Development and preliminary usability evaluation of a tablet-based interactive movement tool for pediatric rehabilitation

Danielle Levac, PT, MSc., PhD*
Assistant Professor, Department of Physical Therapy, Movement and Rehabilitation Sciences
Bouve College of Health Sciences
Northeastern University
407c Robinson Hall
360 Huntington Ave, Boston, MA 02115
d.levac@northeastern.edu
(617) 373-5198

Helene Dumas
Adjunct faculty, Department of Physical Therapy, Movement and Rehabilitation Sciences
Bouve College of Health Sciences
Northeastern University
Director, Medical-Rehabilitation Research Center
Franciscan Children’s Hospital
30 Warren Street, Brighton MA 02135
h.dumas@franciscanchildrens.org
(617) 254-3800

Waleed Meleis
Associate Professor, Department of Electrical and Computer Engineering
College of Engineering
320 Dana Research Center
360 Huntington Ave, Boston MA 02130
Northeastern University
meleis@ece.neu.edu

*Corresponding Author
d.levac@northeastern.edu
Keywords: User-centered design; Usability testing; Cognitive Walkthrough; Think Aloud; Rehabilitation; Pediatrics; Tablets; Alternative interface modalities; Interactive health care application

Abstract

Introduction: Motivating interactive tools may increase adherence to repetitive practice for children with disabilities, but many virtual reality and active video gaming systems are too challenging for children with significant needs. We developed the Fun, Interactive Therapy Board (FITBoard), a movement toy bridging digital and physical interactions, and evaluated its usability among physical (PTs) and occupational therapists (OTs) at two clinical sites.

Methods: The FITBoard is a tablet application involving games controlled by hand, head or foot touch of configurable, wired surfaces. Usability evaluation involved a Cognitive Walkthrough and Think Aloud process in which participants verbalized aloud while completing a series of 26 task actions involved in selecting a game and configuring the FITBoard to achieve the therapeutic goal. Therapists then responded to questions about usability perceptions. Unsuccessful actions were categorized as goal or action failures. Conventional qualitative content analysis supported understanding of usability problems.

Results: Five PTs and 2 OTs participated. Goal failure was experienced by all participants in 2 tasks and action failure was experienced by all participants in 2 tasks, with 14 additional tasks experiencing goal or action failure by > 1 participant, for an overall failure rate of 65.4%. Content analysis revealed 4 main categories: hardware usability, software usability, facilitators of therapy goals, and improvement suggestions.

Conclusions: FITBoard hardware and software changes are needed to address goal and action failures to rectify identified usability issues. Subsequent research will evaluate therapist, parent and child perspectives on FITBoard clinical utility when integrated within regular therapy interventions.
**Introduction**

Children and adolescents with physical or developmental disabilities such as cerebral palsy (CP) participate in rehabilitation to learn new motor skills, maintain existing skills and support capacity for self-care and independent living [1, 2, 3]. Motor learning impairments necessitate abundant, challenging, progressive, varied, and feedback-rich practice opportunities to elicit functional change [4]. Providing these intervention characteristics is a major consideration in rehabilitation planning [5, 6, 7]. Therapists must select activities that are customizable to individual abilities and goals and that sustain children’s motivation to engage in repeated practice.

Enhancing and sustaining children’s motivation is important for rehabilitation because motivation is an affective state that may mediate the functional brain changes (i.e. neuroplasticity) that influence motor learning [8, 9]. Motivation is a child characteristic thought to influence changes in motor ability for children with CP [10], although no clear link has been made between motivation and rehabilitation effectiveness in pediatric populations [11]. Therapists can enhance motivation by involving the child in selection of therapeutic tasks that are relevant to his/her interests and goals [12]. In recent years, games presented on interactive digital screens, from hand-held tablets to active video games (AVGs) to fully immersive 3D virtual reality (VR) systems, have become accessible motivating therapeutic task options for children [13]. VR and AVGs encourage children to interact with onscreen simulations using body movements, with therapeutic advantages of repetitive practice, customized difficulty levels, metrics to track progress, and facilitation of monitored home-based tele-rehabilitation [14, 15].
The VR/AVG literature demonstrates benefits for skill acquisition in children with disabilities [16], however, inexpensive, off-the-shelf AVGs such as the Nintendo Wii or the Microsoft Kinect, can be too challenging for young children, children with perceptual or cognitive impairments, and children with more severe physical or cognitive limitations [17, 18]. VR systems designed specifically for rehabilitation use can address some of these barriers but may have greater cost and training requirements.

In contrast to full-body movement interaction, iPads and other tablets are popular therapy tools used to stimulate both fine motor movements and cognitive processes through a variety of games and apps [19]. These touch devices are portable, accessible, and fairly inexpensive. Children with disabilities, including preschoolers, can quickly become competent with these devices [20]. The body of evidence on whether the use of touch screens can support cognitive learning for children with disabilities is small, primarily focusing on children with Autism Spectrum Disorder [20, 21]. For children with fine or gross motor impairments, alternative interface modalities such as switches and push buttons are recommended to replace the ‘swipe and touch’ movements requiring control and force regulation to interact with the screen [22].

We developed an alternative interface modality called the Fun, Interactive Therapy Board (FITBoard), a movement toy bridging digital and physical interactions. The FITBoard is a tablet application involving custom-designed games controlled by hand, head or foot touch of configurable, wired surfaces (rather than tablet screen touch). The FITBoard is designed to help children practice movement skills during physical or occupational therapy. Children reach and touch
keys on the FITBoard panels to control the games on the tablet screen. The games are designed to meet the needs of children and youth at a variety of cognitive and functional levels and provide challenging, progressive, varied, and feedback-rich practice opportunities to address therapeutic goals and elicit functional change.

Undertaking usability testing is important because many new interactive health care applications remain unused when they don’t meet the needs of users [23]. Usability evaluation is part of a user-centered design process to understand effectiveness, efficiency and appeal of a tool for users [24]. Usability testing provides the opportunity for individuals who will ultimately be users of the product to participate in its refinement [25]. The objective of this paper is to describe the usability evaluation of the FITBoard among physical and occupational therapists at two pediatric clinical sites.

**Methods**

**Fun, Interactive Therapy Board**

Development of the FITBoard was initiated by gathering input on desired device characteristics from physical and occupational therapists at a local children’s rehabilitation hospital through an informal needs assessment session. Five therapists expressed the need for a device with the following characteristics: low-cost, gaming-based, flexible to address multiple needs and cognitive abilities, usable through hand, foot or head movements, durable for energetic physical play, involving sensory stimulation from touching different surfaces, made of surfaces that can be easily sanitized, and capable of tracking patient progress.
Our team of electrical, computer and mechanical engineering undergraduate and graduate students brainstormed through various iterations using different materials to construct and program a device to match the requested characteristics. The resultant FITBoard (see Figure 1) is a physical interface running a tablet application that displays games controlled by hand, head or foot touch of configurable, wired surfaces. It functions via panels that have keys with pressure switches and resistors that provide differing analog inputs to an Arduino microcontroller. The key covers hinge from one side, allowing the pressure switch to be activated regardless of where the panel covering it is pressed. The panels also each have a velcro component to enable different materials representing cues for game actions or other sensory-stimulating touch surfaces to be attached.

The interface is a box-like design with folding panels that are foldable and extendable based in a case resembling the Pelican product (www.pelicancases.com). Top folding panels are made of acrylic and friction hinges and bottom panels slide in and out using guide rails made from aluminum extrusions. The top panels are double-sided and fold out to keep the lid light, while the bottom panels slide for extra stability. The middle panels sit below the sliding path so the device can be used with the bottom panels extended or kept inside the case. There are removable head and foot controls that can be positioned to accommodate user needs. The FITBoard rests on a wheelchair-accessible height adjustable wheeled desk to accommodate users of different heights.

The application is displayed on a Microsoft Surface tablet, chosen because it has a USB port for the Arduino to communicate button press signals into the game. The 7 custom-built games are built in Unity3D and scripted in C#. The games are appropriate for a variety of ages and
cognitive abilities. For example, in the Paint a Picture game, key presses result in a splash of color on the screen. The user can try to cover the screen with paint splashes of varying colors within the pre-set time limit. In the Drive the Car game, users press keys corresponding to direction and speed to steer a car through a course of varying obstacles and difficulties. Each game incorporates visual and auditory effects, offers multiple challenge levels, can be played with head, foot or hand controls and provides positive feedback to the user about game play success.

To use the FITBoard, the therapist configures the physical device to the target therapy goal(s) (e.g. positioning the panels so the child has to reach across their body; using foot controls to facilitate stepping). The therapist then signs in to the application, selects an existing client or adds a new client, and selects a game to play (See Figure 2). The therapist then selects the specific FITBoard keys that he/she would like the child to use to play the game and adds a laminated (e.g. arrows, colored circles) or other material as a cue to remember that key’s action. Once at a game menu, settings such as game difficulty (e.g. speed) and time can be selected, or the user can choose to simply continue with previously used settings. Game play data is saved on the tablet.

<< Insert Figures 1 and 2 approximately here>>

Research Design

User-centered usability evaluation. The study was approved by the IRB at the 2 clinical sites XX and XX.

Usability evaluation methods
Usability evaluation was undertaken with a Cognitive Walkthrough (CW) [23] and Think Aloud (TA) [26] approach. CW is a form of task analysis that enables evaluation of early prototypes to uncover possible errors in design that would interfere with the user’s ability to learn how to use the system and carry out the required tasks [23]. CW involves a moderator observing users completing a walkthrough of tasks required to use the system, pre-divided into single actions. In this study, users were required to ‘Set up a new therapist and client account’; ‘Select, set up and play a game’; ‘Exit the application’; ‘Identify a client goal and provide a rationale for FITBoard use’; ‘Configure the FITBoard for the identified’; and ‘Select and implement a game for that client’. Table 1 depicts the steps for each task. As the moderator observes the participant moving through the tasks, he/she records observations as to whether the user is successful or whether there are ‘goal failures’ (the user tries to accomplish the wrong thing) or ‘action failures’ (the user would like to perform the correct action but does not know how) [27].

The Think-Aloud method is a widely-used usability evaluation method often used in conjunction with CW [23]. It involves asking potential users to ‘think aloud’ as they interact with the product. TA is complementary to CW because it focuses on cognitive processes relevant to task completion. It is considered the gold standard method because it supports greater understanding of the problems users are having with interaction [23]. Sessions are audio recorded and the participant is encouraged to speak constantly as if alone in the room. He/she is given non-obtrusive reminders if they fall silent; otherwise, the moderator does not interfere.

**Study procedures**
In 1-hour individual audiotaped sessions in private testing rooms, led by moderators DL or HD, participants began by following a series of printed actions to set up a new therapist and client account, select and play a game, and close down the FITBoard application, in order to become familiar with the functioning of the system. They were then asked to describe a client and therapeutic goal for FITBoard use and complete the next task actions involved in selecting a game and configuring the FITBoard to achieve the therapeutic goal. Moderators observed, documented and categorized actions during the CW as goal failures (user tries to accomplish the wrong thing) or action failures (user would like to perform the correct action but does not know how). After completing the CW and TA, participants responded to semi-structured interview questions about FITBoard use. Questions focused on features therapists appreciated or found frustrating about FITBoard use.

Participants

Pediatric physical and occupational therapists were recruited through volunteer sampling at two clinical sites to participate in the study. The investigators held study information ‘lunch ‘n learn’ sessions at each site to describe the project and provided therapists with copies of the consent form and responded to questions. Therapists provided written informed consent prior to participation.

Analyses

Goal and action failures were summarised with descriptive statistics. Think-aloud process and interview question audiorecordings were transcribed and conventional qualitative content analysis [28] was employed to identify usability problems, understand FITBoard features perceived to be beneficial and gather suggestions for improvement.
Results

Five pediatric physical therapists and 2 occupational therapists (mean 19.3 years of clinical experience, range 3 to 33 years) participated from 2 in-patient pediatric rehabilitation clinical sites.

Cognitive walkthrough

Goal failure (user tries to accomplish the wrong thing) was experienced by all participants in 2 tasks (‘Using game descriptions to select a game’ and ‘Select appropriate game settings’) while goal or action failure (user would like to perform the correct action but does not know how) was experienced by all participants in 3 tasks (‘Select game keys’; ‘Open/close/slide FITBoard panels’ and ‘Select appropriate game settings’). Fourteen tasks experienced action failures by 1 or more participants. There was an overall rate of 34.6% successful task completion as compared to 65.4% failed tasks (either goal or action, by some or all participants). Table 1 provides results of the Cognitive Walkthrough. Table 2 provides examples of goal and action failures experienced.

Five of the 7 therapist participants who completed the full Cognitive Walkthrough identified a client to consider while trialing the FITBoard. Hypothetical client impairments included reduced strength and altered muscle tone due to upper extremity hemiplegia (n=1), hemispatial neglect (n=1) or static and dynamic standing balance (n=3). Therapists provided rationale that FITBoard use would increase awareness and movement of affected upper extremity; engage the child while maintaining desired periods of static standing balance; and encourage stepping outside of the base of support to improve dynamic standing balance. Therapists reported that they would
position the client in sitting (n=1), standing when using the 2 foot controls (n=2), and standing without the foot controls (n=2).
<table>
<thead>
<tr>
<th>Task</th>
<th>Task Description</th>
<th>Goal failures (n)</th>
<th>Action failures (n)</th>
<th>Successes (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Set up a new therapist and client account</strong></td>
<td>Turn on tablet</td>
<td>0</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Attach keyboard and type in password</td>
<td>0</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Plug in USB</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Locate FITBoard icon</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Sign up for new therapist account</td>
<td>3</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Add a new client</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td><strong>Game selection, set up and play</strong></td>
<td>Use game descriptions to select a game</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Use the interface to select 4 keys</td>
<td>0</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Apply contact material to keys</td>
<td>0</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Play game</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><strong>Exit the application</strong></td>
<td>Log out of app</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Remove contact material</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Turn off tablet</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Identify a client</strong>*</td>
<td>Identify a client</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Identify a task/activity</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Provide rationale for how FITBoard will assist in that task/activity</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td><strong>Configure FITBoard for client</strong>*</td>
<td>Log in to FITBoard app using existing therapist and patient ID</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Identify patient starting position</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Open, close slide top or bottom panels</td>
<td>0</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Add head OR foot controls</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Raise/lower the desk</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td><strong>Select and implement game for client</strong>*</td>
<td>Use game descriptions to select suitable game</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Use the interface to select 4 keys</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Apply contact material to keys</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Select appropriate game settings</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Progress, modify or change the activity</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

* 5 of 7 participants completed these tasks.
**Table 2: Examples of goal** (user tries to accomplish the wrong thing) **and action** (user would like to perform correct action but doesn’t know how) **failures**

<table>
<thead>
<tr>
<th>Task</th>
<th>Goal OR Action failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using game descriptions to select a game</td>
<td>GOAL: Participants did not ‘long press’ on the game icon to bring up the game descriptions.</td>
</tr>
<tr>
<td>Use the app interface to select game keys</td>
<td>ACTION: Participants were not able to understand how icons represented actions in the game.</td>
</tr>
<tr>
<td>Open/close/slide FITBoard panels</td>
<td>ACTION: Participants were not sure how much force to use to move or slide the panels and in what direction.</td>
</tr>
<tr>
<td>Select appropriate game settings</td>
<td>GOAL: Participants missed the ‘game settings’ option on the screen and did not select it.</td>
</tr>
<tr>
<td>Attach keyboard and type in password</td>
<td>ACTION: Participants did not recognize magnetic interface to attach keyboard.</td>
</tr>
<tr>
<td>Plug in USB</td>
<td>ACTION: Participants did not know where to plug in the USB.</td>
</tr>
<tr>
<td>Locate FITBoard icon</td>
<td>ACTION: FITBoard icon was small and participants had difficulty locating it on the screen.</td>
</tr>
<tr>
<td>Sign up for new therapist account</td>
<td>GOAL: Participants tried to ‘log in’ without first signing up for a new account.</td>
</tr>
<tr>
<td>Apply contact material to keys</td>
<td>ACTION: Participants were not clear where to find contact materials, which ones they should use.</td>
</tr>
<tr>
<td>Play game</td>
<td>ACTION: Participants did not see results of key presses on screen because not pressing correct keys at correct time for the game interface.</td>
</tr>
<tr>
<td>Log out of app</td>
<td>ACTION: Participants quit without logging out.</td>
</tr>
<tr>
<td>Turn off tablet</td>
<td>ACTION: Participants were not sure how to turn off the tablet.</td>
</tr>
<tr>
<td>Log in to FITBoard app using existing therapist and patient ID</td>
<td>ACTION: Participant tried to sign up instead of log in</td>
</tr>
<tr>
<td>Add head OR foot controls</td>
<td>ACTION: Participants were not sure where to plug in head or foot controls.</td>
</tr>
</tbody>
</table>
Think aloud and interviews

Content analysis of the Think Aloud and interview transcripts revealed 4 categories: hardware usability (i.e. FITBoard fragility), software usability (i.e. key configuration and game settings), facilitators of therapy goals, and suggestions for improvement.

i. Hardware usability

All therapists expressed concern at the physical appearance of the FITBoard as well as the fragility and durability of the device. Therapists reported being uncertain whether the force required to move and slide the FITBoard panels would cause the panels to break and were concerned that pediatric clients would pull the exposed wires. For example, one therapist said: “So, I’m thinking at what point do I tell a kid ‘don’t hit that so hard’...also how easily they [the panels] pop off... so my concern with this is with kids no matter how much you tell them ‘I got you’, if they go to fall, they will grab onto this, and I just feel like this is something I wouldn’t want to pull on, so it almost like narrows who my population who I think would benefit from it”.

Another therapist said: “I know this is a prototype but I would hope that the permanent thing is a little sturdier...too many wires that a patient could inadvertently pull off, break off, knock over... someone with strong tone or any sort of spasticity...it felt very fragile.” Additional hardware concerns identified included the sensitivity of the panel keys, the shine of the panels, the inability to mount the tablet above the FITBoard and the lack of support for the tablet keyboard that is needed to sign in.

ii. Software usability

Participants found aspects of the application interface confusing, particularly the game selection screen where they were not able to complete the task of viewing the game description (a ‘long
press’ on the game icon on the tablet screen would make the game description appear). When shown this action following the CW, participants expressed concern that without a picture of the game it was difficult to understand the description. For example, with respect to the Whack a Mole game, one participant said: “Well I don’t know what the holes look like. So are they in a grid then it kind of makes sense? Are they on top of each other because of the up down? Without seeing the screen of what the moles look like I don’t know what that means. I’m not sure for top and bottom what I’d choose.”

In the key configuration screen where participants selected specific keys on the FITBoard to interface with the game, participants disliked the incongruity between the visual representation of the key icons on the FITBoard panels and their actions in the game, reporting it was very confusing to understand which key undertook which game action. Participants also reported challenges locating and then understanding how to set the game difficulty levels including game duration and speed. For example, 1 participant said: “I would try it if the levels were adjusted better.”

One participant was concerned about the visual appeal of the games, saying: “… I would love to see what the kids think because now video games have so many components to them and they are so animated and dynamic and they have music and they have sounds and they can be more complex so depending on the age of the kids and their cognitive abilities, I don’t know how they would like this, it would really vary. Kids used to other games might not be thrilled with this and then the older kids and teens might not like the games.”
iii. **Facilitators of therapy goals**

Participants reported appreciating the many options (e.g. head switches, foot pedals, panel positions) to elicit movement and the selection of tactile touch contact materials for interaction (e.g. arrows, toy animals), as well as the many opportunities to individualize the intervention to make it patient-specific. For example, one therapist said: “I think it would be good for kids that like video games...maybe they are working on gross movement...a child with hemiplegia – it would be a fun game to get reach to the side, and yet it’s not a lot of fine motor so you can get them to do some gross moves with their upper extremity.” Another therapist described potential use of the FITBoard with a particular child stating, “I can make him reach out of his base of support, I could make him tap his foot and I think it would engage him as well because he loves video games.” Another therapist focused on the ability to interact with the game using only simple head movements, saying it would be appropriate for a current patient because “…she has very poor head control so something we were trying to do today in rehab we were drawing tic-tac-toes and trying to get her to look up and get her head up. So this could be something for her that I use this for.” This was echoed by a second therapist, who said: “I like that you can... make it so specific to the patient you have... You do have something for even if it’s for something like head control... because we do get a significant amount of people that, that is a serious thing we are working on and it’s hard to make that fun sometimes.”

**Suggestions for improvement**

Therapists suggested adding a pause feature to the games: “...I get so many interruptions at random times in the session... work with kids that need that closure... they want to make sure you can pause and finish that game and get that score, or like they won’t be able to listen to what a nurse has to say or take a medication, unless they can pause that game. So, having the control...
to pause that game without having to restart it would be helpful... to be able to apply it in a hospital.” One therapist suggested a more intuitive way to access and store the touch materials, saying “....they would benefit from being labeled so easier to put your hands on stuff...” In addition, further touch materials were suggested, including materials to facilitate use by clients with limited fine motor control, “I think that for her [the patient] I’d work on some grasp and I don’t think she could get a good grasp and fall off of it. So, something she could rest her hand here and squeeze a little I mean depending on their hand skills. The other thing you might want to do is look at different shapes, because you could also be using that hand to work on some grasping control.”

Additional hardware suggestions for improvement were to increase the stability of the head and foot controls when touched, to cover the microcontroller to protect it from cleaning fluids, and to increase the mobility of top and side panels so they could be positioned higher and surround the user. Additional software suggestions for improvement included the need for games to provide more feedback about success/error rate and to include games that required only 1 or 2 keys rather than 4 keys to play. Suggestions were made to improve the user instructions with additional details, add a game description sheet to accompany the FITBoard, and round off sharp edges of laminated pieces that attach to the keys.

Discussion

This study evaluated the usability of the FITBoard, a newly developed rehabilitation tool for children with disabilities. Usability was evaluated through CW and TA methods to enable
identification of problematic tasks involved in using the FITBoard and to identify areas for improvement.

The overall goal and action failure rate in this study, 65.4%, was similar to others in the literature. Peute et al. [27] undertook a CW and TA evaluation of a new online laboratory test ordering tool, finding that 16/25 (65%) of actions resulted in goal or action failures. Valdes et al. [29] used CW and TA to evaluate 2 newly developed motion tracking rehabilitation therapeutic tools. They reported that 69.5% of the actions evaluated in their sample of 11 therapists had some element of failure, but did not classify failures into goal or action components [29].

Our testing situation was unique because it focused on evaluating usability of both novel hardware and software interfaces, which differs, for example, from usability testing of a new website, where users could be expected to be familiar with general layout and functioning of a keyboard, mouse and monitor. The CW and TA process illuminated usability problems and flaws in the process of using the FITBoard from beginning to end that led to errors for some or all participants that need to be repaired before subsequent testing and use. The primary usability problems included structural issues with the FITBoard that prevented users from being comfortable interacting with it as intended (i.e. opening and closing panels, attaching foot and head controls). Other problems related to lack of clarity in FITBoard software interactions (e.g. how to select keys to play the game, how to find game descriptions before selecting a game). The results from CW and TA identified problematic tasks that must be addressed before therapists are able to trial the FITBoard with children and families.
Despite these limitations, participants easily identified a client and functional goal that would be relevant to FITBoard use. In addition, they appreciated the diversity of options that the FITBoard provides which may be useful to motivate and engage children in maintaining upright head control, which was identified as a priority in the needs assessment. Therapists appeared to view the FITBoard as relevant to the goals for the patients on the caseloads and were able to inform the needed changes to the FITBoard prior to evaluation of its clinical utility.

Rehabilitation therapists have been introduced to many technological options including virtual reality, active video gaming, and other tablet apps that are commercially-available and/or developed specifically for rehabilitation. As such, it is difficult for house-made systems and games to compete with commercially-available ones in terms of aesthetic appeal or intuitive user interfaces. We know from barriers and facilitators assessments in the field of VR/AVG use that the main barriers to introduction for these new technologies include practical difficulties such as cost, adequate space for to use, and time to learn how to use, including how to choose specific games/applications most relevant to patients’ goals [17, 30, 31]. Our needs assessment informed us that therapists wanted a tool that would work for kids with more significant physical or cognitive impairments and for a younger age range than what it typical for AVGs. In addition, it needed to be low cost and robust for repeated use.

The FITBoard provides the ability for use with young children and children with significant disabilities, however, it has a bigger footprint than initially desired, given the goal was for a
device that could fold down to be stored in a briefcase-like fashion. We emphasized durability of individual materials (e.g. case, acrylic) but overall, the FITBoard is less robust than originally intended.

**Limitations**

Although our development process began by soliciting input from therapists, it could have been more user-centered and iterative if it had taken place in closer proximity to the therapists and they could have provided ongoing input. Instead, the device was built in a University lab and prototypes were not brought to therapists at regular intervals to ask their opinions throughout the process. This limitation was evident, for example, in findings related to therapists’ recommendations about having panels extend higher and laterally to surround the participant, which might have been able to be implemented in early stages of construction but likely won’t be a feasible change for the subsequent testing phase.

The CW and TA process was undertaken by authors DL and HD, researchers known by therapists to be invested in FITBoard development. Despite assurances that all feedback was welcome, therapists may have felt uncomfortable expressing negative opinions about the device in their presence. Finally, the study is limited by a small sample which may not have been sufficient to discover all usability problems. While Bastien [24] suggests that 8 participants is sufficient for a Think Aloud Process, there is no consensus on the number of participants required. Two of the seven participants did not have time to complete the full Cognitive Walkthrough. Also, we only had 2 OT participants. This is important because OTs may have different therapeutic rationale
and interests in using this device; including additional OTs might have led to the discovery of different usability problems. Finally, the CW has been criticized as being too rigid and therefore limiting the types of problems discovered [32].

**Next steps**

Study results are guiding changes to the FITBoard to address hardware and software usability issues. Our next steps are to introduce the revised FITBoard to the clinical sites and undertake a clinical utility study with therapists, children and families to determine how FITBoard use addresses relevant therapeutic goals. Therapists will use the FITBoard on several occasions, recording their functional goals and perceptions of how FITBoard use was able to address the goal; therapists, parents and children, as able, will complete standardized measures evaluating satisfaction, engagement and motivation. Finally, we will conduct interviews with children, parents and therapists to further identify barriers and facilitators for FITBoard use. Based on the results, we can move forward with approaching industry with respect to making changes to the FITBoard interface and application to support creation of additional, improved devices with a larger budget for construction and game development. We would then undertake longer-term feasibility and effectiveness research in home or school settings to understand the potential role of the FITBoard in therapeutic programs.

**Conclusion**

Usability testing methods (CW and TA) revealed hardware and software concerns, uses to address therapy goals and suggestions for improvement for the FITBoard, a newly-developed,
low-cost rehabilitation tool for movement skill practice that integrates the motivating attributes of video games with the functional, touch-based sensory input of traditional rehabilitation interventions. FITBoard hardware and software changes are needed to address goal and action failures and respond to identified usability issues. The goal is to produce an accessible, user-friendly, low-cost product that can be integrated into school, home, or community programs to enhance practice dosage of functionally relevant movement skills for children and youth with disabilities.

**Acknowledgements**

We are grateful to the Deborah Munroe Noonan Memorial Research Fund, administered by the Medical Foundation, for funding our feasibility and usability testing process. We are also very grateful for funding from Northeastern University’s Undergraduate Provost Research and Creative Endeavors Award and financial support from Northeastern’s Enabling Engineering Student Club. The authors thank undergraduate students Raymond Huang, Emma Bobola, Brandon Nyguen, Gino Jacob, Winston Ge, Todd Roberts, Nicholas Sullo, Monsurat Olaosobikan, Grant Ritter, Adam Perruzzi, Christopher Mohen, Cullen Lampazzo, Jose Castillo, David Yi and Immanuel Mensah Ampomah for their dedicated work constructing and programming the FITBoard. Thank you to the therapists who took part in this study.

**Declaration of Interest**

The authors report no conflicts of interest.

**Data set availability**

Data is available by contacting the corresponding author.
References

13. FIX


