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Matti: Tangible User Interface for Engaging Patients in Physical Therapy Towards a Motivating Rehabilitation

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Abstract. Maintaining high levels of patient motivation and enjoyment during physical rehabilitation is crucial for achieving optimum therapy outcomes. However, the prolonged and repetitive nature of postural control rehabilitation in children with Developmental Coordination Disorder (DCD) often leads to a rapid decrease in motivation levels. Digital therapy devices and exergames offer valuable solutions to this problem by providing therapists with the ability to incorporate objective outcome measures into their practice. Adjustable Tangible User Interfaces (TUI) are ideal for implementing digital innovation into physiotherapy clinical settings. Therefore, this study aimed to discuss the development rationale and iterative co-creation process of Matti, a pressure-sensitive, adaptable TUI for rehabilitation purposes. A structured overview of TUI requirements within a clinical setting was provided for future developers. The results showed that the Matti device can be used as a viable tool for exergaming rehabilitation. Future investigations on the measurement capabilities are required to enable the reliable adoption of objective outcome measures. The impact of TUI and gamified postural control assessment on patients' motivation and therapy outcomes should also be evaluated.

Keywords: Digital Health; Exergames; Rehabilitation; Tangible User Interface

1. Introduction

Mobility is an integral part of the level of independence for an individual, playing a crucial role in the perceived Quality of Life (Whulanza and Kusrini, 2023; World Health Organisation, 2013). Central to mobility is the ability to maintain balance, a fundamental prerequisite for self-reliance. Approximately 1 in 20 children aged between 3 and 17, experience problems with 'dizziness' or 'imbalance' (Li *et al.*, 2016). However, only 32.8% of these children received a medical diagnosis comprising neurological disorders, ear infections, head/neck injury or concussion, and DCD. Among these conditions, DCD also referred to as *dyspraxia*, is a developmental disorder characterized by an impairment of motor coordination, significantly impacting both academic and daily activities (Blank *et al.*,

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2019; American Psychiatric Association, 2013). Current prevalence estimates for this disorder range from 2% to 20% of children, with 5% to 6% being the most frequently cited figure in literature (Gaines *et al.*, 2008). Among a broad range of motor skill deficits to be faced by children with DCD, a lack of stability, postural control, and coordination is expected (Verbecque *et al,* 2021; Geuze, 2003).

Physical therapy (PT) acts as the cornerstone in rehabilitating illnesses, injuries, and conditions that limit mobility and functionality (O'Sullivan, Schmitz, and Fulk, 2014). This type of intervention often requires patients to perform repetitive training exercises over an extended period to regain or improve certain functions (de Sousa *et al*., 2018; Maharaj and Lallie, 2016). Exercise regimes often demand considerable effort and patient cooperation (Hagger and Chatzisarantis, 2007). Motivation is a significant factor that helps maintain the necessary levels of therapy compliance in children (Tatla *et al.,* 2013). Recent studies showed that highly motivated patients show optimum therapy outcomes (Meyns *et al.*, 2017). Therefore, it is essential to ensure the maintenance of motivation during the rehabilitation process.

Using interactive systems as a training platform has been considered to maintain and enhance motivation during rehabilitation. Many interactive systems have been developed to support various rehabilitation programs. Some of these systems specifically focus on improving or maintaining motivation during the rehabilitation process. Examples of such interactive solutions include serious games (Bonnechère, 2018), virtual reality applications (Neto *et al.* 2019), interactive collaborative environments (Hudák *et al.*, 2020), and Tangible User Interface (TUI) (Salazar-Cardona *et al.,* 2023). Developing new systems based on the TUI approach is considered promising since the devices are more intuitive and accessible for patients with a low level of technology experience (Marshall, Rogers, and Hornecker, 2007).

The implementation of video games in a clinical or rehabilitation setting has also been widely explored. The gaming aspects incorporated in rehabilitation have been shown to imbibe enjoyment in the patient while also maintaining higher levels of engagement during exercise regimes by providing feedback on performance (Colombo *et al.*, 2007). For example, exergames, which receive input directly from the movement of players, have experienced a considerable rise in interest from the scientific community and physical therapists (Aufheimer *et al.,* 2023; Tobaigy *et al.*, 2018). Previous studies evaluating the effects of rehabilitation interventions using commercially available exergames showed modest but positive outcomes, supporting supplementary integration in clinical practice (Bonnechère *et al.*, 2016). According to therapists, the main disadvantage to the general implementation of these tools is the lack of adjustability (Bonnechère *et al.*, 2018).

Serious exergames, which are designed with another primary goal than mere entertainment (Magista, Dorra, and Pean, 2018), offer therapists the requisite level of control. Due to the increase of various types of sensors developed for gaming purposes, engineers and game designers have been able to create specific tools for physical rehabilitation. Collaboration between the groups could also improve the attitudes of clinical professionals toward the concept of serious games.

Based on the innovative approach to fostering balance and coordination skills, Matti was developed as a TUI, providing engaging and motivating therapy for patients. Matti acts as a training platform by offering the user an interactive surface that provides specific therapeutic exercises in the form of exergames. This study describes the effort to explore the potential of Matti as a TUI and exergame device within the physical rehabilitation practice. The initial and iterative co-design process with different stakeholders including therapists, patients, game developers, and engineers, as well as the implementation of the device (as a Minimum Viable Product/MVP) among DCD children was explored. Finally, the iterations used to develop Matti into a Minimum Marketable Product (MMP) were discussed.

2. Methods

Matti: A Tangible User Interface for Supporting Motor Rehabilitation

Using a user-centered design approach, an interactive gaming mat was developed as a tangible interface that can support motor rehabilitation. This interactive surface, named Matti, was initially conceptualized as a training platform for children with DCD. The development was initiated through a collaboration with the Department of Physical Therapy and Rehabilitation of Ghent University (Belgium). Based on the experience in rehabilitating children with DCD, patients were observed to have challenges in performing certain motor activities due to a lack of postural and motor control. Furthermore, frustration levels could quickly rise due to excessive exercise repetitions and the slow improvements of perceived skills. Therefore, the proposal to develop a new exergame specifically aimed at DCD children to improve balance and increase motivation was presented.

2.1. Matti 0.1: Prototype (Minimum Viable Product)

To materialize the idea, Matti 0.1 was developed as a Minimum Viable Product (MVP) through an iterative design process engaging physiotherapists and DCD children (Joundi *et al.*, 2019). Figure 1 shows the overall system of Matti 0.1, which consists of 2 main parts, namely the hardware and software. The hardware is an interactive mat used to play exergames similar to the therapy exercises. Meanwhile, the software runs the exergames personalized by the physiotherapists to meet the needs of the patients.

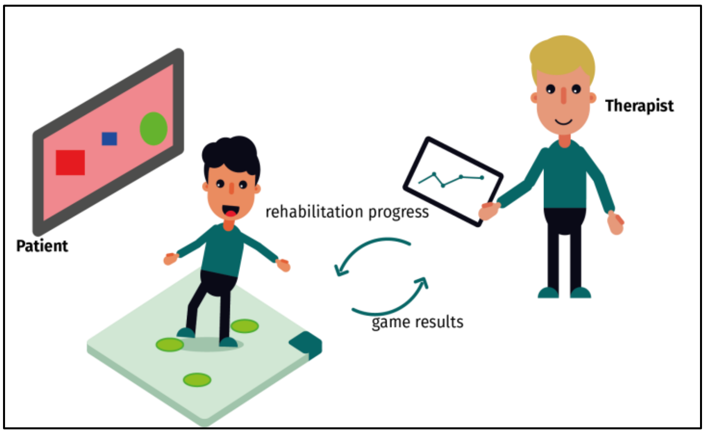


Figure 1 Overall system concept of Matti 0.1.

Application of the Matti system commenced with the physiotherapist defining the therapy exercises (exergames) according to the rehabilitation needs of the patient. Visual feedback is provided on a separate screen while the patient interacts with the mat to play a game. After playing exergames on Matti, the game results are communicated to both the physiotherapist and the patient. By monitoring these results and analyzing the rehabilitation progress, the physiotherapist can adjust the exercises according to the predetermined therapeutic goals.

2.1.1. Hardware and Software

The setup of a therapy session with the Matti system requires only 2 hardware elements, namely a TV/desktop screen and an interactive gaming mat. The TV/desktop is connected to a computer or laptop, while the interactive gaming mat is also connected to the laptop running the Matti software on the offline Creative Therapy platform application. Furthermore, the screen is used to visualize the exergames the patient has to play. The physiotherapist uses a laptop or computer to adjust the settings of the game and visualize the results. The interactive gaming mat, using a 15 x 15 matrix of pressure sensors and integrated RGB LED lights, has 2 main functions such as to obtain input from the movements of the patient and to provide visual feedback. This relationship of input (pressure sensors) and output (LED lights) gives Matti the potential to function as a TUI, specifically an interactive surface. Figure 2 shows Matti hardware parts, including a desktop screen, laptop, and mat.

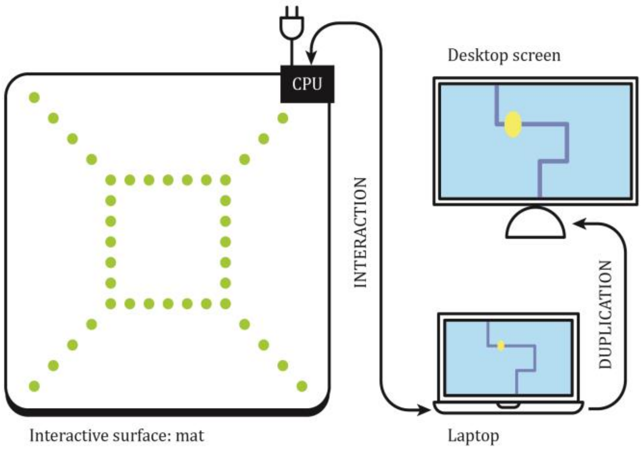


Figure 2 Hardware parts of the Matti 0.1 system

The goal of Matti is to motivate the patients to perform therapy exercises while playing enjoyable and challenging games. The physiotherapists can use the software through the laptop to select relevant exergames. An example of the developed exergame was the Octopus game, as shown in Figure 3. It is a simple maze game in which the player (i.e., the patient) needs to follow a predefined path presented on the screen. The goal is to move the octopus from the top to the bottom of the screen while remaining on the dark blue line. To achieve this, the patient has to step on one of the 5 squares on the mat with the LEDs. The movement on the squares corresponds to the directional command, guiding the octopus along the designated path.

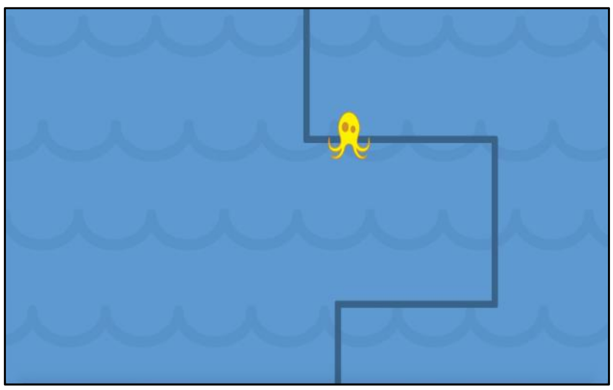


Figure 3 The Octopus game as part of the Matti 0.1 software

The challenge of exergames needs to be balanced with the motor skills of the patients. To address this, the development of the games within Matti was based on the Flow Theory (Csikszentmihalyi and Larson, 2014; Csikszentmihalyi, 2009). Figure 4 shows how lower motor skills in DCD children require personalized adjustments to the challenge of a specific exergame. The initial game state proved too challenging for a child with DCD (Challenge of game 1), potentially leading to frustration or anxiety in the player/patient. By modifying certain settings or parameters of a specific exergame, a new game state (Challenge of game 2) is created, striking a balance conducive for the patient to enter the 'Flow state.'

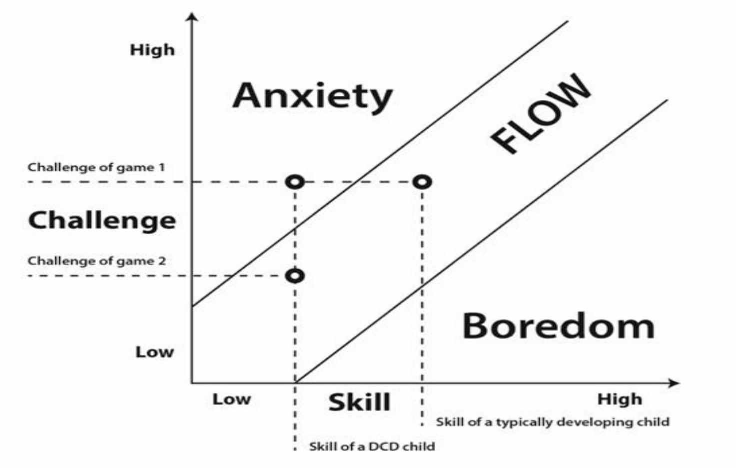


Figure 4 Personalised challenge adjustments for children with DCD based on Flow Theory

The user evaluation sessions and interviews, described in another study (Dujardin, 2019), resulted in an extensive list of necessary features required for the practical application of this type of TUI across a wide range of clinical populations. These features are categorized into 5 distinct categories, namely general, ease of use, feedback, and adjustability requirements. A complete list of necessary features is listed in Table 1.

Table 1 Overview of TUI requirements in a clinical setting

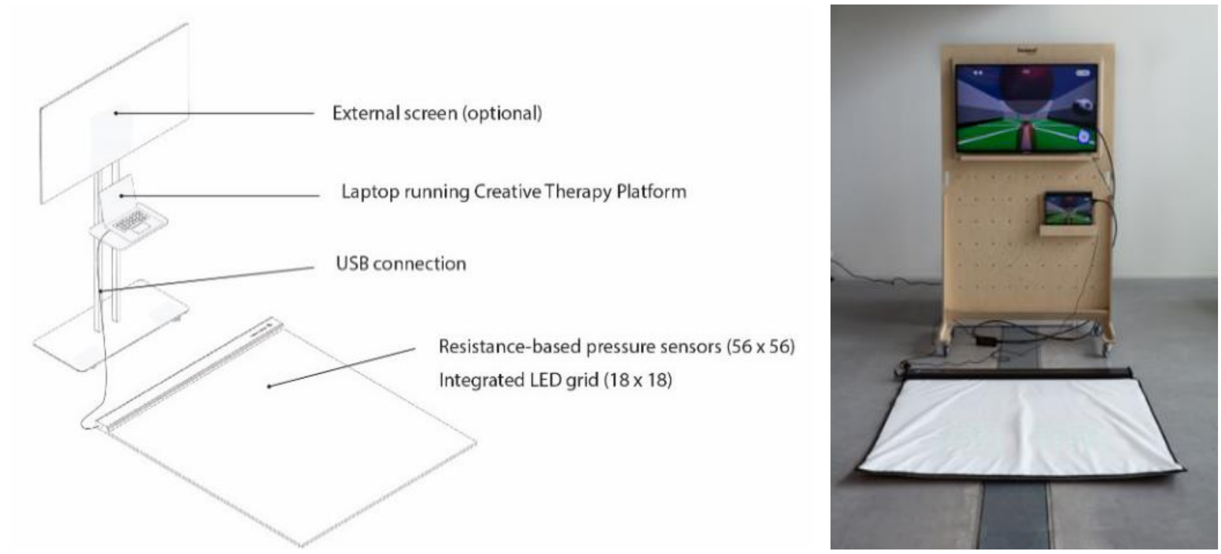
Aspects	Requirements
General	Construction of exergames according to ICF framework Multifunctional use of TUI (exergaming, motor analysis, etc.) Accurate measurements Low cost Tracking and visualizing the progression of a patient Safe to use
Ease of Use	Water- and stain-repellent material Efficient storage and transport solution Intuitive system ('Plug and play') Fully adjustable exergames Software platform accessible through different devices
Feedback	Visual feedback for both therapist and user on TUI Optional use of external display during exercises
Adjustability	Exergames are playable in various positions and with external tools (weights, rubber bands, etc.) Both adjustable and pre-made settings available for exergames Usable on both horizontal and vertical surfaces
Specific Population	Stable, flat, and fixed surface (e.g., elderly population) Variable degrees of cognitive involvement (e.g., pediatrics, elderly, intellectual disability, etc.) Variable degrees of intensity and load (e.g., sports)

2.2. Matti 1.0: Minimum Marketable Product (MMP)

Due to the nature of the co-creation process, all observed and reported issues and suggestions were implemented before bringing Matti to market. More exergames were developed, and motor analysis features were introduced.

2.2.1. Hardware and Software

To decrease the reported and perceived slowdown within the system, an innovative sensor-input method was developed in close collaboration with the manufacturers of the pressure-sensitive elements (SensingTex) and experts from Ghent University, as shown in Figure 5a. The pressure-sensitive grid was expanded to include 56x56 pressure sensors over a 1.20 m^2 surface. Additionally, the integrated LEDs were expanded to an 18x18 grid (Dujardin, 2019).



(a)

(b)

Figure 5 (a) Technical drawing Matti 1.0; (b) Matti setup with External Screen

All external electronics were relocated to one side of the surface and covered by an elongated hard-plastic cover (Figure 5b), which can withstand direct vertical impact. This was done to increase the longevity of the hardware and make sure patients could exercise safely. The hardened bar also enables the user to quickly roll up the device, thereby enhancing transportation without harming any of the integrated sensors and LEDs. To enable real-time communication between the Matti devices and the online Creative Therapy platform, state-of-the-art software solutions were developed in-house.

Figure 6 Matti 1.0 Device Platform

2.2.2. Adjustable Exergames

The overall lack of exergames was a vital drawback for both patients and therapists. Furthermore, different patient populations require various kinds of motor exercises. In order to provide both therapist and patient with the necessary flexibility, the initial exergames were tweaked or altered, while 6 new adjustable exergames were introduced to the platform, as shown in Figure 7. These new games could train and stimulate static and dynamic balance, agility, motor coordination, weight/postural shift, range of motion of upper and lower limbs, as well as cognitive and executive functions. Exercise and performance variability are enabled through the ability to adjust almost every setting, including duration, active area, and required input duration. Additionally, all exergames can be played from various body positions, such as standing and planking.

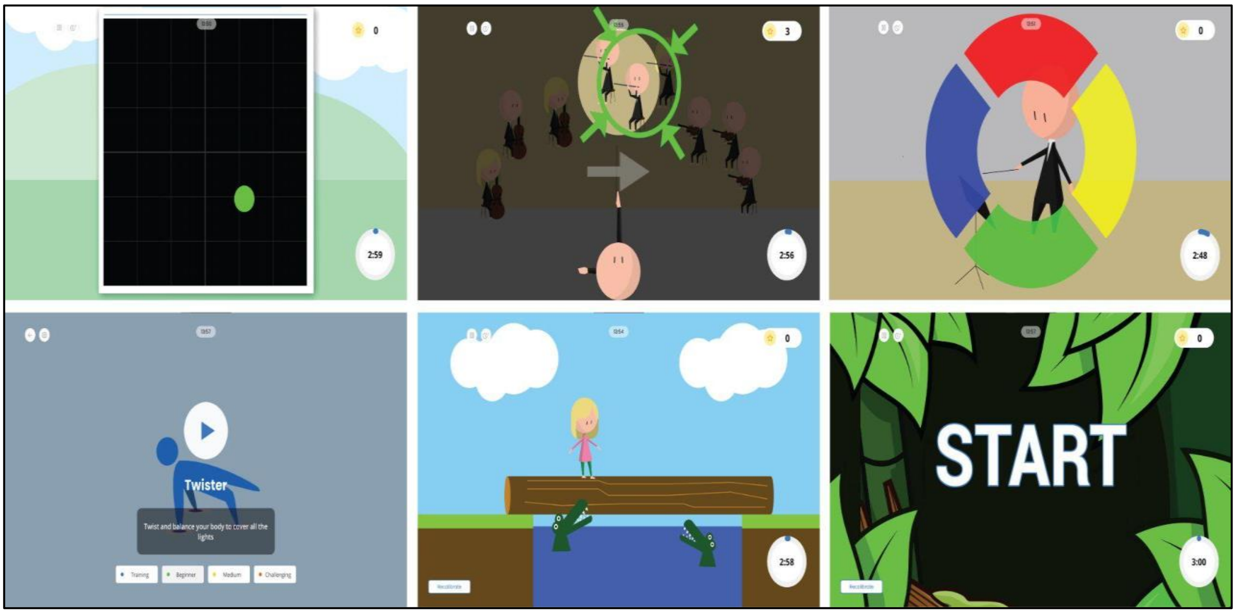


Figure 7 Adjustable Exergames in Matti 1.0

Since commercial videogames are an ever-evolving visual medium, therapeutic exergames need to have a certain visual appeal to entice children who regularly partake in modern video gaming. A collaboration was set up to develop a brand new exergame following both state-of-the-art game design principles and clinically relevant insights from practitioners. Through an iterative process, the game 'Netsurfer' was developed, as shown in Figure 8. This exergame requires the player to alter the position of the bipedal stance for the avatar to pass unhindered through various gateways. The enhanced graphics of this game also acted as a relevant benchmark to gauge the performance of both Matti and the Unity engine on the online platform.

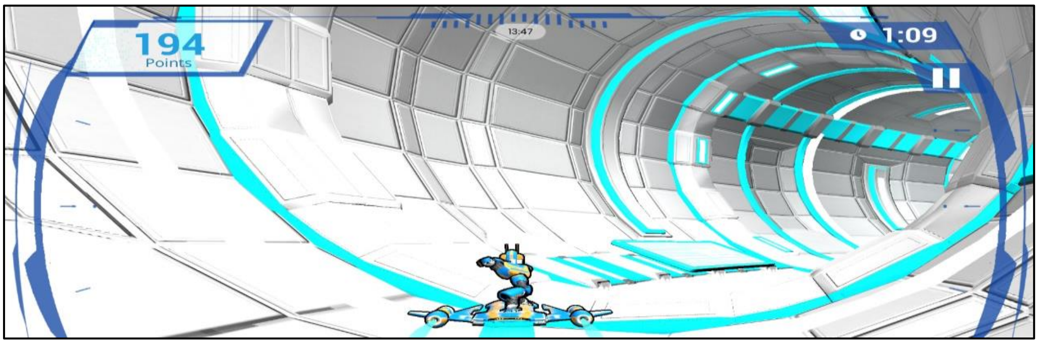


Figure 8 A Screenshot of the Exergame Netsurfer

2.2.3. Motor Analysis Tools

Assessing motor abilities and the general status of the patients is essential for evidence-based rehabilitation. However, studies show that measurement practices among physiotherapists are often inadequate (Jette *et al.*, 2009). Factors such as time constraints and lack of expertise are frequently cited as significant contributing barriers. Most performance-based motor assessment tools require therapists to multitask, focussing on the guidelines and the correct registration of quantitative and qualitative variables. Digital tools present a viable solution to address these challenges. In the first complete version of Matti, 4 simple analysis tools were integrated, enabling real-time measurement and visualization of surface contact and Center of Pressure (COP). The tools can accurately determine unipedal stance times and the number of repetitions during stationary stepping and jumping exercises.

2.2.4. Future Development

In line with the development process of the Matti device, any future development will incorporate input from all relevant stakeholders. Currently, a new study project is in process to evaluate the limits of the measuring and analysis capabilities of the device and adjoined platform. This project comprises both in vitro and in vivo testing, with the latter being performed using healthy individuals and participants suffering from various conditions affecting motor skills.

3. Discussions

Implementing technology in a clinical setting depends on multiple factors. These include adaptability, complexity, compatibility with existing work practices, and product cost of healthcare providers (Ross *et al.*, 2016). Specifically, the recommended requirements for a TUI in the clinical rehabilitation setting, obtained through structured interviews with physiotherapists in various fields, further show the multifactorial approach necessary to develop useful devices (Dujardin, 2019). The Matti 1.0 system (MMP) appears to meet most of these requirements, making it a viable TUI within the field of rehabilitation therapy.

The results obtained by Dujardin (2019) show the absolute necessity for continuous interaction between the different stakeholders within both medical (therapists, patients, etc.) and industrial fields (software, hardware, game developers, UI/UX designers, etc.). According to Bonnechère *et al.* (2016), collaboration between these 2 groups could lead to digital exergaming tools, significantly improving therapy outcomes due to higher adaptability and relevancy to clinical practice. The engagement of key stakeholders in the earliest possible phases of the implementation is vital to the overall process (Ross *et al.*, 2016). The importance of current monitoring, evaluation, and adaptation of systems was noted. In the case of Matti, while the hardware configuration is relatively fixed, the device's control through an external software platform enables iteration, evaluation, and adjustment of both the exergames and overall functionality. Through a shared software-based platform, users maintain continuous communication with developers, ensuring that updates to the system are automatically implemented.

It might also be necessary to investigate how the needs and requirements for different populations vary. For example, when playing similar exergames on Matti 0.1, senior users experienced more difficulty with their exercises than DCD children (Octavia *et al.*, 2023). Due to the multiple specializations within the field of rehabilitation sciences, namely neurological, pediatric, geriatric, and sports, a device designed for use in clinical practice should be able to cater to the various populations inherent in these specializations (Dujardin, 2019; Surjandari and Zagloel, 2017). A high-performance athlete could require high-intensity, variable, and complex reaction-based workouts, while a patient with an intellectual disability might only need straightforward repetitive exercises. Therefore, it is essential to develop fully customizable exergames through an intuitive and accessible interface that does not require any advanced computing knowledge. By connecting users and developers through a shared software-based platform, an iterative co-creation process can serve as a foundation for future development towards various populations.

The TUI discussed in this study shows some limitations. A general requirement of a TUI in a clinical setting is the multifunctionality of the system. In the case of Matti, the device could act as an exergaming platform and a motor analysis tool. This would enable it to increase and maintain both the motivation of the user and the evidence-based practices of the therapist (through objective movement data). However, the added value of the Matti system on both aspects of the therapeutic process remains to be shown.

The cost of the device might also impact its applicability in various contexts. While the overall cost of the device might be significantly lower than most high-tech, immobile devices such as posturography instruments, gait analysis set-ups, or force plates, Matti is currently unable to provide the same levels of accuracy. The Matti system needs to deliver clinically relevant, reliable, and valid motor analysis results to support the evidence-based decision process of the therapist and ensure proper follow-up of the patient. Given the lack of measurement practices of physiotherapists (Braun *et al.*, 2015; Jette *et al.*, 2009), affordable and efficient digital measuring tools have become indispensable in the arsenal of clinical practitioners. Since a very limited number of clinical physiotherapists encounter these types of complicated devices in daily practice, Matti could serve as an approachable and affordable measurement instrument for clinicians. Though the final version of the device already includes 4 motor analysis tools, future studies should assess the psychometric properties of these tools in both healthy and pathological groups. The interactive nature of the TUI prompts future investigations to evaluate the influence of gamified or interactive motor tests on test performance results.

The relatively high production cost of the Matti device hinders the adoption among physiotherapists working in low to middle-income countries. Low-cost prototyping devices such as Makey Makey, which were also used in the earliest stages of TUI development, could offer accessible and customizable alternatives (Lin and Chang, 2014). These devices enable the creation of rudimentary exergames similar to those discussed in this study.

4. Conclusions

In conclusion, by adhering to most of the requirements of TUI in the rehabilitation setting, the pressure-sensitive exergaming Matti device appears to be a promising tool for patient engagement in a clinical environment. Furthermore, since an iterative co-creation process was implemented in every stage of development, the device quickly adapted to the demands and necessities of various clinical populations. Future research is required to assess the effects of the adaptable exergames on short- and long-term patient motivation. The psychometric properties of all implemented motor analysis tools should also be investigated thoroughly before using the device as a diagnostic instrument. TUI in rehabilitation also provided new insights into the effect of digitized (or gamified) motor skill assessments on test performance results.

Acknowledgments

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