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Review

Evaluation of Wearable Technologies in Physiotherapy and Rehabilitation

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Abstract

Wearable technologies are defined as electronic devices which can be carried on clothes and accessories and provide psychological monitoring and biological feedback as well. Rings, bracelets, watches, jewelry such as lenses or spectacles, headbands, e-textile goods, and hearing aids are all types of wearable devices. In this study, "wearable technologies," "physiotherapy," "physical activity," "sleep," and "smart textiles" keywords have been searched in PubMed, Google Scholar, Cochrane, and Scopus databases between 2001 and 2023. Wearable devices used in central nervous system diseases, athletes, sleep, physical activity, and weight control as well as smart textiles used in rehabilitation have been included in our study. Wearable technology makes it possible to expand the database of health-related information in addition to helping to monitor, improve, and maintain health. These technologies are commonly used in many diseases' diagnoses such as epilepsy and sleep disorders, in the follow-up of parameters related to physical activity and athlete's health, treatment, and rehabilitation processes of central nervous system diseases like Alzheimer's, and Parkinson's. In addition, smart textile products are used for sensory processing problems of individuals with autism spectrum disorder and figure out the risk of diabetic foot ulcers. By examining wearable technologies used for different purposes in physiotherapy and rehabilitation, this study contributes to the use of these technologies in new scientific studies.

Keywords: Physical activity, physiotherapy and rehabilitation, sleep, smart textiles, wearable technologies.

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Wearable technologies are defined as electronic devices which can be carried on clothes and accessories and provide psychological monitoring and biological feedback as well. Rings, bracelets, watches, jewelry such as lenses or spectacles, headbands, e-textile goods, and hearing aids are all types of wearable devices.[1]

Wearable devices are considered one of the important applications of devices that can send and receive data over the internet, now called objects of the internet. Due to the widespread use of the Internet of Things, users' opportunities to take control of their health and make healthy life choices have increased thanks to devices that can be connected through the internet.[2]

Wearable technologies can be used for different purposes, including health monitoring, management of chronic diseases, diagnosis and treatment of diseases,

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and rehabilitation.[3] In addition to allowing the user to monitor and improve their health status, these devices also contribute to the significant development of medical technology thanks to the sensors they contain.[4] Wearable devices can contain a wide variety of sensors such as accelerometers that measure acceleration, electrocardiograms that measure the electrical activity of the heart, galvanic skin receptor sensors that measure stress level and emotional state, glucose monitors that measure blood glucose levels, or photoplethysmography that measures blood volume.[5]

The use of wearable devices is widespread in the diagnosis, follow-up, treatment, and rehabilitation processes of many diseases. These devices provide significant benefits to both the wearable technology user and the healthcare professionals who monitor the user during the treatment process of musculoskeletal system problems or cognitive diseases.[3] It is estimated that the use of wearable devices designed to monitor physical activity and weight control will increase more than fivefold every half year.[6]

Wearable technologies are also used to detect sleep disorders. Sleep plays an important role in people's daily activities, and sleep disorders seriously affect the quality of life. Many studies have shown the relationship between poor sleep quality and many negative effects on our health, including but not limited to obesity, diabetes, heart disease, hypertension, mood disorders, weakened immune system, and increased risk of death.[7,8] To treat sleep disorders, it is very important to first detect, record, monitor, and analyze the disturbed sleep pattern. In the literature, polysomnography (PSG) is accepted as the gold standard in traditional sleep monitoring and examination method.[9]

With the rapid development of technology in recent years, smart textile products, which are wearable devices, can be preferred for many purpose-specific reasons. Smart textile products are used for purposes such as sensory development of individuals diagnosed with autism spectrum disorder, performance development of visually impaired swimmers, and determination of the risk of diabetic foot ulcers.[10–12] Smart textile products are developed with the principle of improving and using a determined technical feature. These developed products can detect and react to any external influence or changes in this influence.[13] Thanks to a series of sensors incorporated into textiles, smart textiles can detect environmental conditions and external stimuli such as light, heat, pressure, electromagnetic waves, sound and ultrasound waves, and movement.[14]

In this study, "wearable technologies," "physiotherapy and rehabilitation," "physical activity," "sleep," and "smart textiles" keywords have been searched in Pubmed, Google Scholar, Cochrane, and Scopus databases between 2001 and 2023. Wearable devices used in central nervous system diseases, athletes, sleep, physical activity, and weight control as well as using smart textiles in rehabilitation have been included in our study. This study aims to reveal wearable technologies used in the field of physiotherapy and rehabilitation by making use of current literature and contributing to the greater use of these technologies in new scientific studies.

Clinical and Research Consequences

Wearable Technologies in Central Nervous System Diseases

Central nervous system diseases are a broad category of neurological disorders that cause reduced motor abilities and are considered one of the largest public health problems.[15] Central nervous system diseases include Alzheimer's, Parkinson's, brain tumors, stroke, and other important diseases that threaten human life.[16] Wearable technologies provide significant benefits in the treatment of central nervous system diseases such as Parkinson's, Alzheimer's, and hemiplegia.[3]

ActiGraph

ActiGraph is a wearable device that can measure step count, activity intensity, total sleep time, sleep efficiency, waking after sleep onset, and total number of movements. Offering USB and Bluetooth® Smart functions, this device captures and records high-resolution human movements thanks to its 3-axis accelerometer. It is quite light (19 g) and provides easy use. When the literature is examined, it is seen that it is used in studies on determining the number of steps and fatigue level in individuals diagnosed with Multiple Sclerosis (MS).[17,18]

Biovotion everion

Biovotion Everion is a wearable device that can non-invasively collect real-time physiological data such as heart rate, respiratory rate, blood oxygenation, and skin temperature. It is usually worn on the upper arm. In addition, other clinical and non-clinical parameters that can be measured by this device are movement intensity, number of steps, energy consumption, sleep quality, and heart rate variability. It is one of the devices used to determine fatigue in individuals diagnosed with MS.[19]

Fitbit flex

Fitbit Flex is a device that automatically tracks daily activity count, distance, calories burned, and sleep. The elastomer material used in this watch is similar to that used in many sports watches, and it is flexible and durable. It also has a 3-axis accelerometer and vibration motor. It also has the feature of losing 7 days of detailed movement data minute by minute. It was used in a study on disability assessment in individuals diagnosed with MS.[20]

Keeogo exoskeleton

Keeogo exoskeleton has limited walking endurance or mobility. It is a wearable device designed for people who have difficulty climbing stairs or carrying objects. This wearable robotic device also has a strap system that is significantly different from other wearable devices.[21]

Wolk hip airbag

Wolk hip airbag is a wearable device that aims to prevent hip fractures and other injuries in the event of a fall. It is ergonomically important as users can wear it comfortably under their clothes. The device has six motion sensors and thanks to these sensors, it records every movement 500 times per second. Thanks to its software, this device processes all data and constantly determines whether the user has fallen or not. When its advanced algorithm detects a fall, the belt inflates and prevents the user from falling and getting hurt. Its use can be very beneficial, especially for patients diagnosed with stroke and the elderly population whose fall risk needs to be determined. The subject of studies is to reduce the fear of falling in individuals with stroke during rehabilitation and post-treatment processes.[22]

Wearable movement sensor

The wearable motion sensor consists of six sensors that detect the general movements of babies aged 12–16 weeks. Sensors weighing 10.25 g are placed so that they do not hinder the baby's natural movements or behavioral state. It is effective in early diagnosis of cerebral palsy and neurodevelopmental disorders and can improve lifelong health outcomes for at-risk infants.[23]

Shimmer 3

Shimmer 3 is a device with a gyroscope, magnetometer, three-axis accelerometer, and a processor capable of 3D motion estimation. In addition, it demonstrates Bluetooth data streaming functionality. All signals can be measured simultaneously and in real-time. There is a study used to evaluate spasticity in individuals diagnosed with cerebral palsy. It may be an alternative method to evaluation methods of spasticity in the field of physiotherapy and rehabilitation.[24]

Empatica E4

Empatica E4 is a wearable device that allows the measurement of sympathetic nervous system activity, skin temperature, and heart rate. It has Bluetooth feature, battery, and internal memory that can record up to 60 h. The device weighs 25 g. Thanks to its 3-axis accelerometer, it can detect motion-sensitive activities. There are devices currently used in individuals diagnosed with epilepsy. With the development of technology, it is thought that the use of these devices will increase by both patients and their relatives.[25,26]

Biometrics-differential sensors/SX230

The biometrics-differential sensors/SX230 device can capture signals during both static and dynamic activities and is simple to use without the need for cream or gel on the skin. It can be easily used with an electromyography (EMG) device in small muscles or large muscle groups. It was used in a study analyzing daily EMG results in women with Parkinson's disease.[27]

Parkinson's KinetiGraph

Parkinson's KinetiGraph consists of a small device worn on the wrist to collect data over 6–10 days. This smartwatch is used to evaluate symptoms such as tremors, bradykinesia, and dyskinesia during activity in patients with Parkinson's disease.[28]

Wearable Technologies for Athletes

Xsens MVN Systems

Xsens MVN systems are systems that analyze the lower extremity and pelvis kinematics of football players when they shoot. Unlike videography methods used as the gold standard in the literature for measuring the biomechanics of high-speed movements, it is easy and inexpensive to use in the field. When the literature is examined, it is seen that it is used as a safe device in motion analysis measurements. Since this system is small and easily adaptable to the body, it seems to be advantageous over other methods in evaluating the athlete's field performance.[29]

ISWIM System

The ISWIM system is designed for swimmers. It has sensors that examine the dynamic movements of athletes and provide the opportunity to instantly correct incorrect kinematics with vibratory feedback. It provides instant feedback to the athlete by measuring swimmers' roll angles (medial-lateral rotation) and stroke speeds during competition or training. While the swimmer receives single vibration feedback when swimming at a normal roll angle, and double vibration feedback if swimming at an extreme roll angle. In case of insufficient angulation, they do not receive any vibratory feedback.[30]

OPAL, APDM

OPAL, APDM wearable sensors are a system that measures whole-body kinematics. These sensors, which use gyroscopes and accelerometers, can synchronize up to 24 units wirelessly. This device provides real-time results to its users with a delay of <30 ms. Apart from its use mentioned in the central nervous system diseases section, it is also preferred by athletes. It allows both laboratory and sports-specific in-field use. Although there are many studies in the literature, a study conducted on swimmers stated that, unlike video analysis methods, both in-water and out-of-water analyses can be performed simultaneously and the method is safe.[31]

Sleep Wearable Devices

Ōura Ring

The Ōura ring was developed to estimate sleep parameters, heart rate variability, respiratory rate, and intensity of physical activity. It is a sleep monitoring device that uses acceleration and gyroscope data, photoplethysmogram signal, and body temperature. The Ōura ring has been shown to have 96% sensitivity in detecting sleep and 65%, 51%, and 61% accuracy in detecting "light sleep," "deep sleep," and "rapid eye movement" (REM sleep), respectively.[32,33]

Vívosmart® 5 Garmin Wristband

Vívosmart® 5 Garmin Wristband is a wearable wristband that collects information about falling asleep, waking from sleep, time spent awake, and duration of stay in basic sleep stages. It identifies sleep durations using a combination of sleep stages, heart rate, heart rate variability, and body movement data. In addition, the bracelet monitors your breathing rate and blood oxygen saturation levels throughout the night. For deep sleep, the nominal sensitivity is 0.56, and the specificity and accuracy values are 0.92 and 0.87, respectively.[34]

Whoop Bracelet

WHOOP is a wearable device that provides measurements of heart rate, heart rate variability, and sleep staging. This device has an accelerometer to track sleep. It also calculates the user's heart rate variability through the optical sensor. It provides information about the time it takes to fall asleep, time spent asleep, sleep efficiency, number of conscious and/or unconscious awakenings during the night, and position changes. It has been demonstrated that it is a device that can be used to estimate the stages of sleep in cases where PSG is not performed.[35,36]

Dreem Headband

The Dreem Headband includes five EEG electrodes, a three-dimensional accelerometer, and a pulse oximeter embedded in the device. The Dreem device has proven capacity to precisely monitor sleep-related physiological signals and accurately process them into sleep stages.[37]

Owlet Sock

The owlet sock is a miniature, wireless smart sock worn by newborn babies as a sock. It provides information to parents and healthcare professionals about the baby's oxygen saturation, skin temperature, heart rate, and sleep patterns. Owlet sock can detect sleep apnea observed in newborns.[38]

Go2sleep

Go2sleep is a wearable sleep measurement device. It estimates the depth of sleep by measuring the user's pulse and blood oxygen levels through finger sensors. It has the feature of warning the user in case of sleep apnea.[39]

Wearable Devices for Physical Activity and Weight Control

Modius

Modius is a wearable device that activates the hypothalamus, increases metabolic rate, and burns fat by stimulating the vestibular nerve. This headphone-shaped device is preferred by adults for weight loss and weight management. For weight loss purposes, it is recommended to use it 5 days a week, in 45-min sessions, for a total of 3 months.[40]

Lumo Lift

Lumo Lift is a wearable device with a sensor that is usually worn just below the clavicle. It provides information about the user's posture by sending vibration alerts. It also measures steps, distance, and calorie expenditure. The collection and monitoring of data is transferred to an application connected to the smartphone. It is known that posture training significantly reduces lower back pain.[41,42]

Moticon

Moticon is a wearable device that examines the correct pressure distribution and forces of the movements of patients and athletes with sensor insoles located on the sole of the shoe. It is linked to an application through which data are transferred to the smartphone. In this way, data can be analyzed from a smartphone. There are two types of sensor insoles. The Moticon OpenGo model has proven to be applicable in both clinical and research settings to evaluate temporal, force, and balance parameters during different types of movement compared to other sensor insoles.[43]

Smart Textiles Used in Physiotherapy

Adrenaline Dress

Adrenalin Dress can measure a person's body temperature, adrenaline, and stress level. It can detect and analyze the user's sweating, breathing patterns, and body temperature through sensors.[44,45]

Beagle

Beagle is a hooded scarf designed to stimulate or diminish the senses of its wearer. The device features sound reduction, audio integration, aromatic stimulation, and haptic personalization technologies. This scarf consists of hood pockets. It allows the user to change their sensory experience with the touch of a button. It can be given as an example of smart textile products designed for individuals diagnosed with autism spectrum disorders.[10]

Nadi X Yoga Pants

Nadi X Yoga Pants have haptic sensors in the fabric layer in the ankle, knee, and hip area. It guides through vibration and sound using sensors embedded in the pants. The application includes a library of yoga poses, visuals, and audio data. It has Bluetooth connectivity and an iOS operating system. The trousers connect to the mobile application through Bluetooth and thus guide the user visually and audibly. In this way, it can instantly warn if something is missing or goes wrong in the position.[46]

Blind Cap

The Blind Cap is a smart cap developed for visually impaired swimmers. It informs visually impaired swimmers that they have reached the end of the line and need to turn back. It connects through Bluetooth with any Android-based smartphone. The smart bone also makes it easier to make connections between athletes and coaches decently. The trainer ensures that the swimmer receives the necessary warning only when he presses a button on the phone screen. Thus, athletes do not need to touch their heads or bodies to make a turn with a simple mechanism. This smart test product can be preferred to improve the performance of disabled swimmers.[11]

Hexoskin Pro Kit

Hexoskin Pro Kit is used for advanced physiological health monitoring, longitudinal clinical studies, stress monitoring, and performance training. It is compatible with iOS and Android operating systems. It connects through Bluetooth and can record for more than 36 h. Hexoskin can determine pulse, heart rate variability, respiratory rate, respiratory volume, and activity level (steps, cadence, and calories). When the literature was examined, it was stated that this device was reliable for determining heart rate, submaximal exercise, and maximum exercise. It has also been found to be valid for measuring tidal volume and minute ventilation during submaximal exercise.[47]

BalanceBelt

BalanceBelt is designed to provide tactile feedback regarding body position for individuals with balance problems. This device contains several small vibration motors and an accelerometer. The device provides warnings about the user's body position with vibrating feedback. In this way, the user can correct his posture and improve his balance. It is thought that it may serve as an effective aid to improve the quality of life in patients with severe bilateral vestibular loss.[48]

Conclusion

Wearable technologies are an area where the application area has increased and significant developments have occurred in the last decade. Various wearable solutions are being implemented to assist clinicians in assessing and diagnosing, using commercially available devices or developing custom systems. In addition to contributing to the monitoring, improvement, and sustainability of health, these devices also enable the expansion of the health-related database.

These technologies are commonly used in many diseases' diagnoses such as epilepsy and sleep disorders, in the follow-up of parameters related to physical activity and athlete's health, treatment, and rehabilitation processes of central nervous system diseases such as Alzheimer's and Parkinson's. In addition, smart textile products are used for sensory processing problems of individuals with autism spectrum disorder and to figure out the risk of diabetic foot ulcers. Since wearable technologies have a wide range of uses, health-care professionals recommend these devices to their patients for many different reasons.

Although there are studies conducted with wearable devices in the literature, it seems that they are not included enough in scientific studies. Many randomized controlled scientific studies are needed before the use of these technologies in the diagnosis and treatment processes of diseases can be considered the gold standard. Since these devices can be used in both diagnosis and treatment processes, studies can be designed for different purposes in scientific studies.

Physicians and physiotherapists play an active role in determining the purpose-specific wearable devices for rehabilitation. Considering wearable technologies' contributions to healthy individuals and patients, these technologies should be used more. In this context, it is very important to increase the awareness level of individuals and provide information about the devices. Smart textile products, like other wearable devices, provide benefits to health-care professionals in the diagnosis and treatment process. It can be predicted that smart textile products will be given more space in scientific studies in the coming years.

This study is important in terms of revealing wearable technologies used for different purposes in the field of physiotherapy and rehabilitation, user-specific wearable device selection, providing necessary information about the devices, and contributing to the greater use of these technologies in new scientific studies.

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