ArchHero: Rehabilitation of Flatfoot in Adults by Means of a Serious Health Video Game

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Abstract. Flatfoot is a pathology that affects a large percentage (15-20%) of the Mexican population; however, little emphasis has been placed on the physical rehabilitation of this condition. One of the main associated problems is the limited availability of physical rehabilitation options, which can lead to long-term complications, such as pain, postural imbalances, and decreased mobility. In this context, serious video games for health have proven to be effective tools due to their ability to provide immersion and motivation, fostering adherence to therapeutic treatments.

This work proposes the development of a serious video game called ArchHero, focused on the rehabilitation of flatfoot. It is designed to stimulate foot musculature and promote the correction of plantar curvature through interactive exercises, mainly the Short Foot exercise, which strengthens the intrinsic muscles of the foot. This solution seeks to improve the accessibility and effectiveness of therapy, providing an innovative, comfortable, and immersive alternative that enhances patient engagement and long-term rehabilitation outcomes.

Keywords: Interactive therapy, Flatfoot, Plantar curvature, Rehabilitation, Serious video games.

1 Introduction

Flatfoot is a condition that affects a significant portion of the population [1] and, in many cases, does not receive adequate attention in terms of rehabilitation. This pathology is characterized by a decreased or absent plantar arch, which can cause pain, muscle fatigue, and postural issues, ultimately affecting mobility and quality of life. Although conventional treatments exist, patient adherence to physical therapy is often

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low due to the monotony of the exercises and lack of motivation [4][2]. In this context, the goal is to develop ArchHero, a serious video game designed for flatfoot rehabilitation in adults. This project aims to integrate technology with therapeutic strategies to offer an immersive and motivating experience, facilitating treatment continuity. Through interactive exercises, it is expected to strengthen foot muscles and improve stability, contributing to the correction of plantar curvature. By incorporating gamification, the objective is to increase patient engagement in the rehabilitation process, reduce treatment dropout rates, and improve clinical outcomes. The target audience for this project consists of adults between 18 and 25 years old with moderate degrees of flatfoot, meaning they can benefit from physical therapy without requiring surgery.

Additionally, ArchHero is designed as a tool that can be used in both clinical and home settings, allowing patients to perform their exercises autonomously and at their own pace. Adult Acquired Flatfoot Disease (AAFD) is a progressive dysfunction of the posterior tibial tendon, leading to collapse of the medial longitudinal arch and alterations in foot biomechanics. This condition is more common in middle-aged women, particularly those who are overweight or have a sedentary lifestyle. Symptoms include ankle pain, instability while walking, and fatigue in the foot and leg. Depending on the severity of the deformity, treatment options range from therapeutic exercises and orthotic support to surgical interventions in advanced cases [2]. The diagnosis of this condition is made through clinical observation and imaging studies such as X-rays and MRI scans. Parameters like Meary's angle and the "too many toes" sign [4] help assess the severity of the deformity and guide appropriate treatment. However, access to advanced diagnostic tools and specialized therapies is often limited, emphasizing the need for accessible and effective alternatives like ArchHero. Through the development of this video game, we seek to provide a rehabilitation tool for patients with AAFD Grades 1 and 2A. The integration of pressure sensors will allow real-time monitoring of user performance, dynamically adjusting the difficulty of exercises according to progress. This solution aims to improve patients' quality of life by making functional therapies more accessible and promoting long-term adherence to treatment.

Fig. 1. Visual representation of the too many toes diagnostic method [4].

Fig. 2. Radiographs demonstrating the talonavicular angles and the heel-first metatarsal-sial angle [4].

Fig. 3. Radiographs demonstrating the Meary angle [4].

Additionally, the project proposes incorporating Galvanic Skin Response (GSR) sensors to monitor stress levels during rehabilitation sessions. By measuring electrodermal activity, it will be possible to assess the patient's physiological response to exercises, allowing for real-time difficulty adjustments. This approach seeks to optimize the rehabilitation experience by maintaining a balance between challenge and comfort, ensuring that therapy occurs in an environment that supports both physical progress and emotional well-being.

2 Related works

Adult flatfoot has been the subject of numerous studies analyzing its causes, diagnosis, and treatment options. According to the thesis by D. C. Bustos Madariaga [5], this condition affects the body's biomechanics, leading to both postural and functional problems. Traditionally, treatment has relied on the use of orthopedic insoles; however, recent research has examined the impact of therapeutic exercise in strengthening foot muscles to improve the plantar arch and reduce symptoms such as pain and fatigue [6][4][5]. Bustos Madariaga's study [5] classifies flatfoot into different degrees based on flexibility and severity. A distinction is made between flexible and rigid flatfoot: the former allows correction of the plantar arch when the foot is not bearing weight, while the latter presents a persistent deformity even in the absence of load. Additionally, depending on its progression, flatfoot may be managed through rehabilitation or require surgery. Moderate cases respond well to therapeutic exercises, orthotics, and physical therapy, whereas more severe cases characterized by persistent pain, advanced deformities, and instability may require surgical intervention to correct foot alignment and restore function. Recent studies have highlighted the importance of early re-habilitation, not only to relieve symptoms but also to prevent long-term complications and improve patient quality of life [4][2]. In this regard, developing accessible and engaging alternatives for physical therapy is essential to increase treatment adherence and optimize clinical outcomes.

2.1 Methods of flatfoot diagnosis

Flatfoot diagnosis relies on a combination of clinical tests and imaging studies. Henry [4] highlights the most commonly used methods, which include assessing foot alignment through functional tests such as the Too Many Toes marker and the Single-Limb Heel Raise test, along with weight-bearing radiographs to measure key angles like Meary's angle and talar coverage over the navicular bone.

Current diagnostic methodologies for flatfoot have several limitations. While the podoscope is useful for visualizing plantar pressure distribution, it provides only a two-dimensional representation, making it insufficient for a comprehensive assessment of foot dynamics. Additionally, result interpretation can be subjective and dependent on the examiner's experience, introducing variability and reducing diagnostic objectivity. Biomechanical measurements, joint mobility tests, and gait analysis require specialized equipment that is often expensive and available only in select centers. Moreover, the accuracy of these assessments depends on the practitioner's expertise, which can impact the reliability of results.

Advanced technologies such as 3D scanners and plantar pressure platforms enhance diagnostic precision, yet their high costs and complex data interpretation may limit accessibility. These methods are also sensitive to environmental factors and, in some cases, to measurement conditions, which can affect consistency in real world scenarios. While an effective combination of these techniques could improve diagnostic accuracy, technical and economic barriers remain.

Despite its usefulness in visualizing plantar pressure distribution, the podo-scope is limited by its two-dimensional nature and subjective interpretation, which can affect the accuracy of flatfoot severity assessment. Likewise, biomechanical measurements, joint mobility tests, and gait analysis require costly specialized equipment and rely heavily on the evaluator's expertise. These factors not only increase costs but may also compromise result validity when conducted in controlled environments that do not fully replicate real-life conditions. Additionally, advanced technologies such as 3D scans and plantar pressure platforms improve diagnostic accuracy, their high cost, data processing complexity, and sensitivity to external conditions hinder their routine use in clinical practice. These limitations highlight the need for diagnostic methodologies that integrate objectivity, precision, and accessibility.

2.2 Flatfoot rehabilitation

Flatfoot treatment involves multiple rehabilitation strategies, given that the condition varies in severity. According to D. C. Bustos Madariaga [5], treatment options range from orthopedic insoles to therapeutic exercises and physiotherapy techniques aimed at preserving foot musculature and enhancing its function.

Common rehabilitation methods include proprioceptive exercises, functional taping, physical agents, and, notably, the Short Foot exercise [4]. This exercise focuses on activating the intrinsic foot muscles to enhance stability and postural control. Studies indicate that regular practice can help increase the plantar arch and reduce flatfoot symptoms. Additional ankle mobility and strengthening exercises, along with gait training, further optimize patient recovery.

Complementary techniques such as manual therapy, electrostimulation, and closed kinetic chain exercises have proven effective in flatfoot rehabilitation. Combining these approaches can enhance foot function and gait while preventing deformity progression and related complications [4].

2.3 Types of video games in physical rehabilitation

This topic has gained relevance in recent years. According to Ravenet's review [3], the most used consoles and peripherals in physical rehabilitation are those equipped with motion sensors, such as the Nintendo Wii®, PlayStation EyeToy®, and Xbox Kinect®

Video games have been incorporated into various rehabilitation approaches, ranging from neuromuscular to motor and postural rehabilitation.

The most used rehabilitation games include:

- Balance games: Designed to improve stability by challenging postural control in virtual or augmented reality environments.
- Coordination games: Require precise limb movements and promote neuromuscular synchronization.

- Strength and endurance games: Aim to increase muscle capacity and effort tolerance in patients with functional limitations [3].

Additionally, these games have proven effective for lower extremity rehabilitation by offering repetitive, predictable tasks that promote neuroplasticity and functional adaptation.

Studies have shown that rehabilitation video games enhance more than just mobility; they also provide engaging and motivating experiences that encourage treatment adherence. Combining video games with traditional physical therapy has yielded positive results in patients with neurological injuries, musculoskeletal disorders, and postural control issues, highlighting their potential as an effective complementary tool for functional recovery [3].

3 Methodology

Flatfoot is characterized by a weakness in the posterior tibial tendon, which serves as the primary force behind walking. This tendon plays a crucial role in maintaining the stability of the medial arch, providing cushioning, and contributing to propulsion during gait [2]. The medical community recognizes four common types of flatfoot based on the degree of foot arch collapse. Specifically, Type I is defined by a slight reduction of the plantar arch without significant functional impairment; Type II involves a moderate loss of the arch accompanied by some instability during the stance phase; Type III is marked by a more pronounced deformity that significantly affects alignment and load distribution; and Type IV represents the most severe cases, with structural deformities and considerable functional compromise [4].

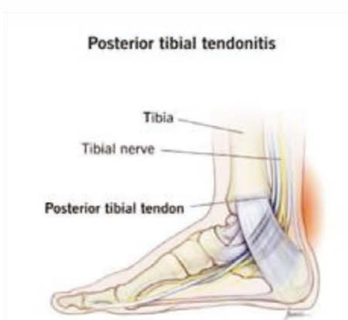

Fig. 4. Posterior tibial tendon. [7].

Flatfoot diagnosis primarily relies on standing radiographs, which allow for the measurement of various interosseous and intermuscular angles. For instance, the talonavicular angle evaluates the lateral deviation of the navicular bone relative to the calcaneus, while Meary's angle assesses the alignment between the first metatarsal and the heel. Both parameters are critical for quantifying the severity of the deformity [6].

Additionally, the "Too Many Toes" test is employed, wherein the number of visible toes on the lateral aspect of the foot is observed; however, this test only confirms the presence of flatfoot without classifying its specific type [4].

In terms of treatment, three primary methods are currently used: surgical intervention, orthopedic insoles, and physical therapy. While surgery can correct structural abnormalities and insoles help redistribute weight, physical therapy is essential for strengthening the musculature and improving posterior tibial tendon function. Nonetheless, conventional physical therapy often suffers from low adherence due to the monotonous and effortful nature of the exercises.

To address these limitations, the present project proposes the development of ArchHero a device that incorporates serious video games for health. These video games, which have been successfully used in physical rehabilitation to enhance balance and gait [4], provide an immersive and rewarding environment that promotes the constant repetition of therapeutic exercises. In particular, the "Short Foot" exercise is integrated as the primary strategy for strengthening the posterior tibial tendon, offering both ease of implementation and objective progress measurement.

The project is structured around three fundamental pillars:

1. Continuity in Physical Therapy: The device is designed to encourage consistent treatment adherence through an interactive and motivating video game environment that promotes regular exercise repetition.
2. Diagnosis and Monitoring: It integrates pressure sensors based on the "Too Many Toes" technique to objectively evaluate foot load distribution, facilitating continuous monitoring of therapeutic progress.
3. Stress Response-Based Difficulty Modulation: By incorporating galvanic skin response (GSR) sensors, the device measures a user's stress levels in real time. This data dynamically adjusts the game's difficulty, ensuring the therapeutic environment remains both challenging and approachable. When stress levels are high, the device automatically reduces challenge intensity to prevent frustration and emotional fatigue; conversely, when stress is low or moderate, the difficulty increases progressively to keep the user engaged without causing overwhelm.

This adaptive feedback system optimizes the rehabilitation process by maintaining a balance between challenge and comfort. As a result, it is expected to boost user motivation and extend therapy duration, ensuring that exercises are performed consistently and effectively.

Understanding foot biomechanics is fundamental to addressing flatfoot rehabilitation, as it involves analyzing the interaction of anatomical components during activities like walking and running. While traditional rehabilitation focuses on exercises and physiotherapeutic treatments to improve foot function and prevent complications [4], the innovative use of serious video games in this project offers a dual benefit: enhancing both the therapeutic and entertaining aspects of the re-habilitation process.

ArchHero leverages pressure sensors and tracking systems to provide real-time feedback, thereby increasing patient participation. The modular design of the device integrates insights from biomechanics, physical rehabilitation, biomedical engineering, and serious video game technology. Moreover, the thesis by D.C. Bustos Madariaga [5] supports this non-invasive therapeutic approach for treating adult flatfoot, further validating the rationale behind this innovative project.

4 Discussion, application, trends and opportunities

4.1 Innovation

The fusion of low-cost pressure sensors with interactive environments based on serious video games represents an innovative alternative that could transform the diagnosis and treatment of rigid flatfoot. By incorporating galvanic skin response (GSR) sensors, the device can adapt the difficulty of the video game in real time according to the user's stress levels, ensuring personalized treatment and preventing emotional overload. This gamified therapeutic process fosters greater adherence to treatment, thereby enabling effective long-term rehabilitation.

4.2 Social Impact

The project has a significant impact on society, particularly for individuals with limited access to specialized rehabilitation services. By offering a more accessible and engaging treatment through gamification, this approach has the potential to improve patients' quality of life, reduce recovery time, and promote healthy habits from an early age. Early detection of anomalies combined with personalized rehabilitation via serious video games allows for more effective interventions, which can reduce pain, improve mobility, and prevent complications associated with the pathology. Additionally, the integration of biomedical data, engineering design, and biomechanical knowledge paves the way for new re-search and advancements in digital health, fostering collaboration across various disciplines.

4.3 Development or market potential

The project demonstrates high development and market potential in response to the growing demand for technological solutions in rehabilitation. Its modular and cost-effective design makes it highly attractive for clinics, hospitals, and physiotherapy centers that seek to innovate in their treatment methods. Furthermore, the possibility of customization and adaptation for various biomechanical pathologies broadens its commercial reach and viability across different markets. Although the current approach remains theoretical, the robust rationale underlying the project lays the groundwork for future experimental implementations, clinical validations, and the development of functional prototypes to bring this proposal into practical application.

4.4 Definition of system requirements

Based on previous research, specific requirements for the theoretical system have been established:

- Functional: The system must accurately capture plantar pressure distribution, integrate with video games, and adapt to different user profiles [8].
- Technical: It should utilize low-cost sensors, perform real-time data processing, and feature a user-friendly interface [8].
- Ergonomic: The device must be comfortable and should not interfere with the user's mobility [8].

4.5 Evaluation of applied technologies

A thorough analysis of available technologies was conducted to determine the most appropriate options for the proposal:

- Pressure Sensors: These were selected for their affordability, flexibility, and ease of integration into the system [8].
- Data Analysis Software: Theoretical evaluations suggest that advanced processing algorithms can significantly enhance the interpretation of collected data [8].
- Gamification and Visual Feedback: A proposal was developed for a serious, adaptive video game that utilizes sensor-captured data to provide real-time visual feedback to the user.

5 Conclusion

ArchHero represents an innovative approach to flatfoot rehabilitation, combining technology and gamification to enhance therapy adherence. Conventional rehabilitation methods often suffer from low motivation and accessibility barriers, making this interactive approach a viable alternative.

By integrating pressure sensors and GSR monitoring, the video game is planned to adapt in real time to a user’s performance and stress levels, ensuring personalized treatment. This approach not only improves adherence but also contributes to a more engaging rehabilitation experience.

The project’s potential extends beyond flatfoot rehabilitation, as its modular design allows adaptation to other biomechanical pathologies. Further experimental implementations and clinical validations are recommended to assess its effectiveness in rehabilitation and potential applications in other physical therapy domains.

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