistic organ dysfunction (PELOD) [21], the Pediatric Cerebral Performance Category (PCPC), and the Pediatric Overall Performance Category (POPC) scores on admission were used to quantify cognitive and functional ability of each patient at baseline [22]. Physiologic measurements (heart rate, blood pressure, respiratory rate, and oxygen saturation) were recorded at baseline, during, and after the intervention by the bedside nurse. However, data recorded during the intervention was only available for 3 patients. Adverse events were defined as the occurrence of any of the following during the intervention: accidental tube dislodgment, musculoskeletal injury, pain or discomfort (requiring more than the usual patient’s sedation/analgesia), arrhythmia, persistent tachycardia, hypo- or hypertension, or tachypnea for age, increased work of breathing, and fall in oxygen saturation to < 85%. The relationship between adverse events and the intervention was ascertained by the bedside nurse and/or physician of the participant. At the end of the study period, the parents and/or caregivers were asked to indicate their perception of the intervention on a self-administered questionnaire, which included a 7-point Likert Scale and a section for optional commentary.

2.4. Statistical analyses

Given our feasibility objectives, we did not specify a sample size apriori; rather, we planned to evaluate the number of participants enrolled over an eight-month study period [23]. Descriptive summaries were used to present baseline patient demographics. Categorical data are reported as percentages and continuous data as a mean (standard deviation [SD]) or median (minimum [min], maximum [max]) where appropriate. The Student’s matched pair t-test was used to compare cardiorespiratory parameters at baseline and post Wii™ play, and upper limb activity counts during Wii™ play and the remainder of the day. One-way repeated measures ANOVA was used to compare hand-grip strength over the study period. Spearman’s ρ was used to explore the correlation between Wii™ play time, severity of illness, and caregiver perception of the intervention respectively. All statistical analyses were conducted using SPSS Version 18 (www.SPSS.com) and statistical significance was set at p ≤ 0.05. All presented p-values are two-tailed.

3. Results

This trial was conducted from January to August 2010. Of 140 patients screened, 100 met exclusion cri-
teria, 21 were approached for consent, and 12 (57.1%) consented to participate and were enrolled in the trial (Fig. 2). Table 1 presents the baseline demographics for each participant. There were 5 (41.7%) males and the median age was 11 (3, 16) years. Median PRISM III score on admission was 9.5 (0, 21), and the median PCPC and POPC scores were 1 (1, 2) and 1 (1, 3), respectively.

Four of the 12 enrolled participants did not receive the intervention (Participants No. 9–12, Table 1): 3 were discharged prior to receiving the intervention, and 1 withdrew due to dislike for the accelerometer. The measurements are therefore presented for the 8 participants who actually received the intervention, unless otherwise indicated. Four (50%) of the 8 participants who received the intervention were mechanically ventilated during the intervention. The median time from PCCU admission to start of the intervention was 9.5 days (1, 56). Participants played Wii\textsuperscript{TM} for a median of 25 (8,120) minutes per day, and a total of 54.5 (15, 224) minutes over the 2 days. One participant played both Wii\textsuperscript{TM} boxing and bowling games, while the remainder played only Wii\textsuperscript{TM} boxing. Two (25%) of 8 patients met or exceeded the exercise prescription. Reasons that the exercise prescription was not met for the remaining 6 patients are outlined in Fig. 2. With respect to clinical outcomes, the median PCCU and hospital length of stay was 14 (16, 66) and 23.5 (6, 85) days respectively. There was a significant worsening in participant’s POPC scores from baseline (1 ± 1) to PCCU discharge (2 ± 1) (mean ± SD change of 1.08 ± 1.00, p = 0.02), whereas the PCPC score was unchanged from baseline to discharge.

3.1. Upper limb activity and muscle strength

Mean upper-limb activity was significantly greater during Wii\textsuperscript{TM} play as compared to activity during the remainder of the day when not playing Wii\textsuperscript{TM} (57.12
Table 1
Participant demographics

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (years)</th>
<th>Sex (M/F)</th>
<th>PCCU admission diagnosis</th>
<th>PRISM III</th>
<th>Baseline PCPC</th>
<th>Baseline POPC</th>
<th>Mechanically ventilated during intervention</th>
<th>Time from PCCU admission to intervention (days)</th>
<th>Total number of Wii™ play times</th>
<th>Total duration of Wii™ play time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>M</td>
<td>Scoliosis surgery</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>No</td>
<td>14</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>F</td>
<td>Transverse myelitis</td>
<td>21</td>
<td>1</td>
<td>1</td>
<td>Yes</td>
<td>56</td>
<td>5</td>
<td>157</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>F</td>
<td>Septic shock</td>
<td>18</td>
<td>1</td>
<td>1</td>
<td>Yes</td>
<td>10</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>M</td>
<td>Diabetic ketoacidosis</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>No</td>
<td>9</td>
<td>4</td>
<td>224</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>M</td>
<td>Propionic acidemia with cardiomyopathy</td>
<td>12</td>
<td>2</td>
<td>3</td>
<td>No</td>
<td>1</td>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>F</td>
<td>Septic shock</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>Yes</td>
<td>19</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>M</td>
<td>Empyema</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>Yes</td>
<td>3</td>
<td>2</td>
<td>77</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>M</td>
<td>Prolonged QT syndrome and cardiac arrest</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>No</td>
<td>4</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>11</td>
<td>F</td>
<td>Epiglottitis</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>F</td>
<td>Diabetic ketoacidosis</td>
<td>13</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>F</td>
<td>Asthma exacerbation</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>12</td>
<td>3</td>
<td>F</td>
<td>Neuroblastoma</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

*M, Male; †F, female; ‡PRISM III, Pediatric Risk of Mortality III score, assessment range 0–74, with higher scores indicating a greater risk of death [20]; §PCPC, Pediatric Cerebral Performance Category; ¶POPC, Pediatric Overall Performance Category; (assessment range for POPC and PCPC scores 1–7, with higher scores indicating greater disability, e.g. 1 = normal vs. 7 = cardiopulmonary death) [22]; NA, Not applicable, intervention not applied; PCCU, Pediatric Critical Care Unit.

Fig. 3. Comparison of upper limb activity during Wii™ play-time and the rest of the day for participants who received the intervention ($n = 8$). Upper limb activity expressed as a fold difference in average activity counts during Wii™ play-time compared to activity counts during the rest of the day.

± 46.60 vs. 9.36 ± 4.12 counts, $p = 0.049$, $n = 8$.

Figure 3 displays the ratio of average upper-limb activity counts during Wii™ play-time to the remainder of the day. There was a median 5-fold higher upper-limb activity during Wii™ play-time as compared to the activity during the remainder of the day. There was no significant difference in grip strength on days 2, 3, or 4, represented as a percentage of baseline values ($F(3,18) = 1.71, p = 0.20, n = 7$). Average grip strength over days 2, 3, and 4 was $51.3 \pm 102.1\%$ of baseline. The mean ± SD for the change in grip strength was $40.4 \pm 75.9\%$ on day 2, $2.70 \pm 116.4\%$ on day 3, and $60.8 \pm 114.4\%$ on day 4.

3.2. Physiologic and safety outcomes

The mean ± SD baseline vital sign measurements were as follows: heart rate $103 \pm 18$ beats per min, respiratory rate $30 \pm 13$ breaths per min, mean blood pressure $68 \pm 32$, and $\text{SPO}_2$ $96 \pm 1\%$. There were no statistical differences in any of these physiological measurements post Wii™ play as compared to baseline (Table 2). There were no accidental tube dislodgements, reported changes in pain or sedation requirements, or other adverse events during the study period.

3.3. Caregiver feedback

The response rate for the questionnaire was $75\%$ (6/8). The mean (SD) scores out of a total of 7 for the caregiver perception of the intervention were $5.7 \pm$
Table 2
Vital sign measurements of the 8 participants at baseline and following Wiı™ play

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Post-intervention</th>
<th>Change (mean ± SD)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median (min, max)</td>
<td>108 (64,123)</td>
<td>103 (69, 138)</td>
<td>2.57 ± 14.47</td>
<td>0.65</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>103 ± 18</td>
<td>103 ± 22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory rate (breaths/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median (min, max)</td>
<td>30 (9, 50)</td>
<td>28 (13, 38)</td>
<td>-0.14 ± 10.96</td>
<td>0.97</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>30 ± 13</td>
<td>29 ± 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean blood pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median (min, max)</td>
<td>74 (63, 99)</td>
<td>75 (65, 96)</td>
<td>-0.33 ± 2.52</td>
<td>0.84</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>68 ± 32</td>
<td>78 ± 13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPO₂ (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median (min, max)</td>
<td>96 (94,98)</td>
<td>98 (94,100)</td>
<td>1.29 ± 1.50</td>
<td>0.06</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>96 ± 1</td>
<td>98 ± 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p value for difference between Baseline and Post-intervention, calculated via Student’s matched pair t-test; ¹SPO₂, oxygen saturation measured by pulse oxymetry.

Table 3
Comments from the parent/caregiver satisfaction questionnaire

<table>
<thead>
<tr>
<th>Participant</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>“I wish that he wasn’t on so much medication for pain which inhibited his drive to want to play. Other than that I think this is a great idea. I think it helped him with his own feeding by arm strengthening.”</td>
</tr>
<tr>
<td>2</td>
<td>“Thank you for bringing it she really enjoyed it.”</td>
</tr>
<tr>
<td>3</td>
<td>“I think the main reason she didn’t want to do the Wii was that the game didn’t appeal to her (she was more motivated by Dora). She was also quite resistant to any activity, not just this one.”</td>
</tr>
<tr>
<td>4</td>
<td>“This activity really helped with soreness and stiffness from inactivity. Physically, it loosened up stiff and sore muscles and mentally took his mind off of what was happening and even brought on some smiles. It helped all around, not just physically.”</td>
</tr>
<tr>
<td>5</td>
<td>Participant: “it was hard at first but then it got easier. The game was kind of boring.”</td>
</tr>
<tr>
<td>6</td>
<td>“Answer was neutral [for satisfaction] because he was having a ‘bad day’ and did not play as much as he would have. Ordinarily, he would ‘LOVE’ Wii and would have played a lot. Also, he had visitors and they provided emotional support rather than Wii.”</td>
</tr>
</tbody>
</table>

Fig. 4. Caregiver impression of the Wii™ intervention for participants who received the intervention (n = 8). Data are presented as mean (SD) score for each item in the questionnaire. Parent rating is based on a Likert scale from 1 to 7, with 1 representing “strongly dissatisfied” or “strongly disagree” and 7 representing “very satisfied” or “strongly agree.”

1.8) for enjoyment, 6.9 (± 0.4) for their impression of whether the intervention was safe, and 5.3 (± 1.8) for potential benefit provided to their child (Fig. 4).

Fig. 5. Intubated, mechanically ventilated patient during Wiı™ play. (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/PRM-140260)

We found a strong correlation (ρ = 0.86, p = 0.02) between the total Wii™ play-time and caregiver perception of the child’s enjoyment with the intervention. A weaker correlation (ρ = 0.73, p = 0.07) was observed between total Wii™ play-time and perception.
of benefit. There was no correlation between severity of illness (PRISM III score) and total Wii™ playtime ($\rho = 0.07, p = 0.88$). Table 3 presents some of the comments recorded in the questionnaire. Figure 5 depicts an intubated, mechanically ventilated patient while playing Wii™.

4. Discussion

Improved mortality amongst adults with critical illness has increased the prevalence of the “post-intensive care syndrome,” a phenomenon of acquired functional, cognitive, and mental health sequela observed amongst survivors [24]. Long-term sequelae ranging from significant functional disability to neuropsychological impairments can be seen in up to 69% of survivors of critical illness, resulting in significant economic burden to patients and the health care system [25,26]. While there is a paucity of evidence in pediatrics, it is recognized that children can also suffer neurocognitive and functional morbidity following critical illness [27], which in turn can negatively impact school performance, their quality of life, and that of their caregivers [22]. Prolonged immobility and ICU-AW have been implicated as risk factors for poor functional recovery in these children [8]. Subsequently, there is growing interest in preventing these significant short- and long-term critical illness related morbidities. Emerging research focused on acute ICU-based rehabilitation in adults suggests that early mobilization can improve ICU outcomes and recovery following discharge [28]. In contrast, there is very little research amongst children [29].

In recent years, VR technologies such as Wii™ have been employed in the physical rehabilitation of patients. In addition to being novel and enjoyable, VR exercise applies relevant concepts of rehabilitation (i.e., multiple repetitions, varying intensities, and task-oriented training of the extremities) [30]. VR exercise has been demonstrated to be safe and potentially effective in the rehabilitation of adult stroke patients [31] and in children with developmental delay and cerebral palsy [32]. It is an attractive means of encouraging physical activity amongst children as it is fun, popular amongst their peers, can be used by those who are not accustomed to playing video games, and can engage participants in vigorous exercise without perceiving the activity to be difficult [33]. However, while the use of gaming systems by health care providers is increasing, there is still limited research on their potential therapeutic benefits [34]. Furthermore, VR games are not without risks, as injuries associated with recreational (i.e., non-rehabilitation) Wii™ use have been reported [35]. The use of VR games as an adjunctive rehabilitation technique in the critically ill population has not been adequately researched.

Wii™ use during physical therapy has been reported in a case series of 22 critically ill adults [36], however our prospective study is the first, to our knowledge, to evaluate the feasibility of VR gaming as an acute rehabilitation technique in critically ill children. In our small sample of participants, the brief 10-minute per session prescription for VR exercise appeared to be safe, and resulted in a significant increase in upper-limb activity during the intervention, when compared to non-intervention periods of the day. The patient’s participation with the VR intervention correlated with their enjoyment of the game.

We observed the following threats to feasibility in this study. The enrollment rate was slower than anticipated, primarily due to the limited availability of research staff. As the focus of this pilot study was safety, patient stability and physician comfort with the intervention had to be fulfilled. These factors and the requirement of participants to understand the intervention led to a small selection of patients who ultimately fulfilled all eligibility criteria. Subsequently, the time from PCU admission to intervention may not necessarily be considered “early”, although what defines early mobilization in the critically ill population is currently debated in the literature [28,37]. The majority (75%) of patients did not complete the full 2-day intervention due to excessive sedation, transfer from PCU, or inability to comply with the intervention. This speaks to the narrow patient selection and timeliness of this type of intervention amongst critically ill children; by the time these patients are perceived to be stable enough to participate, they may be close to being discharged from the PCU. Nevertheless, it is important to emphasise that we were able to apply the intervention in 4 of the 8 participants while they were mechanically ventilated, in whom methods to enhance active physical activity are limited. Furthermore, we were also able to apply the intervention in patients who, due to their critical illness, experienced a deterioration in their baseline functional ability. The challenges that we experienced in conducting this trial in a critically ill pediatric population are not unique and have previously been identified [38], and can serve to inform future research design and efforts.

We assessed primarily one type of VR game in this pilot trial, which, based on the feedback from the ques-
tionnaire, appears to have influenced the degree of participation. Wii Sport Boxing™ can elicit a moderate to vigorous aerobic response, and enable healthy young adults to meet the recommended daily physical activity levels [33]. The VR game used in this trial was not specifically designed for rehabilitation; Wii Sport Boxing™ encourages primarily upper limb movement in bed-ridden patients. Furthermore, this game choice clearly does not appeal to all children. These are important factors to consider not only in the design of future studies of this nature, but also in the evaluation of factors that influence compliance with a rehabilitation intervention amongst participants and providers. Anxiety and enjoyment have been identified as factors that can influence motivation [39]. As such, we observed a correlation in this trial between enjoyment and compliance with the intervention. Conversely, if the child is disinterested, or the benefits are not perceived, they are less likely to adhere to the intervention [40]. While we did not find a correlation between severity of illness and duration of Wii™ play, we did observe a correlation between enjoyment with the game and duration of play. Hence, the variability in total Wii™ play duration in this cohort may indeed have been influenced by enjoyment and perception of benefit. We did not observe any overall change in grip-strength in this study, a secondary clinical outcome objective. While dynamometry is a reliable, rapid, and simple method of manual muscle testing, which may overcome some of the limitations of the Medical Research Council scale, both of these are volitional tests that are affected by a patient’s wakefulness, attention, and motivation [41, 42]. Our data suggest that while this method is suggested as a simple screening test for ICU-AW, its utility and validity in PCCU patients requires further study.

Whether acute rehabilitation in critically ill children can prevent adverse sequelae of immobility and improved functional recovery in these patients is an area ripe for research. While rehabilitation should ideally be operationalized by physiotherapists who can apply therapies specific to the patients’ needs and monitor individual patient progress, this is not feasible in many PCCUs given resource limitations [43]. Hence, complementary treatments to physiotherapy that other caregivers can facilitate may be of benefit. There are multiple unique challenges to operationalizing rehabilitation strategies in critically ill children, some of which were identified in this trial. First, it remains unclear which patients are at highest risk of morbidity and hence may benefit most from such interventions. Second, the majority of children admitted to PCCU have complex chronic conditions, and heterogenous baseline cognitive and function abilities [44]. Subsequently, some of the exercise interventions currently used in critically ill adults may not be applicable in this population. Third, while adult ICU studies have identified that exercise is safe, feasible, and improves clinical outcome, the timing, nature, and efficacy of acute rehabilitation in the PCCU is uncertain. Novel rehabilitation techniques that are safe and effective, yet engaging and enjoyable – specifically in the pediatric population – may encourage participation, self-efficacy, and caregiver and provider buy-in, which was the rationale for considering the use of VR exercise to enhance rehabilitation in the PCCU setting. Furthermore, VR exercise is inexpensive (current retail cost of $99.99 per unit), does not require specialized resources or personnel to implement, and can be used in the inpatient and outpatient settings. As the benefits of combining VR exercise and rehabilitation are increasingly recognized, this technology may find a role as a complement to physical therapy in critically ill children. However, further research is needed to evaluate the impact and cost effectiveness of VR exercise as a rehabilitation strategy in this population.

5. Conclusion

Research on acute rehabilitation in critically ill children is in its infancy. While VR gaming has been used effectively in the rehabilitation of specific pediatric populations, there is a limited selection of critically ill children in whom this intervention may be safely applied. This pilot trial exposed many challenges and limitations that need to be considered when designing future interventional studies on acute VR-based rehabilitation in the PCCU environment. Given the assumed morbidity and negative outcomes associated with immobilization in critically ill children, and the promise that rehabilitation during critical illness is effective and improves recovery, the magnitude of this problem needs to be defined, its determinants evaluated, and novel complementary approaches in this unique population need to be considered in order to improve the outcomes and overall recovery in critically ill children.

Acknowledgement

We thank the patients and their families for their participation in this study.
The listed authors adhere to the ICJME definition of authorship. All of the listed authors contributed to the study design, acquisition of the data, analysis and interpretation of the data, statistical analysis, drafting and final approval of the manuscript.

This study was not funded.

**Conflict of interest**

The authors report no conflict of interest.

**References**


[31] G. Saposnik, M. Levin, G. Outcome Research Canada Work-


