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Review

Tele-Physiotherapy Platforms: A Review

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Received: 11 June 2025; **Revised:** 20 July 2025; **Accepted:** 23 July 2025; **Published:** 8 August 2025

Abstract: Physiotherapy has been a subject of research, targeting the facilitation of monitoring and remote assistance provided by the physiotherapist, whenever collocation of doctor and patient is not possible. This is known as tele-physiotherapy, or tele-rehabilitation. It has evolved significantly over the past few decades due to advancements in technology, but has also become a necessity during particular periods, for example, during the COVID-19 pandemic. Initially, tele-physiotherapy was mostly performed using video conferencing and mainstream telecommunication services; however, recent developments have seen the emergence of sophisticated tele-physiotherapy platforms that integrate various technologies such as sensors, wearable devices, and digital health platforms. Moreover, the incorporation of Machine Learning (ML) and Artificial Intelligence (AI) enables real-time analysis, treatment personalization, and the introduction of feedback mechanisms, thus improving the usability and efficiency of rehabilitation sessions. Tele-physiotherapy solutions address the scope from a wide variety of aspects and demonstrate variable effectiveness. This review examines 19 studies and solutions and compares 14 of those proposals that offer a tele-physiotherapy solution for patients. Although their services, complexity and functionality vary, the basic criterion for inclusion in the evaluation was that they offer a tele-physiotherapy service as a part of their main scope. Some of those solutions are commercially available, some are at a research level, but all of them were primarily addressed from the aspect of usability.

Keywords: Tele-Physiotherapy; Remote Rehabilitation; Wearable Sensors; Machine Learning

1. Introduction

Physiotherapy is a critical area in healthcare and is essential for the recovery of patients with chronic diseases, post-surgical period disorders, and musculoskeletal problems. It is commonly understood that person-to-person sessions with the therapist are essential for the good progress of the therapy; however, this might be limited due to challenges of geographical, financial, or other logistical nature. Moreover, it is far more encouraging for patients with motion problems to avoid transportation as much as possible.

Although remote video sessions would offer an obvious solution, considering the availability of this technology to every mobile phone and household, more effort has to be put into developing solutions that would guarantee better accuracy and reliable end-to-end service.

With rapid progress in the areas of sensor technologies, wearable systems, Machine Learning and Artificial Intelligence, it is possible to evolve from simple video consultations towards more advanced systems that combine real-time data acquisition, accuracy, session data recordings, automated evaluation, and personalized recommendations. Such integration can be the basis for solutions that can cover the gaps and connect the dots between conventional therapy and modern techniques in telemedicine, offering improved results, wider acceptance, and essential assistance to patients and therapists. A summary of tele-physiotherapy evolution is shown in **Figure 1**.

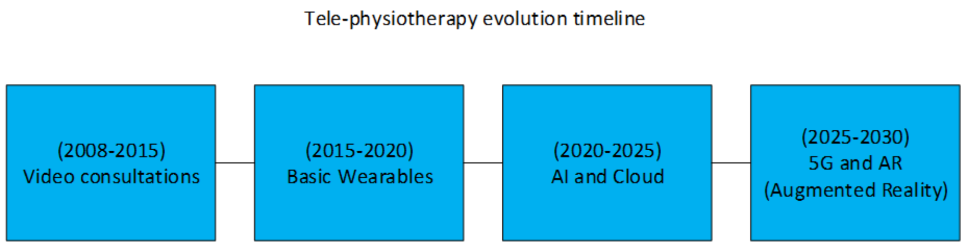

Figure 1. Tele-Physiotherapy Evolution Timeline.

The tele-physiotherapy journey includes the patient side, usually at home, with the required capturing devices, monitoring sensors plus any related hardware and the clinic side, where the doctor's equipment reside. The application may be hosted on independent provider or on the cloud. The two sides interact as described in **Figure 2**.

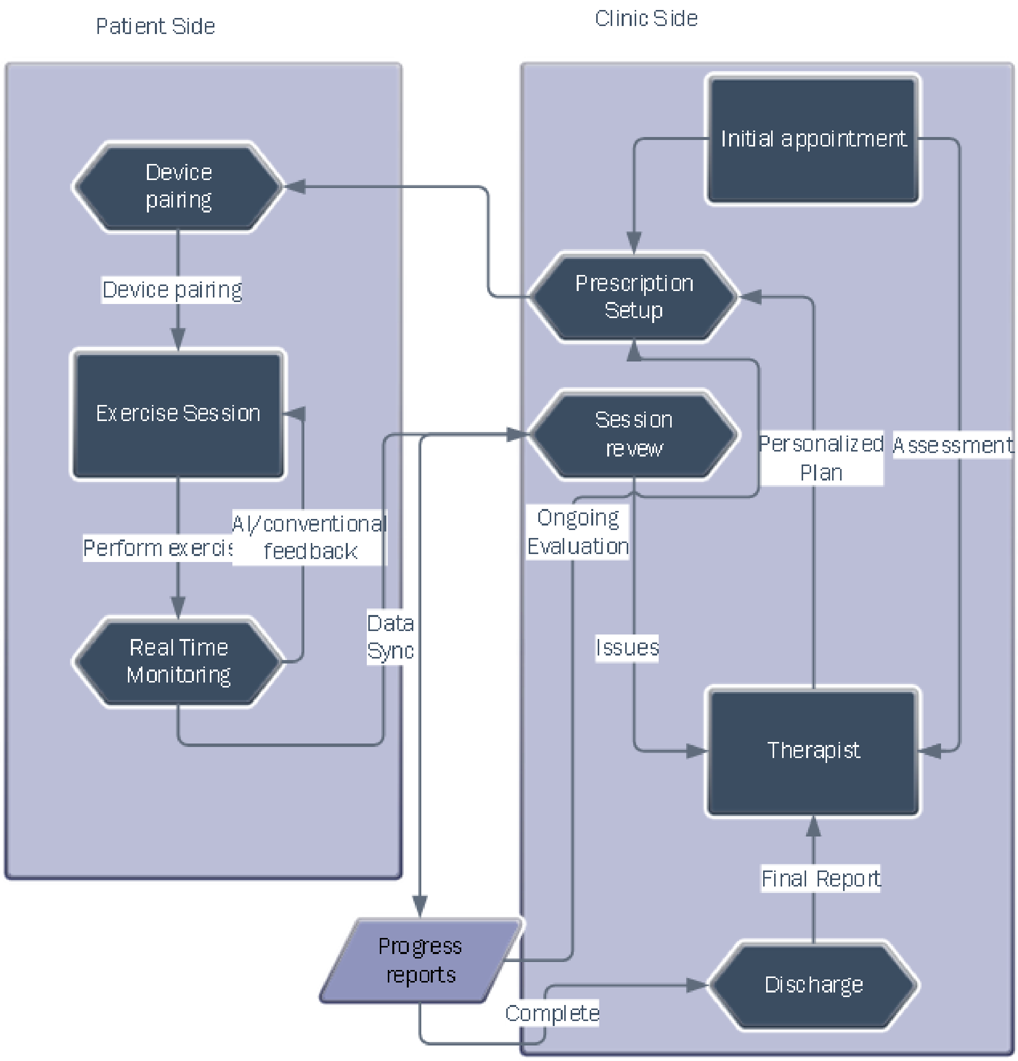

Figure 2. Tele-Physiotherapy Flowchart.

Several studies have evaluated tele-physiotherapy applications with specific findings:

Cottrell et al. screened 5913 abstracts where 13 studies met the eligibility criteria [1]. According to results, it is suggested that tele-physiotherapy is effective in the improvement of physical function (Standardized Mean Difference (SMD) 1.63, 95% Confidence Interval (CI) 0.92–2.33, I2 = 93%). According to sub-group analyses it is shown that tele-physiotherapy in addition to usual care is favored more (SMD 0.64, 95%CI 0.43–0.85, I2 = 10%) than usual care alone. Also, treatment which is delivered solely via tele-physiotherapy is equivalent to face-to-face intervention (SMD Mean Difference (MD) 0.14, 95% CI−0.10–0.37, I2 = 0%) for the improvement of physical function. The conclusion was that real-time tele-physiotherapy appears to be efficient and can be compared to conventional methods of healthcare. Moffet et al. evaluated the results from a controlled trial with 205 patients randomized into two groups [2], having the same rehabilitation intervention in both groups; only the approach for service delivery differed (telerehabilitation or home visits). Characteristics of all participants were similar at baseline. Both groups displayed very high satisfaction levels (over 85%), a result which, together with evidence of clinical effectiveness and cost benefits demonstrated in the same sample of patients, is a strong indicator that the use of tele-physiotherapy improves access to rehabilitation services and efficiency of service delivery after TKA (Total Knee Arthroplasty). Sarfo et al. based their search in PubMed and Cochrane library from January 1, 1980, to July 15, 2017, targeting pilot trials, randomized controlled trials, or feasibility trials where an intervention group that received tele-physiotherapy for stroke survivors was compared with a control group on standard care [3]. The provided evidence suggests that tele-rehabilitation interventions have either better or equal effects on motor, higher cortical, and mood disorders when compared with conventional face-to-face therapy.

As technology expands and provides more solutions, healthcare provides a wide field of applications. A number of reviews already explore such options, several of them focusing on tele-physiotherapy. A review by Kakegawa and Matsuda focuses on wearable sensors (electromyography (EMG), accelerometers, gyroscopes) for tele-physiotherapy monitoring and motion capture techniques, addresses the issues of sensor accuracy, calibration challenges, and real-time data transmission [4].

Rashidieranjbar et al. survey generative AI in healthcare in general and whether this can be a substitute for a doctor [5]; it is not specific to tele-physiotherapy, however. In a similar aspect, Mohapatra et al. focus on AI-driven platforms and their application in physiotherapy, classify ML algorithms or movement analysis and personalized rehab plans and provide taxonomy of ML techniques – providing more focus towards AI/ML and how it can be utilized [6].

Our review aims to provide an overall view of existing proposals and studies, from both commercial and research perspectives, which offer a solution to the tele-physiotherapy challenge. They may range from 'off the shelf' solutions to highly complex implementations, all targeting to provide rehabilitation to patients located remotely from the therapist. Different concepts and technologies are reviewed, from older and simpler videoconference platforms to more modern AI/ML-based solutions. The focus is to evaluate across technology, usability and scalability and in parallel to address the gaps and challenges for future research.

For the scope of this review, searches have been performed in Google Scholar and in Google using the keywords "tele-physiotherapy", "telerehabilitation", "remote rehabilitation", "sensors", "platform", "machine learning", "artificial intelligence" with appropriate "OR" and "AND" filters on combinations of the keywords. Selection was focused on solutions that offer a complete tele-physiotherapy proposal, at a commercial or research level.

The remainder of this paper is structured as follows. Section 2 reviews existing solutions, ranging from basic videoconferencing platforms to commercial offerings. Section 3 examines solutions leveraging commercially available motion capture platforms, while Section 4 explores systems that integrate sensors and robotic components for the specialized treatment of specific body parts. Section 5 highlights the research initiatives that incorporate sensor data processing and capabilities for remote monitoring, consultation, and assessment. Section 6 focuses on solutions utilizing Machine Learning (ML) and Artificial Intelligence (AI) to provide autonomous feedback, even in the absence of a supervising therapist. Section 7 contains a summary review for proposed solutions which demonstrate an active user base or pilot deployment. Section 8 summarizes the challenges and opportunities in the field. Finally, Section 9 concludes with key takeaways and potential directions for future research.

2. Use of Videoconference Software or Specialized Web-Based Platforms

The simplest method, which involves technology that is quite affordable and part of every household, is through videoconference software over an Internet connection. There are many options offered, such as Skype, Zoom, Viber, and Messenger(s). The patient must guarantee that he is under constant camera coverage. Despite the simplicity and ease of this solution, a series of disadvantages exist, such as sole dependence on video without any numeric data or sensor indicators, no recordkeeping, and being limited to specific demands only.

Several platforms already offer integrated videoconferencing services with useful add-ons, such as

- Exercise prescription and monitoring: Personalized exercise programs tailored to each patient can be prescribed and patients can access them through mobile apps or web portals and receive appropriate guidance. Some platforms also provide integration with wearable sensors or motion tracking technologies.
- Progress tracking and reporting: Such platforms offer tools for recording patient progress over time. This may include tracking improvements, the range of motion, strength or functional abilities. The assessment was performed by appropriate reporting through the platform.
- Patient engagement: Platforms can provide educational materials, videos, tutorials, and other libraries to assist patients in engaging better in treatment.

Examples of such platforms are listed below:

Physitrack is a telehealth platform that includes a user-friendly system for prescribing exercises, tracking, videoconferencing consultations, and patient education tools in order to assist the rehabilitation process [7]. A related study suggests that Physitrack is well-suited to support treatment but not to replace a physical therapist. Patients who used Physitrack accepted the application as part of treatment when it was easy to use, beneficial for their needs and when they were instructed by the therapist [8]. Doxy.me is a telemedicine platform that is not specific to physiotherapy [9], but does provide basic functions, including secure video, for remote healthcare sessions, including physiotherapy. It contains a capable VR interface which was assessed in a study for treating adults with phobias, results yet to be published [10]. Phzio is a tele-physiotherapy platform that offers virtual physiotherapy sessions, related tracking of progress, communication tools for both patients and therapists, and programs for personalized exercise [11]. These platforms are only a few examples in the area of tele-physiotherapy, which is continuously growing and includes many solutions for both patients and health care providers. Each platform offers unique capabilities and features to meet the needs of different patient groups or clinical situations.

3. Use of Motion Capture Technologies and Virtual Reality Over Gaming Platforms

The development of motion capture techniques in various industries (gaming/movies) has provided platforms that can be used in tele-physiotherapy. Such motion-capture gaming platforms can be integrated with software that guides physiotherapy exercises (frequently packaged as a game that challenges the patient for movements of increased difficulty) and with data-gathering and analysis modules.

Moreover, virtual reality setups combined with gaming software are ideal for providing a more entertaining way to perform exercises. Simple tasks, such as progressive arm movement to higher levels, could be presented as a collection of apples from trees in higher and higher branches. The virtual reality environment also ensures precision in task execution and the accuracy of related results. In parallel, a data-collection mechanism can record all motion histories and transmit the results to the monitoring environment. The supervising doctor can have a view and complete record of the entire session.

Some examples of such platforms' usage can be found in the following cases:

PlayStation 3-based Tele-rehabilitation for Children with Hemiplegia was developed for in-home tele-physiotherapy on a PS3 game console for children and adults with chronic hemiplegia after stroke or other focal brain injuries [12]. PS3 uses the home Internet connection and uploads tele-physiotherapy data to a clinical database. Progress can be remotely monitored, in addition to compliance with the established protocol of therapy. Another solution that has a child-friendly interface is the Kinect-based Constraint-Induced therapy program for children with Unilateral Cerebral Palsy, which is a VR-based solution developed using Microsoft Kinect [13]. This platform includes a camera and an infrared emitter with an infrared depth sensor. Patient movements in three dimensions can be measured and real-time feedback can be provided for each movement. A game has been developed (based on research for the preferred game of a group of children) – it is called "Adventure Island." In this game, the child tries to defeat monsters and collect points or place items on specific locations or defeat enemies. The study was conducted in two phases: the first one was a pilot, and the second was a study where eight children had to participate in 18 hours of training sessions for 8 weeks. With regard to the exercise performance in the game, the mean performance score at baseline was 60.30% (SD 18.17%). The performance score increased significantly at the third and fifth weeks from baseline, and progression was stable from the fifth week to the last. For the BBT (Box and Blocks Test), the mean score at baseline was 22.33 blocks (SD = 20.93). The mean score of the BBT increased significantly at the third and the fifth weeks from baseline, and progression was stable from the fifth week to the last, which was consistent with the performance scores. Another Kinect-based solution is Kinerehab which targets an adult group with motor disabilities [14]. It offers enhanced monitoring capabilities and reduces the therapist's workload. In this study, 4 participants (aged 16 and 17 years—3 with cerebral palsy and one with muscle atrophy) took part. The participants were very interested in the system and wanted to continue using it even after the experimental period, as it had increased their motivation in rehabilitation. Finally, a combination of Virtual Reality (VR) and Bio-feedback using MS Kinect is described in Interactive Physiotherapy: An Application Based on Virtual Reality and Bio-feedback [15]. This system is based on the MS Kinect and Oculus VR. It provides an entertaining platform for patients suffering from physical injuries or ailments, such as Parkinson's disease, Arthritis, Carpal Tunnel Syndrome, and Stroke. Various sets of muscle exercises were performed while tracking the patient's skeletal movements. In this study, three healthy participants and one with PD (Parkinson's Disease) participated. The software proved to be an efficient and interesting tool for physiotherapy. The participants preferred the VR-based exercise for physiotherapy over a traditional one.

4. Use of Specialized Commercial Physiotherapy Platforms with Remote Monitoring Capabilities and Active Feedback

Currently, there are some commercially available platforms that specialize in specific therapy situations and integrate sensors that offer enhanced capabilities for monitoring patients' movements and related progress during remote rehabilitation sessions. Real-time data are provided on the patient's movements, and the remote therapist can assess the technique, track progress, and adjust the plans accordingly.

TECHNALIA developed ArmAssist (AA) [16,17]. This tele-physiotherapy platform is used to rehabilitate post-stroke patients on the upper limbs at home. It comprises robotic modules with multiple sensors. When a user is engaged, they perform continuous assessments of the situation and facilitate home-based rehabilitation. The therapist remotely supervises the entire session.

Rehab-Robotics offers physiotherapy solutions that use robotic devices equipped with sensors or other specialized technical setups [18]. Patient movements are tracked and detailed feedback is provided to the remote therapist. Some products that can be used during tele-physiotherapy sessions are

- Hand of Hope is a robotic hand assistant used for neuromuscular rehabilitation of the hand and forearm of a patient [19]. It contains surface electromyography (sEMG) sensors. By reading a patient's own muscle signals, we can detect the desire to move the hand and activate the required movements. The signals were processed and visualized using visual feedback. A study on EMG-aided Robotics Hand for Rehabilitation describes the use of the "Hand of Hope" as convenient to use by patients without a secondary local assistant [20].
- Visio Roller which is an interactive training and exercise system for wheelchair users [21]. The system is addressed to people who have recently been disabled and to those who want to improve their skills in wheelchair usage and muscle training. The system should be in the exercise area of the patient; however, the therapist should be remote.

5. Use of Integrated Tele-Physiotherapy Solutions on a Research Level

Wearable sensors can be a significant asset of tele-physiotherapy systems and can offer a variety of real-time data on patient movements, body posture, pressures involved, and muscle activity. The most widely used sensors in this domain include the following:

Accelerometers are used to measure the acceleration of a body part in 3D space, while gyroscopes measure the angular velocity. They are embedded in many modern wearable devices, such as smart watches, fitness bands, and mobile phones. They can be purchased individually and integrated into a complete system. Accelerometers and gyroscopes provide data for the analysis of movements or joint angles, and can also be used to measure deviations from prescribed rehabilitation protocols.

EMG sensors are used to retrieve data that helps assess muscle performance or fatigue during rehabilitation exercises. They measure the electrical activity in muscles during contraction. Therapists can assess muscle activity remotely and adjust the rehabilitation accordingly.

Force sensors measure the pressure or force exerted by a patient. A variety of wearable devices such as gloves, insoles, and others can embed such sensors to evaluate force exertion, grip strength, or balance. Such measurements are useful for patients with conditions that affect their motor skills.

All listed sensors can provide data to a central monitoring system, which contains the necessary interfaces for providing graphical and data feedback to both patient and doctor while storing the sessions in data storage for later review. In this field, modern technologies in IoT (Internet of Things) and Blockchain technologies are providing solutions that standardize data collection from sensors, processing, distribution and storage. While a plain IoT proposal requires a centralized processing and storage solution, which in turn will provide the analytics information to the end user, a Blockchain alternative offers a distributed system more compliant with the emerging standards (**Figure 3**).

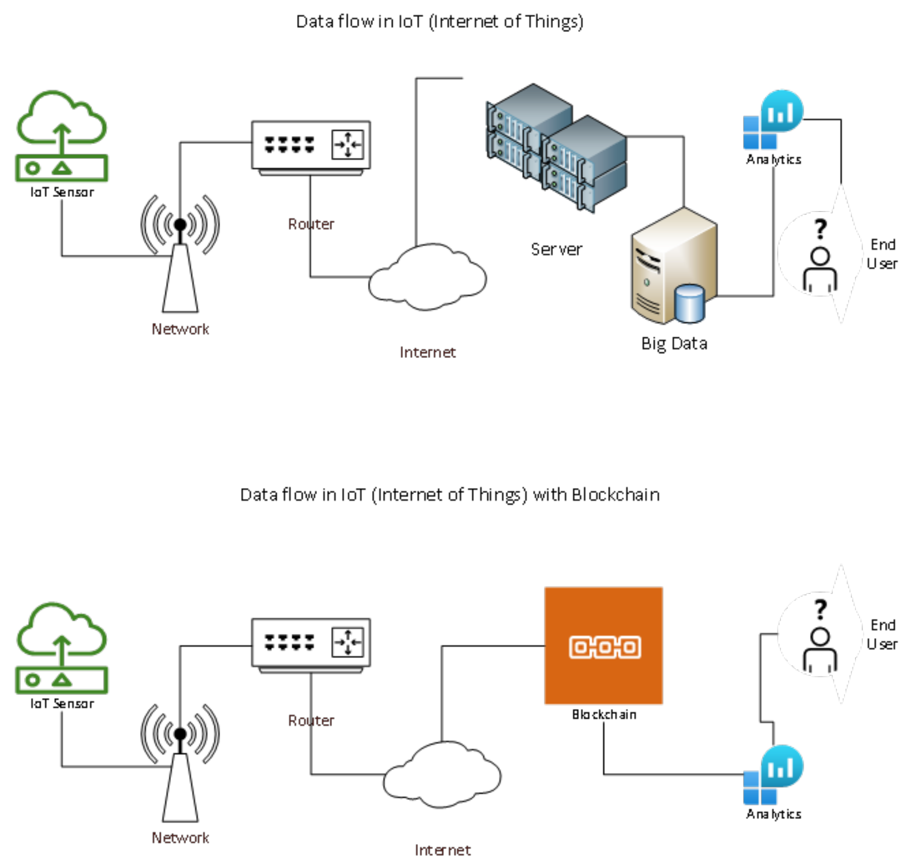

Figure 3. Plain and Blockchain-Based IoT Flowchart.

Some end-to-end tele-physiotherapy solutions at the research level are as follows.

(A) An Internet of Things (IoT) tele-physiotherapy system has been used for elbow rehabilitation and uses accelerometer and gyroscope sensors [22]. All movement data were recorded on a cloud-based system, and remote therapists could access them for assessment and further advice. (B) An innovative tele-physiotherapy platform establishes an integrated solution that provides 3D visual output to the therapist to better assist their patients who are motivated to perform physiotherapy exercises [23]. Sensors track and record movements while the related data are displayed to the therapist. The system also includes a real-time 3d human body model to provide feedback to the patient to encourage and provide visual feedback. Sensors are strapped at designated points in the body to guarantee appropriate monitoring. All related data were collected and stored in a database.

6. Use of Machine Learning and AI in Platforms

Machine Learning and AI can provide additional value in tele-physiotherapy solutions. While Physiotherapy traditionally requires direct supervision by healthcare professionals, the engagement of Artificial Intelligence (AI) and Machine Learning (ML) has enabled tele-physiotherapy solutions that can advance from basic video consultation to systems capable of performing real-time monitoring and evaluating exercises and offering recommendations to the patient.

In ML algorithms either supervised or unsupervised learning approaches are utilized. What we call supervised learning is the training of the algorithms on specific labeled datasets, where each input data point is associated with a specific output. For example, an algorithm can be trained using collections of specific images of patterns labeling them as 'right' or 'wrong' and enabling it to predict whether a gesture or position falls into the right or wrong category. What we call unsupervised learning, is when algorithms are employed when input data lack designated outputs, and their purpose is to identify patterns within the data. Some examples of unsupervised learning algorithm applications can be found in motion pattern clustering, anomaly detection or personal progress tracking.

Several commercial tele-physiotherapy platforms have incorporated ML and AI technologies to enhance remote rehabilitation. These platforms use various methods to monitor patient movement and performance, such as sensors (accelerometers, electromyography (EMG) sensors) and/or cameras. Some commercially available examples focus on simplicity of use and minimal requirements for equipment. Kaia Health analyzes patient movements using computer vision and AI analysis [24]. Visual input comes from a simple device, such as a smartphone camera, and automated feedback is provided to the patient for exercise execution. Kaia Health's system does not use sensors; instead, it has been trained on a large set of visually tracked movement sequences, so it can detect incorrect executions and suggest appropriate corrections. A study compares application evaluation of exercises versus therapist evaluation on Kaia Health where 24 participants received feedback for the correctness of a set of 6 exercises by the application [25], while two physiotherapists evaluated them separately. The analysis compared therapist-1 vs therapist-2 and also the application rating vs each one of them and showed no detectable difference in the rates of interrater agreement in any of the exercises. In a different approach, DorsaVi offers a wearable sensor-based platform that analyzes movement and muscle activity using ML algorithms [26]. It provides reports used by therapists to create personalized plans. It can be used for both physiotherapy purposes and to enhance sports performance by monitoring musculoskeletal health and providing real-time feedback for injury prevention, and can assist in rehabilitation progress and exercise analysis. A related study assessed DorsaVi Version 6 sensors for their concurrent validity with the Vicon motion analysis system for measuring lumbar flexion during lifting [27]. Twelve participants (nine with back pain and three without) wore sensors on T12 and S2 spinal levels with Vicon surface markers attached to those sensors. Participants had to perform five symmetrical (lifting from front) and 20 asymmetrical lifts (alternate lifting from left and right). The findings display that the root means squared errors were slightly better for symmetrical lifts than they were for asymmetrical lifts. However, the root mean squared errors for all lifts were better than previous research and below clinically acceptable thresholds; as such, this study supports the use of lumbar flexion measurements from these inertial measurement units of the Dorsavi system in populations with low back pain, where multi-plane lifting movements are assessed.

Apart from the aforementioned commercial platforms, which focus on a specific aspect of using ML to provide either visual feedback or offline analysis to the therapist, there are also research cases for systems that further explore and enhance such capabilities and feedback generation. Some examples are listed below:

Research on a biofeedback system using machine learning algorithms proposed a system that can be integrated into tele-physiotherapy platforms to assist patients with their exercises [28]. It uses Machine Learning (ML) and focuses on the classification of incorrect or correct execution of nine rehabilitation gestures using MS Kinect for tracking. In this approach six different classifiers were trained and compared including Random Forest (RF), Multilayer Perceptron Artificial Neural Network (MLP ANN), Naïve Bayes (NB), Support Vector Machine (SVM), k-Nearest Neighbors (KNN), and Logistic Regression (LR). The dataset consisted of the data collected from 30 participants performing nine gestures using Leave-One-Subject-Out (LOSO) and 10-Fold approaches. This study is a good example of supervised learning methods, achieving an average accuracy of 89.86% ± 3.38% and F1-Score of 72.84% ± 11.98% for 10-Fold and an average accuracy of 88.21% ± 3.90% and F1-Score of 68.16% ± 13.28% for LOSO. Based on a MEMS sensor-based approach, another study proposed a system that focuses primarily on a cost-efficient tele-physiotherapy prototype [29]. It utilizes cost-efficient micro-electro-mechanical system (MEMS) sensors such as the MPU6050 accelerometer and ATmega328P controller. Collected data analysis versus the expected profile provides feedback on the correctness of the action. This study focused on one limb, which could be extended. Another study that focuses on low-cost and uses mobile phone RGB camera motion tracking is called PyTracker [30]. It uses Machine Learning (ML) and statistical analysis to track and monitor the range of motion and evaluate the performed exercise. More specifically, it uses a combination of classifier matching and manual input to identify features; at the beginning of each session, it identifies the start points through the use of classifiers built from Haar Cascades supplemented by manual input in case of less-rigid features. Smartphones are also used in research that focuses on data collected from sensors built into phones [31]. This proposal is focused again on low cost and availability, taking advantage of the built-in accelerometer, gyroscope, and magnetic field sensors. By attaching the smartphone to the patient's limb and processing the data collected by the smartphone-based sensor, the results can be fed into ML algorithms that can assist in evaluating the correctness of the exercise by the remote physician. The system uses a machine learning approach based on multiple linear regression (MLR) to build a model of the roll angle value obtained from the Android software-derived rotation sensor, but also uses raw data from the accelerometer, gyroscope, and magnetic field sensors to build an MLR model. The specific study focuses on the rehabilitation of the "Frozen shoulder" case and used machine learning to estimate the arm angle of rotation using only the accelerometer sensor.

7. Evaluation of Referenced Tele-Physiotherapy Platforms

For the evaluation of tele-physiotherapy platforms, it was important to cover diverse application areas and initiatives that led to these studies or applications. As such, although specific selection criteria were applied, such as the publication date, older studies had been included if they were considered to cover a viewpoint that added value to the review. More focus was given to demonstrate an active user base or pilot deployment, and provide sufficient methodological detail. In the grading matrix, key dimensions such as Technology, Usability, Accuracy, Cost, and Scalability were assessed. Those dimensions had been treated equally in order to provide an overall grade.

To assess the reviewed tele-physiotherapy platforms, a grading matrix was used, based on the following parameters:

- Technology: This relates to the sophistication and integration of technologies such as sensors, AI, VR, and IoT.
- Usability: Relates to ease of use, patient adherence, and engagement through motivation provided during rehabilitation.
- Data accuracy: Relates to the reliability and precision of collected data.
- Scalability: the potential for the solution to be adapted to different populations of patients and different clinical setups.
- Cost efficiency: Relates to the affordability of the solution on both sides (patients and healthcare providers)

Each solution was graded on a scale of 1–5 (1 = poor, 5 = excellent) for each criterion. Original references and an analysis of the limitations and strengths of each solution were used to create the grading (**Table 1**).

Table 1. Tele-physiotherapy solutions evaluation.

Solution	Technology	Usability	Data Accuracy	Scalability	Cost Efficiency	Overall Grade
Physitrack [7]	3	4	2	4	4	3.4
Doxy.me [9]	3	4	2	3	4	3.2
Phzio [11]	3	4	2	4	4	3.4
Playstation 3-based Telerehabilitation [12]	4	4	4	3	4	3.8
Kinect-based Constraint-induced therapy [13]	4	5	4	4	4	4.2
Kinerehab [14]	4	5	4	4	4	4.2

Table 1. *Cont.*

Solution	Technology	Usability	Data Accuracy	Scalability	Cost Efficiency	Overall Grade
ArmAssist (Tecnalia) [17]	5	4	5	2	3	3.8
Hand of Hope (Rehab-Robotics) [19]	5	4	5	2	3	3.8
Visio Roller (Rehab-Robotics) [21]	5	4	4	2	3	3.6
Kaia Health [24]	4	5	4	5	4	4.4
DorsaVi [26]	4	4	5	4	4	4.2
PyTracker [30]	4	4	4	4	4	4.0
IoT-based Tele-physiotherapy [22]	4	4	5	3	3	3.8
Innovative Tele-physiotherapy Platform [23]	5	4	5	4	3	4.2

In summary:

Physitrack [7]: This platform scores highly in ease of use and patient engagement but relies on basic video conferencing.

Doxyme [9]: While not specific to physiotherapy, Doxyme is easy to use and cost-effective, making it accessible for basic remote consultations.

Phzio [11]: Phzio provides personalized exercise programs and progress tracking, but its technology and scalability are not as advanced as those of some other solutions.

PlayStation 3-based tele-rehabilitation [12]: This solution has a good score in patient engagement owing to its gamified approach, but it relies on a specific gaming console, which is limiting.

Kinect-based Constraint-Induced Therapy [13]: This solution is characterized by its use of virtual reality (VR) and motion capture, earning high marks in technology and usability. They also rely on the use of specific equipment.

Kinerehab [14]: Kinerehab offers a good balance between technology and usability, but its focus on specific patient groups (e.g., adults with motor disabilities) limits its scalability and relies on the use of specific equipment.

ArmAssist (TECNALIA) [17]: This solution has a good score in terms of technology and data accuracy but is less cost-effective, making it more suitable for specialized rehabilitation rather than widespread use.

Hand of Hope (Rehab-Robotics) [19]: Similar to ArmAssist, this solution scores highly in technology and data accuracy, but is limited because of its cost and complexity.

Visio Roller (Rehab-Robotics) [21]: This solution was specifically designed for wheelchair users, limiting its broad applicability.

Kaia Health [24]: Kaia Health scores highly in technology, ease of use, and usability. The AI-driven feedback system makes it a good choice for remote rehabilitation.

DorsaVi [26]: DorsaVi excels in technology and data accuracy, particularly in sports performance and injury prevention. However, they use wearable sensors, which may affect their usability.

PyTracker [30]: PyTracker has a smart approach related to cost efficiency using smartphone sensors but lacks full-body tracking.

IoT-based Tele-physiotherapy [22]: This solution scores highly in technology and data accuracy, but is less user-friendly and cost-effective.

Innovative Tele-physiotherapy Platform [23]: This platform excels in technology and data accuracy with its 3D visual output and real-time feedback. However, its complexity and cost may limit usability and scalability.

8. Challenges and Opportunities

The implementation of tele-physiotherapy platforms presents several challenges that must be addressed to optimize their effectiveness and adoption in healthcare settings. These challenges are primarily associated with patient compliance, data privacy, sensor calibration, and scalability of machine learning models. However, these challenges open avenues for further research and technological innovation.

8.1. Patient Compliance and Usability

One of the critical challenges in tele-physiotherapy is ensuring patient compliance with prescribed rehabilitation exercises, particularly in the absence of direct supervision. Patients may face difficulties in correctly setting up wearable sensors or maintaining engagement over time, which can affect the effectiveness of remote rehabilitation. Therefore, future tele-physiotherapy solutions must prioritize user-friendly design and seamless integration to enhance patient adherence. Implementing interactive elements such as gamification or virtual reality (VR) may further encourage patient engagement by making rehabilitation exercises more enjoyable.

8.2. Patient Diversity and Testing

Another critical challenge is ensuring that tele-physiotherapy platforms are validated across diverse patient populations. Many current solutions are tested primarily on small, homogeneous samples, which may not represent variations in age, mobility levels or cultural differences. This limits the generic application of AI models and sensor-based feedback, potentially reducing their accuracy and effectiveness for patients with unique physical or neurological conditions. More inclusive clinical trials and user studies that account for diverse functional abilities and real-world contexts are required in order to address this gap.

8.3. Connectivity, Costs and Energy Consumption

While in the urban environment, high-speed connectivity is always considered as granted, in rural areas, this is not always the case. The rapid development of mobile telephony and especially the introduction of 5G networks, together with the wide availability of compatible devices, offer a communications medium that can bring fast and reliable data connectivity even to remote areas. A related study emphasizes the crucial effect of reliable and fast wireless communication through the 5G introduction to telemedicine adoption [32]. In a similar manner, "The impact of 5g technologies on healthcare" analyzes the effect of 5G introduction to telemedicine but also points that the ultra-reliable low latency communication feature of 5G will allow the integration of VR (Virtual Reality) and AR (Augmented Reality) [33], which is critical for rehabilitation training and robotic support to train motor skills of the limbs or video consultation. Although VR is not a new technology, the latency factor between terminal devices and data aggregation functions is crucial and 5G can eliminate this latency. Regarding costs, wide adoption of 5G leads to quite affordable connectivity costs and charging plans that offer large or limitless data bundles to mobile subscribers at reasonable prices. Regarding sensors and wearables, costs are definitely dropping, making them quite affordable; however, their future success has been dependent on the energy consumption challenge, an issue which is presented in "Data sensing and analysis: Challenges for wearables" [34]. There is a requirement for quite significant energy reduction in sensing, analysis, and wireless communication.

8.4. Data Privacy and Security

Tele-physiotherapy platforms collect sensitive patient information, including biometric data and real-time physiological responses, ensuring the privacy and security of this data. Compliance with data protection regulations such as the General Data Protection Regulation (GDPR) is essential for maintaining patient trust and confidentiality. Advanced encryption methods, secure data transmission protocols, and robust authentication mechanisms must be incorporated to safeguard patient data from unauthorized access and breach. Blockchain technologies can also offer solution to data authenticity and transaction security.

8.5. IoT (Internet of Things)/IoMT (Internet of Medical Things) Generated Data Processing Challenges and Safety

IoT/IoMT generated data introduce a processing challenge due to their volume and cloud storage. All related diagnoses should occur on the cloud; however, this introduces latency challenges for such volumes of data. The concept of 'fog computing' is introduced for greater efficiency by providing a computing resource close to the sensors, which also acts as a data filter.

8.6. Platform Scalability and Continuity

Solutions need to limit the over-reliance on proprietary hardware, such as Microsoft Kinect or specialized wearables, which can restrict scalability and increase costs for both providers and patients. Additionally, a challenge exists in the interoperability with other telehealth systems or electronic health records, affecting seamless data exchange and integrated care.

8.7. Sensor Calibration and Data Accuracy

Accurate data collection is vital for effective tele-physiotherapy. However, improper sensor placement, variability in patient movements, and environmental factors can introduce noise and inaccuracies during data collection. Ensuring the correct calibration of wearable sensors and developing self-correcting algorithms that can adjust for sensor misalignments are necessary to improve the reliability of the collected data. Several algorithms and processes can be used for sensor calibration – a common approach involves using least squares regression to fit a model that minimizes the sum of squared differences between sensor readings and known values. The least squares method targets to find the parameters of a model (e.g., a linear equation) that minimize the sum of the squared differences between the model's predictions and the observed data points. In sensor calibration, this approach can be used to find a relationship between sensor readings and actual values. This process effectively "corrects" the sensor's output. A similar approach used for ML classification is the Root Mean Squared Error (RMSE), which quantifies the average magnitude of errors in predicted values compared to actual values. The basic equation is

$$RMSE = \sqrt{[\left(\frac{1}{n}\right) * \Sigma(yi - pi)^2]} \quad (1)$$

where yi is the actual value for observation i, pi is the predicted value for observation i, and n is the total number of observations. RMSE offers a measure of the average prediction error. A lower RMSE indicates a better model fit, while the units of RMSE are the same as the original data. Additionally, apart from such algorithms, implementing AI-driven feedback systems that can automatically detect and correct errors in real time can enhance the quality of the physiotherapy sessions.

8.8. Scalability of Machine Learning Models

Machine learning algorithms used in tele-physiotherapy platforms are often trained on specific patient groups, which may limit their generalizability to broader populations. For example, models trained on data from elderly patients or individuals with specific conditions may not perform well when applied to younger or healthier demographics. To address this, future research should focus on developing adaptable ML models that can be generalized across diverse patient populations. This includes the use of transfer learning techniques and the expansion of training datasets to include a wider range of movement patterns and patient profiles.

8.9. Potential Technology Drawbacks and Neglect of the Human Factor

While AI, ML, and wearable technologies significantly enhance tele-physiotherapy through improved real-time feedback and remote monitoring, their implementation may also involve high costs and dependency on specific technologies. Also, the variable accuracy of sensor data can hinder consistent outcomes across diverse patient groups. Furthermore, over-reliance on automated systems may reduce direct doctor interaction, which could affect patient motivation and trust. These concerns should be addressed through robust validation, transparency in involved algorithms and a hybrid care model, which can guarantee the smooth adoption of such innovative solutions. Human factor is always key to success and should not be underestimated or downplayed.

8.10. Opportunities for Future Research

Despite these challenges, the rapid advancement in sensor technology, artificial intelligence, and data analytics presents significant opportunities for enhancing tele-physiotherapy platforms. Integrating Internet of Things (IoT) devices and cloud-based analytics could enable more sophisticated, real-time monitoring of patient progress, leading to improved outcomes. Furthermore, leveraging big data and AI can facilitate personalization of treatment plans, offering tailored rehabilitation programs that adapt to individual patient needs.

Some of the referred challenges (privacy, data security, IoT data management) are already presented in several health care related studies, which already expand on related solutions that may also apply to tele-physiotherapy:

"Intelligent Load-Balancing Framework for Fog-Enabled Communication in Healthcare" emphasizes fog computing (a concept which adds to Internet of Things (IoT) by placing computing resources closer to the devices generating data, thus providing processing efficiency) [35].

"IoT fog-enabled multi-node centralized ecosystem for real time screening and monitoring of health information" emphasizes in tracking and processing of tele-health information through IoT Fog enabled system to deal with the Covid-19 pandemic challenges [36].

"A secure and efficient signature scheme for IoT in healthcare" proposes a solution to security challenges in the Sensor/IoT/Cloud storage ecosystem which is always a major issue in all kinds of tele-health solutions [37].

"A Blockchain-based secure Internet of Medical Things framework for smart healthcare" proposes a framework that combines IoMT (Internet of Medical Things), DL (Deep Learning) and Blockchain technology in order to ensure a timely recognition of stress in people during their daily lives [38]. This solution uses blockchain for transaction security, DL for stress detection from data gathered from IoMT, ECC (Elliptic Curve Cryptography) and IPFS (Interplanetary File System—a decentralized, peer-to-peer protocol for storing and accessing files, websites, and applications) for the secure storage of data.

Future research should also explore the integration of tele-physiotherapy with other telehealth services to create a comprehensive digital health ecosystem. This approach would not only streamline patient care but also enable a continuum of care that extends beyond the rehabilitation setting.

9. Conclusions

A holistic approach to the tele-physiotherapy solution should cater to all the mentioned challenges, but at the same time balance well between cost, usability, acceptance by the patient, scalability, and data accuracy. It will be necessary to combine as much sensor input as possible without compromising cost or ease of use and at the same time offer functionality that will cover motion capture and representation, two-way feedback on both patient and doctor, the ability to scale and adjust to as many cases as possible, and data storage with appropriate security and data privacy. With the inclusion of Machine Learning (ML) and Artificial Intelligence (AI), the system can assist the patient without the involvement of the doctor, whenever necessary, to allow patients to keep their own pace and schedule. Therefore, it is necessary to include a significant volume and variety of data for different physiotherapy cases to feed the ML algorithms to provide a reliable base. To address all challenges and opportunities, a multi-faceted approach is required that balances technological innovation with patient-centered design. By focusing on user engagement, data security, and scalability of AI solutions, tele-physiotherapy can become a viable alternative to traditional in-person rehabilitation, thus expanding access to essential healthcare services.

Author Contributions

Conceptualization, G.K.; methodology, G.K.; validation, G.K.; formal analysis, G.K.; investigation, G.K.; resources, G.K.; data curation, G.K.; writing—original draft preparation, G.K.; writing—review and editing, E.K.; visualization, G.K.; supervision, E.K.; project administration, E.K.; All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

All the research data are available in this paper. For any information or questions please contact the corresponding author. There are no new data created or being unavailable due to privacy or ethical restrictions.

Conflicts of Interest

The authors declare no conflict of interest.

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