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Technological Solutions for Low Back Pain Physical Therapy Real-time Monitoring with Feedback

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Abstract. The advancement of technology may result in significant improvements in physical therapy in terms of sustained rehabilitation, interpretation, and long-term monitoring in a population suffering from low back pain with no identified cause or standardized treatment. The research on systems that monitor vital signs and movement data simultaneously during the physical therapy sessions must be expanded. The aim of the article is to perform analysis and discussion concerning the present technology solutions to monitor vital signs in combination with muscle activity and quality of movement in the light of physical therapy requirements and challenges for the population with secondary conditions. The conclusion – the literature review outcomes show contraindicatory results concerning the combination of sensor, technology use and the artificial intelligence algorithm real-time efficiency on providing information that will change the user's habits and provide specific user targeted simple data interpretation. At the same time studies have proved that participants expressed greater engagement in self-management.

Keywords: low back pain, physical therapy, technology, real-time feedback, wearables

1. Introduction

The technological advance in physical therapy might make significant improvements in terms of sustained rehabilitation, vital signs and movement data registration, interpretation, and long-term monitoring in population with low back pain. There are only 3 articles after this literature search on systems that monitor the mentioned parameters at the same time during physical therapy session for low back pain treatment. The aim of the article is to perform analysis and discussion concerning the present technology solutions to monitor vital signs like heart rate, pulmonary parameters, oxygen saturation in combination with muscle activity and quality of movement in the light of physical therapy requirements and challenges. Low back pain population is a high-risk population for cardiopulmonary complications (Wang et al., 2020), (Leino-Arjas et al., 2006). The aspect of monitoring vital signs like heart rate, respiration rate during exercising has been studied very little. Since the population with low back pain is more common in the age group of forty and older, then it is critical consider the vital sign monitoring for secondary conditions presence. Secondary conditions include cardiovascular conditions like coronary heart disease, peripheral arterial disease and deep vein thrombosis and pulmonary embolism etc., pulmonary conditions like asthma, Chronic Obstructive Pulmonary Disease (COPD), Chronic Bronchitis and others. This article describes technologies used to provide the real-time visual feedback. There has been extensive research related to gait and posture monitoring in population with low back pain (Wasser et al., 2017), (Hendershot, 2012), (Ebrahimi et al., 2017). Also, ultrasound and CT are studied to prove and visualize the effect of intervention. In this article only technologies that are both measuring physiological data and providing feedback during exercising are included.

2. Methods

The search was performed in three data bases (Scopus, PubMed and Web of Science) and included English language human studies and technological framework articles from January 1, 2010, to September 1, 2021. Total of 245 articles were identified using keywords “low back pain”, “technology”, “feedback”, “real-time”, “virtual reality”, “wearables”, “sensors”, “vital signs”, “heart rate”, “breathing”, “respiration”, “oxygen saturation”, “surface electromyography”, “electroencephalography” in different combinations. The following exclusion criteria were applied to the mentioned selection, and duplicates were removed, leaving 23 articles. Articles targeting general pain, neck pain, cancer or headache pain, surgical procedures, mental disorders, informative educational physical activity or habit programs, hospitalization, acute and critical conditions, invasive procedures, or procedure evaluation studies, pharmacological or diagnostic procedures, studies using computer tomography, magnetic resonance as evaluation methods, studies not providing real-time feedback during the intervention were excluded. Search using keyword combination of “low back pain” “feedback” or “virtual reality” and “vital signs” or “heart rate” or “breathing” or “respiration” or “oxygen saturation” or “electroencephalography” showed 9 (0 with the term “virtual reality”) articles out of which 3 were left after applying exclusion criteria.

Article selection included evaluation studies, protocols, pilot studies, controlled trials, efficacy studies and case studies.

3. Physical therapy challenges and requirements to treat non-specific low back pain

Non-specific Low Back Pain (NLBP) and Chronic Low Back Pain (CLBP) are the most common types of Back pain. It affects nearly 80% of the population. This is the type of pain that most people will have at some point in their life. Non-Specific Low Back Pain is not due to any specific or underlying disease.

One of the most important factors for the treatment of CLBP is the adherence to regularly performed home exercises. An effective therapy requires a high degree of initiative by the patients, which can be an obstacle for many. Studies in physiotherapy indicate that patients who did not adhere to exercises had less treatment effect (Stamm et al., 2020).

The evidence of the non-specific low back pain causing underlying mechanisms is controversial (Deyo et al. 2001), (Staud, 2011), therefore, the treatment approaches include a variety of methods. The common approach is a biopsychosocial framework to guide management with initial non-pharmacological treatment, including education that supports self-management and resumption of normal activities and exercise, and psychological programs for those with persistent symptoms (Foster et al., 2018). According to European Guidelines for the management of chronic non-specific low back pain (Airaksinen et al., 2004), (Oliveira et al., 2018), no imaging or other technology should be used in diagnosing LBP thus excluding technologies like computer tomography, magnetic resonance, ultrasound and others. In the guidelines the mentioned technologies are not discussed as a form of feedback during physical activities to enhance the treatment effectivity. The only technology mentioned in the European Guidelines for the management of chronic non-specific low back pain used for biofeedback is electromyography (EMG) (Airaksinen et al., 2004).

The majority of methods to assess chronic low back pain include self-reported evaluation of pain during everyday conditions, situations, and functional tasks like Oswestry Disability Index (Clement et al., 2015) and many others like Quebec Back Pain Disability Scale (Davidson et al., 2002), Roland-Morris Disability Questionnaire (Davidson et al., 2002), Waddell Disability Index (Davidson et al., 2002), the Medical Outcomes Study 36-Item Short-Form Health Survey (Davidson et al., 2002). All listed are subjective evaluations of the patient. In a systematic review (Stanton et al., 2011) only 6 of 82 studies found physical performance as a recovery criterion. In total 66 different measures of recovery were identified. Since there is no defined cause for LBP, there is no standardized approach to treat the LBP and no common parameters defined to monitor during the physical therapy. The variety of self-reported surveys and indirect evaluation methods leads to a complicated situation in terms of metrics also during LBP recovery process.

While LBP is a prevalent cause of disability in the general population, it is even more prevalent and often compounds mobility-related disability in those with lower limb amputation. In a survey of people with amputations, 52% of responders had persistent, bothersome low back pain, and 25% had severe, frequent pain that severely interfered with their daily lives and activities (Keszler et al., 2020)

Since there are no direct metrics to evaluate the level of pain by means of technologies, indirect parameters associated to LBP have been estimated using technologies and those can be effectively used to evaluate the efficiency of LBP treatment intervention. For example sleep disturbances - polysomnography, Armband and Actiwatch watches (Alsaadi et al., 2014), suggesting that the Armband and the Actiwatch are useful objective tools to assess sleep parameters in patients with LBP (total sleep time, sleep efficiency, and wake after sleep onset). Though indirect metrics can be misleading due number of factors influencing, e.g., sleep disturbances besides the presence of LBP.

The only common aspect of LBP physical therapy treatment is – teaching the person to retrain their posture and movements which means – teaching self or body awareness. And for this purpose, wearable technologies and feedback are the most suitable approach. The most commonly used treatment approach sequence is realized in three subsequent steps - (1) Motion correction/retraining, (2) Exercises for LBP, (3) Increase muscle endurance and strength (Lee et al., 2015).

Other indirect metrics to evaluate the efficiency of LBP treatment intervention are overall physical fitness evaluation, aerobic endurance, muscle strength, posture, movement quality, stability and balance. These metrics are evaluated during the most commonly used physical therapy approaches to treat LBP – balance exercises, mobility exercises, proprioception exercises, yoga, proprioceptive neuromuscular facilitation exercises, stretching.

Only a few of the mentioned can be used in real time treatment monitoring during exercising due to technical limitations – setups like ultrasound do not allow freedom of movement, high signal error and artifacts presence caused by movement of physiological processes or electric wiring. The real-time monitoring in the most existing technologies involve general metrics therefore are not included in the article, namely, number of repetitions, intensity level, total time, and others.

Metrics used for real-time monitoring are related to ensuring the precision of the exercise performance – to detect whether the position of the person, performing speed and angle of limbs is correct, to detect balance related precision during the exercise – centre of mass, centre of pressure, centre of gravity and their sway, motor control, to detect relative changes of muscle electric activity.

Indirect metrics which are often associated with chronic non-specific low back pain prevalence are muscle electric activity of deep core muscles and superficial muscles since there are numerous studies suggesting that before any physical activity multifidus and transversus abdominis activation is detected. EMG biofeedback is relevant and accurate and rapid to enhance motor learning. It provides a feedback by display of force produced by the contracting muscle thus helps to strengthen the muscle further (Yuvarani et al., 2020). Also, muscle electric activity pattern in low back pain population differs from the general populations. Even though the evidence is contradictory – there are studies stating that low back pain population has characteristic weak deep core muscles and studies demonstrating data about over-active multifidus muscle.

For guiding the quality of movement, different motion detection technologies are used, namely: accelerometer (AM), electronic goniometer (GM), infrared sensor/camera (IF), high-speed red, green, and blue camera (RGb), gyroscope (Gy), magnetometer (MM), pneumatic force sensor (FS) and pressure sensor (PS) (Verbrugghe et al., 2018).

Physiological characteristics

Even though continuous vital signs monitoring is a significant part of basic care of patients, especially with chronic conditions, at home or admitted to hospital (ViSi Mobile system, Aingeal, Vitalsens VS100), the technical limitations like noise artefacts caused by movement, can exclude even high-quality devices from applications in physical therapy. ECG is one of the cases - even though artificial intelligence is the basis of devices like UPOlife providing the medical data analysis and detecting dangerous conditions in a still state or even during walking and rapid moving (QUASAR) the question still is whether the technology is there to monitoring vital signs during exercising. And if not – is it enough to detect the pre- and post- intervention vital signs, implement and interpret the data in correlation with physical therapy monitoring.

Breathing techniques are commonly used to alleviate pain. Despite their frequent use, surprisingly little is known about their efficacy as well as their underlying physiological mechanisms. Paced slow breathing is associated with pain reduction in some of the studies, but evidence elucidating the underlying physiological mechanisms of this effect is lacking (Jafari et al., 2017).

Heart rate variance (HRV) is recognized as a non-invasive tool for cardiac autonomic modulation. HRV is seen as one of the most promising quantitative markers of autonomic balance. Changes in its patterns are able to provide reliable indicators of health impairments at various levels, and show clearly the role of the sympathetic and parasympathetic nervous system (Zavarize et al., 2020).

Even though the usage of remote health applications has dramatically increased, it is also stated that many interventions contained a feedback loop with a care provider, such as a physician or nurse, who analysed patient data and communicated back with the patient to modify treatment regimens, improve adherence, or consult (Noah et al., 2018).

Literature searches show a variety of remote health applications for cardiovascular applications for example heart conditions like cardiac arrhythmia, hypertension, and others though none of them is directly related to low back pain population.

Electroencephalography - EEG - previous proton magnetic resonance spectroscopy studies on brain chemical changes in patients with chronic low back pain (Zhao et al., 2017) suggests that biochemical changes may play a significant role in the development and pathophysiology of CLBP and shed light on the development of new treatments for CLBP.

Highly controlled EEG APS operant conditioning (neurofeedback) paradigm delivered in the form of visual feedback. Visual analogue scale for pain, Dallas, Hamilton, and HAD were measured before, after, at 6-month and 12-month follow-up. Full-scalp EEG data were analysed to study significant changes in the brain's electrical activity. The intervention showed a great and lasting response of most measured clinical scales. The clinical improvement was lasting beyond the 6-month follow-up endpoints (Mayaud et al., 2019).

An often overlooked and potentially serious component of lifelong care after amputation is cardiovascular health. Amputation typically affects cardiac function by increasing the resting heart rate and decreasing cardiac output, especially in patients with a transfemoral amputation. An individual’s mobility function is impacted by the dynamic capabilities of the cardiac and respiratory muscular systems’ ability to adjust to the limb loss (Keszler et al., 2020). People with traumatic amputations have also been found to have higher fasting plasma insulin and insulin resistance, which is a risk factor for atherosclerosis

Considering all the aspects above, a complex system is necessary to monitor low back pain patient exercising precision in real time and provide a real time visual feedback.

4. Technological advances in movement and physiological parameters monitoring

Wearable technology is broadly divided into head-mounted displays and body sensors. The survey (Iqbal et al., 2016) revealed a total of 13 different body sensors applied for as vital signs monitors (n=9) and for posture-related devices for posture and fitness (n=4). According to the literature review performed, 70% of body sensors applications focus on posture correction.

The focus is on wearable sensors - wearable biosensors are non-invasive devices used to acquire, transmit, process, store, and retrieve health-related data. Biosensors have been integrated into a variety of platforms, including watches, wristbands, skin patches, shoes, belts, textiles, and smartphones (Noah et al., 2018).

There are no studies comparing gamified feedback versus feedback containing just the information about the vital signs which is important to evaluate the efficiency of the feedback.

Recent evidence suggests that individualized cognitive and movement rehabilitation combined with lifestyle advice (cognitive functional therapy (CFT)) may produce larger and more sustained effects than traditional approaches, and movement sensor biofeedback may enhance outcomes (Kent et al., 2019).

Surface Electromyography - muscle activity/ muscle strength. Studies which include real-time feedback from muscle activity demonstrate better improvement in LBP exercise efficiency (Yuvarani et al., 2020) In many occasions (Kent et al., 2019) physician inclusion is still necessary, for example, in ViMove2 application study feedback is provided for movement re-training, posture and gait stereotype programming and rule braking alarm development. Even though the feedback is not constant in the mentioned case, it can still be considered as monitoring during the LBP treatment. Surface electromyography is becoming more and more recognized in frames of studies ((Noh et al. 2014), (Hu et al., 2014), (Neblett, 2016), (Kang et al., 2014)) to treat low back pain. Some of the studies have shown higher or similar effect with to cognitive behavioural counselling. Well-known professional systems like Delsys, Bts Bioengineering, Biopac, Noraxan and Biostamp are challenging in their price level thus limiting to introduce in practice. User friendly wireless solution like Somaxis, BioSignalPlux and MyOnyx are more affordable and working on bringing the evidence of their solution (Lee et al., 2020), (Rogers et al., 2019), (Montes et al., 2017).

Ultrasound and pressure feedback is commonly used as a simple biofeedback system since 1980'ies but it always require assistance from the physician and is limited by the device complexity (Crasto et al., 2019). Ultrasound devices can be used only for in-clinic applications while pressure feedback is suitable for at home use if the patient is appropriately instructed. The pressure biofeedback unit is very limited to a specific kind of exercises and is used strictly as a visual feedback method which does not provide any quantitative data (Li et al., 2020).

Systems for Movement quality. For active movement at home training, the most common applications are Nintendo Wii, Nintendo Wii Balance Board focusing on Wii exercise program and yoga applications (Verbrugghe et al., 2018). Virtual Reality rehabilitation games, Kinect system, CAREN system.

Radio-based recognition systems employ radiofrequencies to detect positions and activities; the most common technologies are RFID, Wi-Fi, ZigBee and infrared light. There are recent studies on other strategies, like the Doppler radar system, which can also be used to detect information on chest displacement. In terms of radio based HAR systems, the base stations must be prearranged, and the tags are often attached to a person's wrist, ankle, head, or other parts. By observing that different activities cause different wireless communication patterns between the attached tags and the base station, activities can be recognized. However, these technologies only work within a specific range of distances from the base stations (Angelucci et al., 2020).

Motion Capture. The most popular rehabilitation solutions include projected avatar on the screen with information about training frequency, measuring angle, time remaining, etc. (Su et al., 2015). However, these applications are limited in a 3D space depth, small angles and the capturing area. Movement compensation mechanisms should be taken into account while using this approach.

Motion capture suits Vicon, Synertial, Getenflux on the other hand allow the freedom of movement but also are complicated from user experience and price aspect.

The inertial measurement unit (IMU) setup are trying to enter in physical therapy field and are affordable. Solutions like BioSensics, Inc., Miotherapy, Inc., Hocoma, Inc., Xsens, Inc., Notch, Inc., Ikinema, Inc. are becoming more popular but still acquire specific medical know-how and therapist’s assistance. The error occurring from inaccurate IMU placement can be statistically significant but not recognized by the user.

Video feedback is commonly used in studies but since there is no reference system the result is arguable – in a study where sensorimotor incongruence was applied - an ongoing mismatch between top-down motor output and predicted sensory feedback of the lower back during movement - There were no significant differences in sensory disturbances or pain intensity between experimental sensimotor incongruence and the other movement conditions in people with CLBP and healthy volunteers (P >.05) (Don et al., 2019).

Telehealth can be effective in reducing pain levels, and more convenient and cost-effective than treatment as usual (Cavanagh et al., 2019) but is used a diagnostic tool on the everyday practice. Despite the numerous barriers to telemedicine, such as educating staff, cost, reimbursement, access to broadband, and patient digital literacy, telemedicine has flourished during the pandemic (Jalali et al., 2021). In the US, the Department of Health and Human Services recently lifted several restrictions on communication apps, (e.g., allowing the use of popular video conferencing applications, like Apple FaceTime, Facebook Messenger video chat, Google Hangouts, Zoom, and Skype) and increasing the range of services that are billable using telehealth. Due to this also the risks have increased (Kaplan, 2020) - intruders joining video conferences or inadequate encryption of communications, leading to the possibility of eavesdropping, cyber-attacks (Jalali et al., 2021). Successful cyberattacks negatively impact hospital operations, delay access to clinical services, and lead to significant economic loss, all of which would be devastating to organizations already under extraordinary economic and clinical strain. It is clear, the medical institutions need to reorganize their infrastructure which requires a multi-disciplinary, multi-stakeholder approach. There are several solutions proposed including medical image sharing (Poleto et al., 2021), (Kim et al., 2020). Moving to a unified data standard like FHIR might ease the encryption process. (Chaves et al., 2021)

Internet-based programs are highly accessible, cost-effective, and less stigmatized than treatment as usual.

Virtual and Augmented reality. VR exists on a continuum from non-immersive to fully immersive. In non-immersive VR body tracking technology transfers movement to alter the perspective of the simulated avatar. Immersion increases with the integration of multi-sensory (e.g., visual, audio, and tactile) experience into the simulation through equipment (e.g., a head-mounted display (HMD) or wearable haptic devices) (Tack, 2019).

Generic games versus rehabilitation games. There are studies confirming the virtual reality (VR) gaming effect on pain reduction but there are hardly any studies or applications on the market offering a VR active exercise therapy and psychotherapeutic pain therapy beyond the pure VR pain distraction applications.

Games as a distraction - Functional magnetic resonance imaging (MRI) shows large declines in subjective pain measures during game activities and a decrease in brain activity related to pain. Clinical and laboratory evidence indicate that the distraction of pain through games is a new and promising non-pharmacological control technique (Zavarize et al., 2020). Playing games during physiotherapy exercises demonstrated reduction of pain and also reduction in heart rate (Zavarize et al., 2020). Using visual feedback in a shape of virtual or augmented reality as a distraction from pain (even if it works) is a debatable aspect since it can lead to a short-term effect. In the same time feedback can be used for focusing, self-awareness and retraining the movement quality which would mean a long-term effect (Lancere et al., 2020).

The requirements in older CBP patients for a VR pain therapy have not yet been determined in studies. The key requirements were target-group-specific applications of the VR exergame through e.g. individual briefing, user-friendly handling, inclusion of movement limitations, presentation of everyday scenarios in combination with biofeedback, age-appropriate feedback through praise and awards and a maximum exercise duration of 30 min and 15 min of relaxation (Stamm et al., 2020).

Positive aspect is VR system should offer the capacity for patients to blend learning patterns into daily activities (Su et al., 2015). In frames of the learning during simulation environment, feedback is essential as much as in the exercising process. For example - rising from a chair and sitting, carrying heavy objects, etc. However, such familiar tasks are rarely found in current LBP intervention studies. More often gamified tasks are provided (Alazba et al., 2018).

Even though the VR applications often require correct posture or body position based on the headset data at the beginning of exercising session (Stamm et al., 2020), populations with chronic posture alterations often have deviated movement trajectories despite the overall "correct" initial position therefore systems should be complex to ensure quality and specific problem targeted performance.

VR may show greater efficacy in patients with CLBP with associated kinesiophobia (fear of movement due to expectation of pain) due to distraction, neuromodulation, and graded exposure therapy. VR may show greater effect with increased immersion. (Tack, 2019). The mentioned focuses on fear and psychological aspects caused by CLBP not the physical therapy to treat the low back pain.

IMUs for Posture, risk of fall. Posture correction is a common approach which also requires the use of IMUs. People with LBP in all populations have the fear of falling since often they have had fall episodes due to reduced stability. The studies have shown that groups using IMUs in posture correcting exercises have improved their posture (Matheve et al., 2018), (Ianculescu et al., 2019), (Ashouri et al., 2017). The characteristic feedback is the combination of visual, audial, and sensory feedback. Since the commercial products as TruPosture (Adela Health, Inc.), Eliko (OÜ Eliko Tehnoloogia Inc) seek the ease of use, the technologies vary from one sensor in the C7 vertebrae level (excluding abnormalities in other parts of the spine) to several sensors along the spine. The most common effect is the change of habit not the actual change in the spinal curvature since posture alterations can be caused by variety of reasons and vary from person to person.

Cardiopulmonary metrics. Hypertension monitoring using wireless blood pressure cuff (Noah et al., 2018) – studies show that systolic blood pressure decreases in telemonitoring with self-care messages on a smartphone; however, self-care smartphone-based support also appeared to worsen depression scores.

Heart rate monitors - there are several studies showing the relationship between changes in cardiac autonomic modulation and the presence of pain, including back pain. Thus, the autonomic nervous system may be largely influenced by painful stimulation and some physiological reactions, such as increased or decreased heart rate and variability, have been used to better understand the pain and its variables.

Phone applications – series of applications are detecting heart rate, respiratory rate and temperature - the PhysioDroid, BioHarness, EQ02 LifeMonitor - uses a thoracic pressure sensor attached to a chest band to detect respiratory and heart rate.

Smart shirts (Bonato, 2009) - other wearable devices such as the LifeShirt (VivoMetrics Inc., USA) have been used in studies to measure various parameters. It has been validated for use to detect tidal volume, minute ventilation and respiratory frequency.

Some of the technologies are fairly limited to the user anthropometric parameters, some are very limited but for a full at home use, the physician's input is still mandatory. The most of the technologies include the combination of heart rate, electrocardiogram, respiration rate, oxygen saturation and others but either the AI algorithms are applied for a general load and activity limitations or very specific ones like chronic obstructive pulmonary disease (Angelucci et al., 2020).

Smart watches are the latest development in wearable devices, highlighted by the release of Apple Watch and Fit Bit Flex, Garmin, Suunto. The new 'Kardia Band' allows monitoring of ECG through the Apple Watch. The usage of these devices is directly dependent on AI algorithms behind them. Studies have shown that very few populations share their medical data with medical professionals.

The most recent trend shows that combination of as many metrics in one device as possible which has become possible due to artificial intelligence algorithms. Though, most of the solution specialize in-clinic applications – Aio Sleeve (Comodotec, Inc.), VitalConnect, Inc., Byteflies, Inc., Leap Technology, Inc., Masimo, Inc., RespiratoryMotion, Inc.

For individual use – HeartMath, Inc. (focusing on psychological benefits based on heart rate and other metrics), SpireHealth, Inc., PMD Solutions, Inc., ZIO (Irhythmtech, Inc.), Health Care Originals, Inc., Cicer (ten3THealth, Inc.).

Oxygen saturation, respiration. Graphene sensors are promising devices to monitor vital health signs noninvasively, including heart rate, arterial oxygen saturation (SpO_2), and respiratory rate (Polat et al., 2019). These wearables promise the ease of use and freedom of movement.

Bluetooth Smart Pulse Oximeters are entering the market but implementation in practice is slow since the practitioners need to explore the very specific application areas and need assistance with technological implementation (O'Carroll et al., 2020), (Wang et al., 2017). On a regular physiotherapy basis pulse oximeters are commonly used for patient monitoring during exercising, especially in populations with cardiopulmonary complications. The inconvenient application has been limiting but the NIRS-based muscle oximetry is becoming more popular (Vrana et al., 2018) and provides information also about local oxygen levels. NIRS usage in muscle oxygenation is related to LBP - Low back pain is suggested to be related to deconditioning of back muscles by a decreased capacity for hyperaemia in exercising muscles (Vrana et al., 2018). NIRS technology is being used to detect muscle fatigue which seems to be more effective than electromyography (Vrana et al., 2018).

Since diaphragm is one of the main deep core muscle, abnormal breathing pattern in low back pain have been recognized (Ostwal et al., 2014). Thus breathing exercises are used to improve low back pain (Anderson et al., 2017). In the mentioned training sEMG sensors have been used (Peper et al., 2016), as well as smart textile (Rozevika et al., 2018), (Paquin et al., 2019), Breath, Inc., Smartex, Inc., photoplethysmography breathing belts (Neurotechnologies, 2011), (Liu et al., 2011), S.L.P., Inc. to provide the visual feedback which increased the chest excursion and diaphragm activation (Odenbach et al., 2016).

There are also complicated systems as ultrasound (Lee et al., 2018) and smart house setups to monitor heart rate and breathing (Adib et al., 2015) which are highly suitable to seniors and people with disabilities or limited possibilities to go outside their home independently.

Table 1. Overview of challenges and user requirements.

Physiotherapy Challenges	**Technological Challenges**	**Data Related Challenges**	**Social Challenges**	**Legislative Challenges**
No standardized treatment/ guidelines	Incompatible infrastructure	Privacy	Patient Digital Literacy	Reimbursement
Wide range of metrics (posture, balance, muscle strength etc.)	Development Costs	Data Processing Time	Functional Specialist Literacy	Device and personnel certification
No info on medical history and examinations	Sensor Network Integration	Interpretation (AI)		Implementation Procedure
Long-term monitoring	VR/AR generalized content	No common medical data standard		National regulatory limitations
Remote monitoring	Incompatible Data Protocols/Systems	De-centralized data bases		
Motivation	Wide Range of devices	Lack of real user needs identification		
Undefined correlations between PT and tech metrics	Medical Know-How for Data Processing			
Lack of Evidence on the New Technologies	Physiological limitations for setup (BMI etc.)			
Wide range of secondary conditions (diabetes, orthopedic etc.)	Environmental limitations			
	Technical limitations (battery life, data storage, size, etc.)			
USER REQUIREMENTS System adaptability (diagnosis related limitations – repetitions, heart rate, etc.) Ease of Use Simple Data Low Price Fast Individualized Accessible Data Security Technical Support				

Fibre optic sensors. Recently, smart textiles based on fibre optic sensors have shown promising results in the field of respiratory monitoring. Especially fibre Bragg grating (FBG) sensors have been used to monitor the respiratory rate by integration of the sensing elements in patches or garments. The deformations of the thorax and the abdomen can indirectly estimate the contribution of the thoracic and abdominal compartments on the tidal volume because the reflected wavelengths sensed by the FBGs are affected by strain and temperature. As an example, a research group in Rome has recently developed a garment based on 12 FBGs placed in specific body landmarks (Angelucci et al., 2020).

It is important to remember that the use of technology in physical therapy and rehabilitation is influenced by the entire eco-system, including the social and legal aspects. It is common for the aforementioned to take precedence over the actual patient needs and challenges. Table 1 summarizes the article's physical therapy, technological, and other challenges, as well as a few eco-system aspects.

Wearable sensors or feedback providing systems separately are less effective than by combining the two, adding medical know-how with the use of AI or physician and providing quality user experience (Table 1).

5. Discussion

When analysing the summary of challenges in table 1, one can hypothesize that one approach to gradually solving the challenges could be to use a user-cantered approach. For instance, an analysis of a specific population with a high priority in terms of their health conditions, followed by prioritized action steps using agile methodology. First and foremost, this would imply increasing user digital literacy, defining only the most important metrics from the perspective of physical therapy, and making health data digitization a legislative priority. As a result of the findings, specific digital content development and sensor network integration would occur. Certain high-level decisions and systematic facilitation mechanisms may boost the motivation and involvement of all parties.

Even though virtual reality and augmented reality has proved to be effective in many proprioception training and other cases, using these technologies as a distraction or movement enhancer without objective real time monitoring data is an arguable benefit since it can come to the level when self-harming movement range of motion can be enhanced due to visual and audible effect to neural mechanisms.

The study outcomes are contraindicatory on whether the user gets actual benefit from his health monitoring and whether the artificial intelligence algorithms can provide information that will change the user’s habits and provide easy to understand data interpretation.

Overall – the use of wearables for physical therapy will be defined not only by the necessity but by – portability, battery life, data storage, feasibility of use, patient compliance, limitations, ease of wearability, clothing accessory, cost-effectiveness and one of the most important criteria – user experience (Iqbal et al., 2016).

Visual based systems often require a more extensive, immovable setup of cameras and specialized data-analysis, and are more dependent on environmental factors such as lighting conditions and background noise. Number of studies include pre-existing games that are not optimized for rehabilitation purposes. The outcomes are evaluated using self-reported surveys therefore there is no objective data-based proof whether those games actually train muscle force, balance, mobility). More research towards construct validity of motion detection systems and their “game protocols” could aid to investigate whether the patient progress is actually devoted to the gaming element training. Other motion detection technologies such as a gyroscope or pressure sensor were also evaluated, although they were less commonly used and were mainly dependent of accompanying accelerometer data. Their motion analysis was mostly indirect (e.g., Nintendo Wii balance board estimating movement through ground reaction force analysis) and they were primarily used to quantitatively measure movement. in a rehabilitation context with an emphasis on qualitative movement, these systems are not applicable in their current setups.

This literature review shows that telehealth, internet-based programs, and mobile apps are the most promising technologies for LBP treatment due to the price and simplicity (Cavanagh et al., 2019). The author’s opinion is that in the light of tendencies when more and more countries are aiming for patient-centred and individualized healthcare system in their healthcare strategies, World Health Organization, governmental institutions are forced to reconsider their digitalization strategies, alter legislative documents, develop new guidelines and re-allocate budget for the IT infrastructure, the gap between scientific findings and practical use should narrow down. This might have a huge impact on the usage of wearables and their implementation in complex systems to ensure holistic and patient-centred approach – providing quantitative information on vital signs, movement quality and long-term sustained rehabilitation.

6. Conclusions

The analysis and discussion of current technologies in relation to the requirements of physical therapy were carried out in accordance with the stated goal. The specifics of low back pain treatment and vital signs monitoring are described to provide an understanding of the physical therapy requirements, challenges, and their influence on technology implementation in practice. The present novel technological solutions were described in section 3 to perform the analysis and describe the interconnection of the mentioned with the existing technologies. The conclusion is that monitoring is only effective if feedback is provided – most commonly, visual feedback – which has been shown to be more efficient than verbal instructions. Wearable sensors or feedback systems alone are less effective than combining the two, adding medical know-how with the use of AI or a physician, and providing a high-quality user experience. (Table 1).

List of abbreviations

Accelerometer (AM)
Chronic Low Back Pain (CLBP)
Chronic Obstructive Pulmonary Disease (COPD)
Cognitive functional therapy (CFT)
Electroencephalography – (EEG)
Electromyography (EMG)
Electronic goniometer (GM)
Gyroscope (Gy)
Heart rate variance (HRV)

High-speed red, green, and blue camera (RGb)
Inertial measurement unit (IMU)
Infrared sensor/camera (IF)
Magnetometer (MM)
Magnetic resonance imaging (MRI)
Non-specific Low Back Pain (NLBP)
Pneumatic force sensor (FS)
Pressure sensor (PS)
Virtual reality (VR)

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