Medical & Biological Engineering & Computing (2022) 60:1239–1252
https://doi.org/10.1007/s11517-022-02544-w

REVIEW ARTICLE

Wearables and their applications for the rehabilitation of elderly people

Valeria P. Bravo[1] · Javier A. Muñoz[2]

Received: 24 September 2021 / Accepted: 27 February 2022 / Published online: 17 March 2022

Abstract

Globally, there has been a change in the population pyramid with an accelerated aging process. This increase requires a greater challenge to maintain autonomy and independence. Currently, there are technologies developed with a focus on health. This is given by the development of wearables and their areas of applications. As a general context, this technology is characterized by the research field in energy generation, the development of external devices for human control and monitoring, clothing, smart textiles, and electronics. The latter are classified into three areas of application: monitoring and safety; fabrics, perception, and physical activity; and rehabilitation. A literature review is conducted to identify the state-of-the-art in these fields within the last years. The progress in monitoring systems and intelligent textiles is evidenced, being able to highlight remote feedback, materials, and wearability both at a commercial and user level. A discussion is included to address the main challenges and future trends in the application of wearables in elderly people.

Keywords Elderly · Health devices · Rehabilitation · Smart clothing · Smart textiles · Electronic textiles · Vibration · Wearables

1 Introduction

The World Health Organization (WHO) states that the elderly population is growing rapidly. Between 2000 and 2050; the proportion of the world's population over 60 years of age will double from 11 to 22% [1]. This constitutes a social challenge, where it is necessary to adapt and improve health, functional capacity, social participation, and safety. This change in the population requires further progress in maintaining autonomy and independence during aging. This requires adopting an anticipatory and preventive approach, in order to maintain the functionality of the older adult. Currently, the increasing elderly population presents an important demand in the healthcare sector. Therefore, greater progress is required in maintaining autonomy, independence, and functionality through physical activity [2, 3]. In this process, there are problems of balance and motor tasks, generated by the loss of muscle mass and strength. This determines an increase in the risk of falls, which can lead to hospitalization and surgery. In adults over 65 years, falls are the second leading cause of death worldwide due to accidental or unintentional injuries [4]. The incidence increases with age, and it varies according to lifestyle.

On the other hand, there is a prevalence of neurological diseases, which reach 15% worldwide [5]. These generate an important source of disability. Cerebrovascular disease, caused by the impaired blood supply to the brain, is one of the most prevalent in the elderly population and one of the leading causes of long-term disability worldwide [6, 7]. It is estimated that 55–75% have a long-term motor and sensory impairment, and more than 60% are unable to incorporate the affected hand in performing activities of daily living [8].

Parkinson's disease is characterized as neurodegenerative and is strongly associated with aging. It is recognized as a progressive and highly disabling disorder. It presents motor slowing, resting tremor, muscle rigidity, postural problems, and postural instability. These can lead to falls and further compromise functionality. Worldwide, an estimated 4 million people suffer from this condition reaching a prevalence of 1–2% in those over 65 years of age, increasing to 3–5% in those over 85 years of age [9, 10].

✉ Valeria P. Bravo
vbravo@utalca.cl

1 University of Talca, Curico, Chile

2 Faculty of Engineering, University of Talca, Curico, Chile

These diseases cause motor, sensory, and/or cognitive alterations, significantly compromising the performance of activities of daily living and the social participation of people. For this reason, strategies have been developed to maintain and improve the functional conditions of older adults with disabilities. Given the characteristics of the motor limitations present in this population, there is a need for access to rehabilitation, technical and technological aids. Currently, the incorporation of assistive technology such as robotics, wearable devices, electrical stimulation, among others, specifically in the rehabilitation field [11], have been the focus of great scientific interest, since they have potential advantages, both for people with disabilities and for health professionals.

The use of wearable devices attached or incorporated into clothing offers monitoring, feedback, treatment, and rehabilitation functions. Also, they have the potential to improve cost-effectiveness by allowing continuous therapy while performing activities of daily living, enhancing the effects of rehabilitation. This can provide more effective hours compared to a traditional 30- to 60-min therapy session, considerably increasing the number of weekly hours of intervention and, therefore, its effects on patients' functional ability in real life. According to the World Health Organization, most people in developing and underdeveloped countries have access to assistive technologies in only 5–15% [12]. The causes may be low availability, costs, and lack of health professionals or knowledge about the usefulness, benefits, and use possibilities [13, 14].

In this review, an analysis is established on the advancement of assistive technologies for rehabilitation, where the development in wearables is described in section II as a general context. Section III presents the search method, where the investigations related to the technology are found. From that point, three research areas are identified: (i) monitoring and safety; (ii) fabrics, perception, and physical activity; and (iii) rehabilitation, which are deeply described in section IV. Section V discusses the limitations of this review, and, finally, section VI finds the conclusions and future work.

2 Context

The development of wearables has a wide area of application and uses. They are used in the commercial area, systems navigation, production processes, sports, prevention, and health. In this last area, it is found an advance in wearable technology, body technology, smart clothing technology, or textile electronics. Both the wearables and the electronic system devices, present different features such as the fit on the skin, sustainability in the storage and generation of energy, portability, light-weighting, flexibility, elasticity, reliability, skin compliance, and sensitivity. Its application is presented mainly in the monitoring of human biosignals and the monitoring of people in health systems.

There is a huge potential in the area of human healthcare and monitoring control, where the emphasis is placed on its biomedical application to provide valuable information in the health and wellness field, e.g., heart rate, brain waves, and muscle biosignals. Currently, there is a new research trend on flexible and extensible physical sensors integrated into platforms for monitoring human activity in wearable devices where electrical signals generated by human activities can be measured and quantified. Among these devices, it is possible to mention temperature, pressure, and voltage sensors, flexible fluids, and extensible platforms integrated with sensors [15].

Another trend intended to achieve a potentially transformative development in smart garments [16] is the electronic integration into textiles, which requires the fabrication of devices directly into the fabric itself using high-performance materials, allowing seamless incorporation into textiles. Woven electronics and optoelectronics, achieved by interwoven fibers with complementary functions using graphene fabricated directly on fabric fibers and obtained by weaving graphene electronic fibers into the fabric.

Regarding electronic and smart fabrics, flexible organic transistors are presented in [17], which are based on fabrics using graphene nanoparticle electrodes as electrically conductive. Their application is mainly evidenced in portable electronics. It is highlighted the fabrication of multifunctional textile composites by vacuum filtration and wet transfer of graphene oxide films on a flexible polyethylene terephthalate fabric in association with the inclusion of graphene nanoparticles to improve electrical conductivity, which can be applied to flexible clothing surfaces. Further, it included the development of a method to fabricate a thin, flexible-emitting fabric [18] using organic light-emitting diodes and its subsequent fabrication.

A new trend regarding the fabrication of soft and reversibly actuatable glass elastomer fibers [19] is highlighted. This method uses direct ink printing, which corresponds to a 3D printing technology used for fiber production. Another study incorporates smart fabrics to monitor vital signs [20] that uses a fiber Bragg network sensor embedded in it. Finally, in [21–23], some textile enhancements are found that will generate a breakthrough in the development of tangible products for the benefit of people.

Wearable sensors are also found in wearable ambulatory systems for monitoring physical activity and gait [24–26]. On the other hand, there are studies on automatic assessment of physical workload risks through motion sensors integrated into work clothes [27].

In the textile field, there are electricity conducting fibers, which are used for the fabrication of fabric fiber by means of graphene nanocomposite yarns for incorporation into smart clothing or disposable patch sensors [28, 29]. Within the textile energy storage in wearables, it is possible to highlight energy storage systems utilizing body movement [30, 31] and biomechanical energy storage fabrics based on nanogenerators that mechanically convert the energy into electricity [32].

Other technologies include methods to predict quickly and accurately the 3D positions of body joints [33]; the development of a wearable suit-type robot to promote muscle strength support for users, both for elderly people or people with some difficulty of movement [34]; and finally, devices for personal cooling to control the temperature of an individual [35].

There is research associated with energy generation in terms of materials that can be applied to textiles, where body movement is a precursor for obtaining this energy [28]. It should be noted that disposable elements are considered, which can be incorporated into clothing.

Aspects of water vapor permeability and comfort for prolonged use are analyzed before the integration of nanocomposites with fabrics by laser scribing and heat press lamination, proving their ability to stretch, portability, and washing [29]. Besides, there are conductive fibers, based on thermoplastic polymers by melt spinning, which are converted into conductive fibers at low cost to be used in clothing, fabrics, and others [36].

Using displacement, some wearables transform energy into motion. In fact, a study conducted with self-charging power textile [37] based on flexible yarn supercapacitors and fabric nanogenerators presents an automatic charging system, which combines energy harvesting and storage technologies employing cells in the fabric.

It is important to emphasize that within the textile area, the creation of conductive materials incorporated into the fabric or textile fiber can achieve greater autonomy through the use of thermoelectric materials and techniques compiled to convert them into energy and subsequent uses. The development in this area, through the creation of clothing, smart fabrics, and electronics for the benefit of health, presents an important technological advance. Figure 1 shows the technology evolution mainly for monitoring or treatment purposes, in the areas of physical activity and rehabilitation. Its application has contributed significantly to the life of users, where portability presents a primary differentiation in the use of this type of technology. It contributes to a better evaluation of the functional capacity of real-life users.

The chronology of the technology in Fig. 1 comprises the area of sensors for monitoring human activity and personal healthcare, temperature sensors, pressure sensors, strain sensors, and sensor-integrated platforms [15]. Smart clothes for rehabilitation are also distinguished. Smart textiles were introduced in the early 1990s. In this area, it is possible to find smart clothes for therapy as well as smart T-shirts with different (non-excluding) functions, such as the capability of heart and respiratory rate monitoring, activity recording, electrocardiography (ECG), respiration, electromyography (EMG), just to name the most representatives [38].

Portable technology is also recognized. It stands out for promoting preventive medical care. Devices are incorporated into clothing to recognize activities and behaviors in the user. It includes the acquisition and processing of data and the ability to communicate. They are identified in clothing with integrated sensors for health monitoring and electronic accessories used on the body. Smart garments improve rehabilitation processes, functional capacity in patients, and physiological data. The importance of integration in wearables and the creation of new technologies for smart and electronic textiles, smart clothing can be found to benefit the study of the functional capacity of users, considering data delivery. It is characterized by being a ready-made garment to which electronic textile is incorporated. It presents great support for people in the process of rehabilitation. The

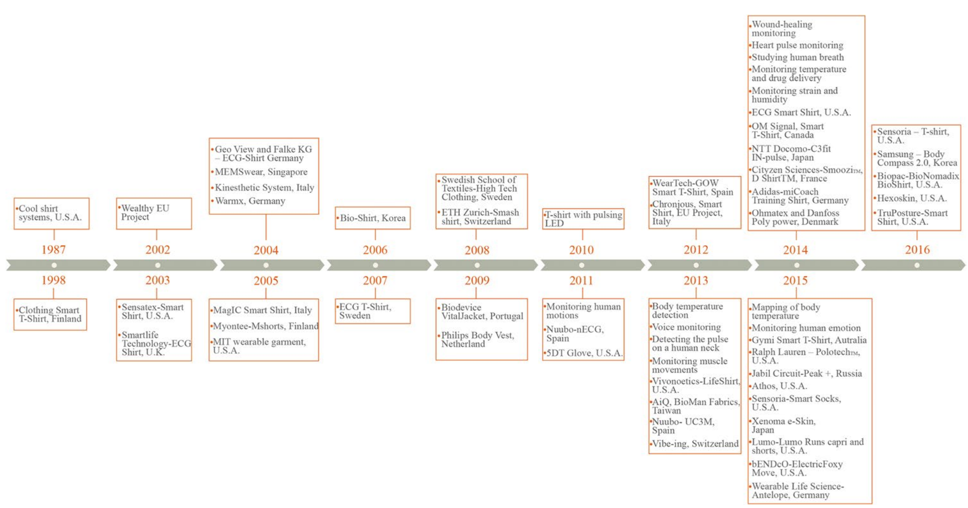


Fig. 1 Chronology of the technology

electronic textile incorporates electronic components [38] with the purpose of obtaining information in the monitoring of health and sports. The smart textile corresponds to a wide area of products that incorporate functionality and the use of common fabrics. They are made up of fibers, filaments, yarns, and woven structures that interact with the user. The application of this type of system focused on the energy area specifically in the creation of intelligent devices incorporated into the textile, sensors for human control and monitoring, creation of conductive materials incorporated into the textile or textile fiber along with smart clothing and electronic textiles used in the field of rehabilitation, presents an advance of wearable technology and sensors [39].

This has been able to contribute to care in the elderly through indoor positioning, activity recognition, and vital sign monitoring [40, 41]. In addition, the development of clothing, smart textiles, and electronics [42], which can incorporate various functions, is highlighted. These present a focus in the area of rehabilitation, being able to generate wearable technologies [43] in electronic textiles through portability, and the increase in the field of research together with the market with exponential growth.

3 Search method

The research is performed based on wearables and their applications in the rehabilitation sector, from 2015 to 2020. The purpose is evidenced in the applications of wearables, on technologies for fabric development such as smart clothing, electronic and smart textiles, and vibration. Its focus is given to the elderly and sports in the rehabilitation field. It considers the design of (3.1) search strategy, (3.2) search terms, (3.3) database, (3.4) selection process, and (3.5) selection criteria.

3.1 Search strategy

A search is established in publications between 2015 and 2020.

3.2 Search terms

Analyzing the search terms, it develops a search equation composed of (Clothing AND smart clothes AND elderly) OR (e-textile AND elderly AND vibration) OR (elderly AND smart textile) OR (sportswear AND smart clothes).

3.3 Database

It is provided by three electronic databases, IEEE Explore, Web of Science, and Scopus. The search terms are considered through the equation, identifying the title, abstract, and keywords of each of the studies and other articles found.

3.4 Selection process

According to the latter, 83 articles were selected as candidates for the search. A total of 53 documents are identified, where articles, conferences, journals, and reviews are considered, according to the search process. Figure 2 describes the selection process.

3.5 Selection criteria

3.5.1 Inclusion

- Identify applied studies through the use of fabrics, garments that contain or incorporate vibration, sensors, or external devices that are attached to clothing concerning the elderly and sport in the rehabilitation area.
- Articles from 2015 to 2020.
- Category of journals, articles, reviews, and conferences.

3.5.2 Exclusion

- Research that evidence applications for other aims or purposes.
- Duplicate articles are deleted.

The selected research articles were analyzed and subsequently, the corresponding area to which they will be associated is determined. These areas correspond to monitoring and safety; fabrics, perception, and physical activity; and rehabilitation. This is defined by the topic of each article to establish an order regarding the investigations found and to know in which disciplines there is a significant advance.

4 Wearable applications for the elderly in the rehabilitation

In the framework of this review, there are three research areas: monitoring and safety; fabrics, perception, physical activity; and rehabilitation, as shown in Fig. 3.

4.1 Monitoring and safety

The use of portable devices is considered an important technology to promote preventive medical care, data collection, functional capacity assessment, and detection of data used in monitoring. They can be found in garments with built-in sensors and in electronic accessories worn on the body. Significant developments are found in the literature.

Fig. 2 Selection process

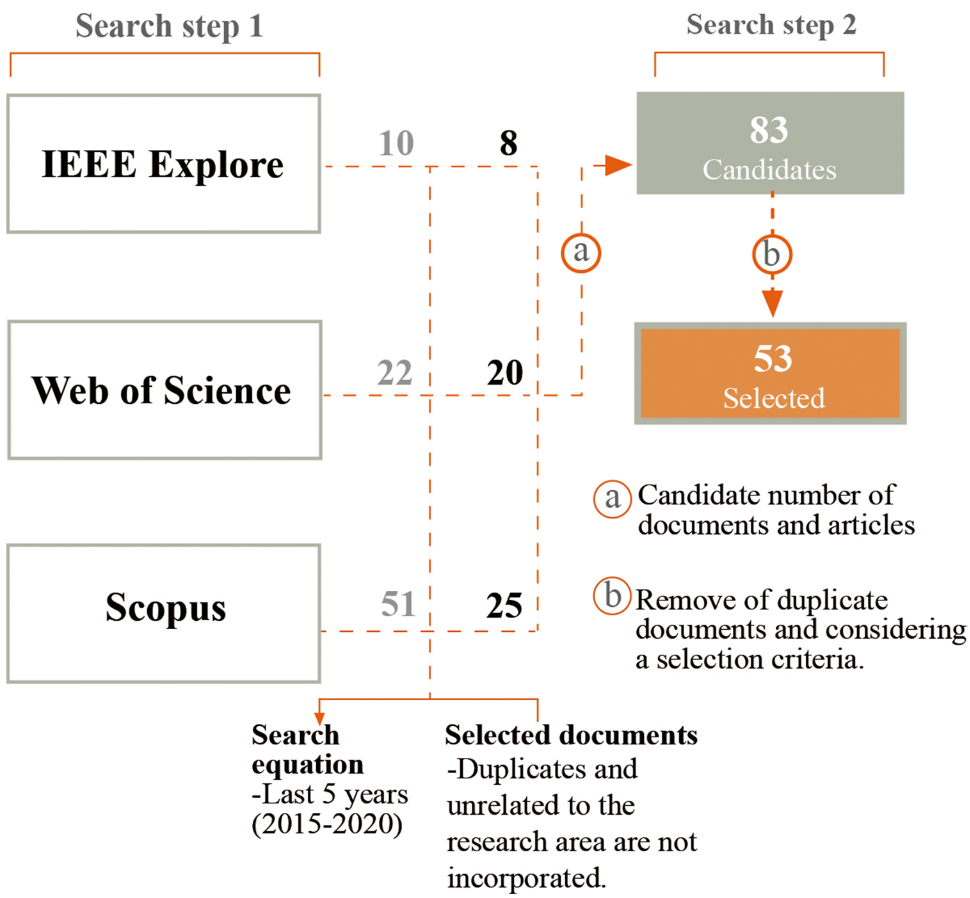
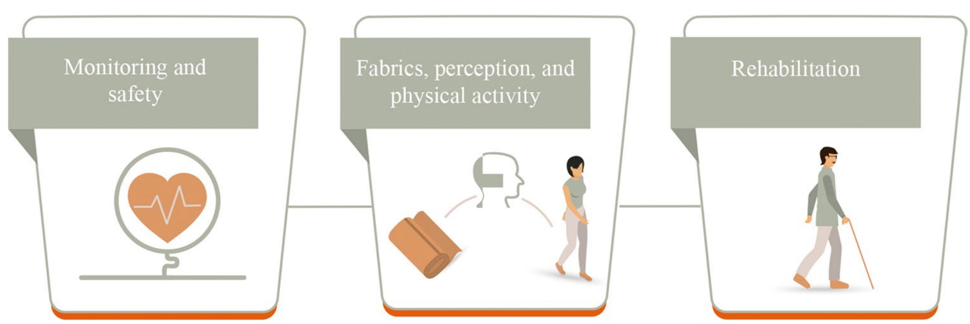


Fig. 3 Research areas



A textronic shirt was developed for older adults [44] that incorporates a remote monitoring system and control of physiological data such as pulse, respiration rate, underwear temperature, and location within the environment. It manages to identify the health status of the person through textile clothing and data acquisition. If any of these parameters change in a way that threatens the life of the person, the personnel in charge will be notified. It is powered by a miniature battery. The sensory shirt features a modular system with textile sensors used to measure biosignals. Also, it considers additional hardware infrastructure like a Wi-Fi network and RFID antennas. It contains a pulse sensor, located on the chest to maintain its quality, a flexible point sensor to measure the rate of respiration, an IPS system for real-time location, and a GPS system for user search. The whole system is managed by a web application embedded in the Synology DS1010+server. Textile sensory elements and textile signal lines are implemented in the structure of garments, and it is the main innovation in this type of system. The relationship between textile, electronic, and computer engineering is highlighted. Multifunctional products are obtained, so the combination of the textile clothing interface with specialized software for data acquisition and alarm signal generation provides a continuous overview of health.

A safety mechanism is created by a similar system of airbags through intelligent clothing [45] that are incorporated into it. The system has multiple sensors that will be placed on the smart clothing used. The signals from the sensors are fed into the inflated bag control unit, which determines from them the angle of impact, gravity, or force of fall. All statistics are collected at the moment of impact by the smart airbag device system. They can be viewed on the smart bracelet, mobile devices, computers, or tablets. Its connection will be made through intelligent microsensors, and it will obtain information about a person who is at risk of falling. This system is applied for athletes' and elderly people's care. It has highlighted its ability to protect and measure the body against any damage by analyzing and delivering data via Bluetooth when the user falls. This information is analyzed by a professional health care specialist. The data obtained are relevant in case of an internal injury, and specific treatment can be applied to the patient. It highlights a breakthrough in the field of smart wearable electronics [46], where it is expected to mass-produce smart garments with data transmission lines and sensors.

An ECG monitoring system [47] with Bluetooth incorporated into a T-shirt allows the signals to be collected and transmitted to an application in a mobile phone and to analyze the ECG signal in real time. The app looks for possible heart problems. If it detects a critical problem, it can alert the user and medical professionals. The shirt is made of a polyester microfiber, a synthetic fabric that absorbs moisture and is used in sportswear. It contains three 5-cm square dry electrodes made of tissue silver. It does not require gel or adhesives. A strategy of placement and pressure of the electrodes is presented to keep the T-shirt in permanent contact with the skin and avoid distortions in the signal. Waterproof cable connectors are used to connect the electrode cables to the box containing the electronic components. This allows the user to remove the electronic components to wash the garment. Using the dry electrodes, the noise was lowered when analyzing the signal. A low-cost product stands out but requires further testing for its verification and effectiveness of results.

There is also a concern in caring for the elderly in the face of natural disasters. A location tracking system is designed in an emergency situation [48]. By means of low-power sensors integrated into smart clothes of washable nature, it is possible to do this. Small rechargeable batteries are used for its operation. Through smart clothing, other elements can be integrated that allow location control in older adults in an emergency. To trace the evacuation route, a recurring neural forecasting algorithm is used that includes a base of environmental sensors. It is expected to improve evacuation management through transceivers integrated into washable smart clothing that are powered by small rechargeable batteries housed in a waterproof housing.

A technology based on a fabric device that uses a portable hybrid triboelectric-piezoelectric nanogenerator is presented in [49]. It is fabricated by electrospinning silk fibroin and poly (vinylidene fluoride) (PVDF) electrospun on nanofibers on conductive fabrics. Nanogenerator shows outstanding electrical performance, with a power density of 310 μW/cm^2. This new fiber has flexibility, air permeability, and is custom embedded in the clothing of any size. It identifies the movement of the body, and the energy obtained in it can be stored to function as a portable energy source. It allows detecting an emergency state such as the case of a fall and sending an alert message to ensure monitoring in real time via the Internet, cell phone, or other portable electronic devices.

An electronic system for the detection of urinary incontinence through a fabric sensor with an embroidered conductive thread is presented in [50]. It examines the woven fabric interlayer of cloth diapers, with high-strength PET fibers as the warp yarns and water-absorbent cotton fibers as the weft yarns. To produce fabrics with sufficient conductivity to detect moisture, two parallel metallic fibers are also woven at a distance of 6 cm as the weft yarn. When the woven fabrics absorb water, the short circuit between the two metallic fibers signals the sensor to create an alarm. The alarm message is transmitted to a central database server via a wireless sensor network. In addition, the caregiver monitors the wetness status of diapers via mobile phone, notebook, and personal computer. It is placed on a mat attached to the bed. It achieves impermeability, cleanliness, and reusability. This development allows recognizing the humidity and occupation of a person through the same sensor. It is considered a differentiating element, and it will allow tracking activity during the night with the aid of subsequent studies.

A bionic sensor for EMG, ECG, vibration, and temperature monitoring was developed for elderly care in [51]. The sensor is small and wireless, and it has prolonged use and good biosignal understanding. It is used for monitoring elderly people and in sports. The training device increases mobility by the given data of muscle activity (EMG). It uses clothing with conductive fiber and a mobile application to visualize the signal delivered via Bluetooth in real time. It is required to reduce the size of the system and increase the duration in the care of older adults in the long term.

The health status of a patient during hospitalization allows medical staff to know his or her vital conditions. A heart rate monitoring system and a prediction tool that measures a patient's parameters are designed in [52]. Conductive foils that integrate the electronic circuit with clothing are incorporated. A conductive vest and chest belt are used, which continuously record physiological index parameters during hospitalization. The parameters are transmitted wirelessly and recorded on a physician's computer. At the end of his hospitalization, the patient's original and recorded physiological data are evaluated by the TIMI risk score. This indicator determines the patient's prognosis. The system is composed at the front end by a Bluetooth heart rate monitor and smart textile. The middle end is an application for receiving data on a tablet or smartphone. The back end is the physician's computer in MATLAB.

A system presented in [53] was designed for continuous long-term monitoring of cardiac health, in which a mobile application collects data from the garment with an accuracy of 96%. It achieves a better reception of the patient and early warning by using this type of technology. This is given by a fitted T-shirt, which contains four sensors to perform daily monitoring. The use of smart garments for elderly healthcare provides a new form of remote monitoring for elderly healthcare. Furthermore, the use of garments allows greater convenience of conventional medical devices [54].

The portable urine leak detection system presented in [55] is generated by using a capacitive fabric sensor of humidity embroidered with conductive yarn in a cotton/polyester substrate. A microcontroller (MCU) with a wireless module for signal acquisition and a smartphone for monitoring complete the overall system. The results show that the proposed system is able to detect urine leakage even when the patient wears a diaper. This system uses a smartphone to receive the information and provide evidence of the leakage. It shows an advance and concern in the elderly, considering the development of a real-time monitoring system that can be used in medical centers or homes for the elderly population.

There is a concern in health care and prevention of diagnosis of people problems through monitoring [56], mainly in physiological control [57] as in the case of mobility and blood pressure measurement [58]. A thin multilayer textile is presented in [59] that detects the user's pressure and position as a form of monitoring in the event of an emergency in case an older adult faces a fall situation. A positive factor is the size and thickness of the system since it is not uncomfortable for the user. It is important to consider convenient, easy-to-use systems for remote monitoring of health status through sensors and modern portable, noninvasive, and low-cost technologies [60].

The elderly healthcare in nursing homes allows achieving efficient support and safeguards to ensure efficient treatment. In [61], some research is shown about the monitoring of physiological functions, activity management, falls, and emergencies in elderly people who live in this type of institution, through smart garments. There is a shirt that incorporates Bluetooth Low Energy (BLE) components and an indoor positioning algorithm. The data is obtained through the garment into a database linked in the cloud. During an emergency, the medical professional in charge is notified immediately. This system facilitates the identification of the health status of the elderly [62]. A folding blanket [63] woven by a weft pattern is developed to be used by the elderly. It has a dimension of 1 m^2, is touch-sensitive, and can detect the position of the user's body on floors or beds. This breakthrough allows this product to be applied in homes and hospitals at a later stage.

4.2 Fabrics, perception, and physical activity

Smart garments present a high impact in their applications, especially when they have fibers incorporated within the garment rather than sensors embedded in it [64]. In this context, a flexible textile-based electroosmotic pump with water transport is presented in [65]. In the design of innovative wearable devices that can actively adjust permeability under a variety of conditions. This is applied to insoles and sportswear. The devices have the ability to transport moisture in the area of smart garments and medical protection.

An ergonomic and portable fabric cap is presented in [66] with four channels with dry electrodes supported by an ultra-soft gel backing to monitor electroencephalogram (EEG) signals and to identify emotions in elderly people. It is possible to consider in the future incorporating more channels to obtain more information, a power supply that allows better portability with the product as well as ergonomics, aesthetics, and appearance considering the specific objective audience.

Wearable technology can become garments in a multisensory experience [67], generating a bridge between visual, physical, and perceptual experience. Its application obeys in the field of sports, the elderly, military, and medical work. It is established in [68] that by the inkjet process, it is possible to achieve a feasible component for the creation of a wire-type conductive stretchable material. This can be used in the field of sportswear, compression underwear, among others.

The development of an encapsulated system integrated into a sports shirt is presented in [69] that can be washed without disconnection. It contains three stretchable fabric electrodes and an electronic module connected via a flexible printing plate design. It delivers information about the physical condition of the user in real-time, through a mobile application via Bluetooth. It should be noted that the use of thermoplastic polyurethane (TPU) is beneficial to protect the conductive thread in case of washing. Another material used is carbon nanotubes [70] due to their lightweight and conductivity. They are a breakthrough for wearable electronics and smart fabrics in both sportswear and conventional clothing. Nowadays, sportswear allows monitoring physical conditions and player performance. The creation of biosensors, nano transistors, and printing electronic circuits directly on elastic materials has enabled the development of new garments [71]. The development of snap-type electrical connectors was investigated in [72], in order to connect them with fragments of textile signal lines. These can be used in smart garments, analyzing their usefulness. It is evident that there is a high possibility that they can be used effectively as electrical connectors in signal transmission systems. In this way, progress can be seen in the use of garments, materials, and implements that allow obtaining information about the health status of the elderly through physiological parameters such as a portable electrocardiogram [73], with low energy consumption incorporated into a textile garment.

In health and skincare, there is a wipe [74] that contains a pH indicator to identify skin damage caused by an allergic reaction in the self-care of an elderly adult during showering. Likewise, it is possible to test products on the wipe before use and verify it. This is also feasible in the case of wound dressings.

The water-transporting fabrics [75] are capable of transporting body moisture immediately in sportswear. Whereby, the dry heat transfer in fabrics shows a better performance than in the case of wet cloth. This material is quite promising for the development of smart textiles in sportswear. Nowadays, the sports industry does not present garments for active older adults. The design and development of sportswear products that incorporate smart fabrics and electronic devices into a new active aging market are gaining relevance [76]. Also, it is worth noting the importance of smart sportswear for self-care for people with Down syndrome [77]. As society is aging, there is an increased concern in healthcare. A system based on smart clothing is designed [78], which does not interfere with the daily life activities of the wearer. The system delivers physiological parameter information, which is stored in a cloud. In case of an emergency, the caregivers are notified immediately. With this system, the frequency of accidents is expected to decrease.

Dementia and gait disorders are some of the problems that come with the possibility of a fall. It requires care assistance. A fall detection system is realized in [79], which is powered by batteries printed on the garment. This is located in the lumbar area and covers up to 660 cm^2 depending on size. The device is located and integrated into the waistband through the design of ergonomic trousers. This indicator presents favorable conditions of use and comfort since it is integrated into the garment.

A reminder system by using metallic fibers incorporated in eco-cloths is developed in [80] for better wearability. These allow obtaining conductivity in the fabric combined with a low-dimensional sensor. This design allows proving that it is possible to use electronics in textiles.

A pressure sock system is designed in [81] that incorporates woven sensors located in strategic areas of the foot to estimate the magnitude of cushioning of the midsole of the shoe interacting with different types of cushioning and barefoot in the evaluations. Through gait tests on the subjects, it was able to identify the increased sensitivity of the device, thanks to different shoe cushioning and its external conditions, such as its degradation in quality because of its deterioration and environment. Its development is highly promising.

The perspiration level of a person indicates their physical, condition, health condition, and comfort in athletes, patients, and elderly people. A textile sensor composed of three conductive threads, where each one is linked to a cotton cover is presented in [82]. These sensors measure the total amount of sweat in the fabric. It can be incorporated in different places of the garment. It presents the quality of being produced in scale and low cost. Globally, there is an increase in new technological solutions that help to make a better contribution to the quality of human life. This can be achieved through functionality and intelligence in garments and fabrics. The focus is on comfort, health care, and safety. It is expected that companies will develop functional and intelligent clothing products for the elderly population [83].

An intelligent shirt is highlighted in [21]. When it is used, it examines the performed physical activities. It identifies when the person presents low activity by the cardiovascular behavior. Therefore, by wearing this garment, an anticipatory state can be obtained to enhance the daily activities proactively.

The garment qualities that older adults are looking for are due to wearability, safety, and thermal comfort [84]. This is beneficial for people with thermoregulation deficiency. With the use of embroidery on or incorporated into fabric clothing, it is possible for a hybrid thread in its stitching design combined with an embroidered heating pad and connection with metal snaps and a conductive cable will generate greater comfort in the presence of cold weather as a form of garment warmer. On the other hand, it is important to consider the development and the use of batteries that must be incorporated into the fabrics. Most of these are rigid and have low flexibility. In the literature, research based on textile batteries [85] of yarns and fabrics coated with metal or carbon is applied to develop energy in fabrics with embroidered patterns. The results establish that the metal-coated yarn as electrodes in combination with carbon yarns as electrolyte and iodine triiodide gel delivers a flexible surface for use in fabrics. However, there is short-term durability throughout this type of application.

An electronic chest strap prototype [86] measures the performance, mobility, and fall detection of the wearer. The band is made of nylon thread for its elasticity capacity and sensors integrated by conductive wires. It is identified that the weight and thickness of the product are not suitable for sports use. However, its fields of application can be in the care assistance of the elderly and disabled people.

Three interactive blankets for the elderly manufactured by optical fiber shawl, color, and heat change are presented in [87]. Each garment contains an integrated microcontroller with a WiFi module and a lithium polymer battery sewn into a detachable patch. Besides, it has an integrated notification system. Its manufacture is given by industrial knitting with platform machines. It is taken into account the fragility when optical fibers are incorporated into fabrics, which is why its manufacturing process was developed manually, making the production process difficult. Moreover, in the case of the heating blanket, the choice of battery will involve the duration time and the thermal capacity of the garment, considering that it must be light.

4.3 Rehabilitation

It is relevant to obtain information regarding the patients and to be able to work with them with the objective to lessen their complications through health care. An intelligent glove was developed in [88]. It presents a system for monitoring the movements of joints and fingers due to rheumatoid arthritis generated to a large extent by elderly people. The device is portable, low cost, and has low power consumption; it allows achieving collaborative work with the medical professional remotely through remote reading through a smartphone using a dedicated app. The flex sensor on the index finger detects and estimated the motion; a BLE Nano is used for processing and wireless transmissions. The wearable smart glove uses a lithium-ion 3.3 V rechargeable 400 mAh battery for consuming power. This Smart Glove also helps in monitoring the patient's response to either medication and/or diverse recommended movements. The system uses two flex sensors and one force sensor. Finger motion is measured by a flex sensor, while the force sensor measures the applied pressure on each finger and transfers all these data to the microcontroller. The Arduino Lilypad processes the data and sends them to a physiotherapist by using a Bluetooth module. It frames a different and reliable way to achieve collaborative work without the need for attendance at a medical center.

To maintain a favorable autonomy, it is relevant to provide mobility to people due to possible locomotion disabilities. Therefore, it is proposed a device called a "smart walker" [89] that is able to monitor and analyze the gait in real time. The measurement system includes a wireless data acquisition module, a heart rate sensor, four load cells, and software. The results show that the device is able to detect and classify steps on a standard four-legged walker. The device can estimate the balance and motor coordination, step length and azimuth, and lift of the walker frame. The medical professional can evaluate the physical condition and adjust the therapy according to the progress of the patient. This system can be integrated into any commercial walker, allowing wider use.

Hitoe [90] is a material applied in the collection of biological data in patients through the use of a textile garment. It is a conductive polymer that is implanted coating the surface of fibers with a conductive polymer, resulting in a very flexible, hydrophilic, and durable device. The material is electrically conductive and can be mixed with accelerometers. It allows establishing the heart rate and its changes for extended periods during 24 h. While wearing the T-shirt, all data collected is sent to a server by a smartphone to be reviewed by a medical expert later. This generates an increase in the quality of therapy in elderly adults, where it is expected to reduce the professional workload through home-based remote rehabilitation.

It is fundamental to maintain good posture when using a wheelchair for an extended period. A dangerous posture is known as sacral sitting. Elderly adults and people with disabilities are predisposed to pressure ulcers, which should be avoided. A smart wheelchair is developed in [91], using electronic fabric pressure sensors (e-textile pressure sensor 40 cm^2) in the seat and backrest. A notification will deliver information for postural change of the user and decrease the workload of the caregiver. The pressure points should be decreased by at least three lines in order to reduce the cost of the product. This allows providing efficient results on posture.

Orthostatic hypotension [92] is common in the elderly population. The use of current compressive garments exerts varied pressures on the body. The incorporation of these products can be complex and even cause immobility during use.

Active knitted compression stockings are designed in [93]. They contain smart materials composed based on shape memory alloys with a knitted fabric in graduated compression with higher tension from the ankle and lower tension up the leg. Compression is activated when the applied temperature reaches 70 °C. This is achieved by Dynalloy's Flexinol® yarn. This favors dynamic and controlled pressures to the body, being able to apply a specific therapeutic treatment. Therefore, there is interest in applying this material in the composition of the garment, and through the body temperature, it is possible to apply defined compression.

The literature review provides favorable progress regarding the use and development of technologies applied to the elderly population, health control, and sports. It highlights several challenges such as the mechanical flexibility of materials, effectiveness of the product under washing conditions, and useful life of the garment or the incorporated system with energy supplies, development, uses, and commercialization. Furthermore, it is possible to apply the closeness to the human body and the possibility of discretion of smart fabrics in applications such as health, safety, and active living. Establishing a relationship concerning the people's needs in incorporating this type of technologies, with the purpose of not interrupting and improving their independence [94] in daily activities in an efficient form and including the assistance of their treatments remotely [95]. The quality of elderly life is related to health, physical limitations, and loneliness. Elderly adults must wear smart clothing to contribute to improving this, achieving independence in their activities. For this reason, elders need to be able to move freely in their daily life.

5 Discussion

In the three areas of this review, the publications found in this research correspond to the areas of engineering, materials science, and computer science. Subsequently, the following limitations are established and analyzed for each area mentioned in the review.

5.1 Monitoring and safety

Regarding the technological advances in monitoring systems, providing physiological data, and warning signals in the event of an emergency in the elderly, there is evidence only at a basic research level. However, further studies are required to reach the market.

Besides, the costs associated with the developments are high, which reduces replicability in the target audience and rather applies an approach for medical and clinical centers. Also, the conductive materials applied in the analyzed developments must provide safety, comfort, and cost consideration by comparing materials with similar characteristics. In this way, an efficient balance will be achieved.

By incorporating sensors in the garment to collect user data, they must be removed before washing the garment, and on the other hand, they must be small so as not to cause any discomfort while wearing the smart garment.

Remote monitoring is beneficial for the elderly and healthcare professionals. However, the usability of garments for both is critical to consider in this process when designing clothing, and electronic components are associated with it. Applying a universal language and an appropriate user manual is required for a positive experience.

5.2 Textiles, perception, and physical activity

The energy storage for the operation of the smart garment or sensors is complex to perform because conventional batteries are characterized by having a greater volume, weight, and rigidity. At the moment that the garment is washed, it does not have a long-term duration, since the encapsulation does not achieve water repellency conditions. For that reason, the encapsulation must be removed before washing. This complicates the actual operation of the garment by the wearer.

The fibers and conductor yarns incorporated in clothing or fabrics made from a mixture of textile fibers must fulfill the characteristics of permeability, flexibility, extension capacity in the case of compressive fabrics, and maintain the same resistance when it is washed, as well as in the case of nanotechnology. To provide security to the user through sewing, embroidery, woven, nonwoven, printed, laminated coating, nato-treated, among others, for optimal efficiency in combination with size and thickness.

Energy consumption and the material and manufacturing costs are essential for the development of smart garments used for both health and sports.

5.3 Rehabilitation

The technology associated with the rehabilitation area depends mostly on the use of smartphones. This generates dependence on the system in elderly people, therefore, reducing its use if they do not have this device.

In the literature review, there are no studies and applications related to electrostimulation or vibration as a form of therapy in patients or elderly people.

The application of heat in rehabilitation is due to investigate other types of conductive fibers and yarns with thermal characteristics, considering body temperature in order to generate new developments and the application of the Peltier effect in fabrics.

6 Conclusion

This review has been presented an analysis of wearable technology and its three areas of application. It should be noted that health and sports are fundamental to the treatment and active life of the elderly population. It establishes an analysis on smart fabric and electronics composed of smart clothing for monitoring and rehabilitation purposes, electronic fabric where the electronic components are applied to health and sport, and smart fabric used in products that present functionality through their fabrics (fibers, yarns, and woven structures). In the area of smart garments and textiles, there were three performance areas analyzed, which are composed mainly of the monitoring and safety, fabrics, perception and physical activity, and rehabilitation.

The monitoring and safety application is the most developed section in this research, presenting several advances in the development of physiological status control by rapidly obtaining data compared with the conventional method. Furthermore, they have the facility to maintain continuous tracking data. Thus, the medical professional will have control of the state in case of an emergency. The emerging area of smart fabrics is in the process of becoming a technological reality. However, its main applications so far have been sportswear, which allows different body measurements to be taken during individual training and to enhance the physical activity of older people. It presents progress in monitoring physiological data, analyzing movement, and monitoring control in case of an unexpected accident. It is attempted to propose fabric-based smart garments for rehabilitation.

Electronic fabrics could be an integral part of this technology that would provide innovative forms of sensory feedback that could potentially enhance body experiences, for example, the stimulus application such as vibration that is incorporated into the garment and applied in treatments as well.

Smart garments provide greater accessibility to rehabilitation services. They improve and optimize healthcare, reducing the need for medical appointments and allowing better conditions for patient rehabilitation interventions in the comfort of their homes, increasing patient diagnosis and intervention, and enhancing the quality of rehabilitation through a portable system.

The cost has become critical to achieving the affordability of smart wearables. A way is to empower the interconnectivity and interoperability that should be considered in the design of smart garments in patients who are receiving rehabilitation treatment. In other words, having the ability to connect other sensors or add hardware (garments, accessories, or software components) to measure other data measurements. In this way, combine and analyze all the collected values.

The future of portable electronic fabrics will be determined by the ability to manufacture products with integrated electronic components that are useful in satisfying everyday daily life needs.

The application of printing on fabrics and 3D printing incorporated into textiles is a developing field, which aims to achieve conductivity in its further applications. The production standards will help to decrease the manufacturing time of electronic textiles and the final manufacturing costs as well. However, many of these technologies are still in the research phase, where requirements such as washability, toxicity, and resistance to tensile forces have still to be addressed. Moreover, the development of new standardized tests to control sources of e-textile failures, such as cyclic loading and current flow, is crucial to ensure the endurance of e-textiles over time. Also, there is a necessity to implement improved strategies for component encapsulation and life extension of e-textiles. The development of e-textiles with energy storage functions and the use of batteries should not be implemented by rigid formats, however, through flexible textile batteries with long-term duration. Furthermore, in this line, it is considered the use of Bluetooth and the comfort of the fit of the garment on the wearer. This is an important challenge to face. In this way, an opportunity will be achieved in order to insert these new developments in the market, as in the case of health and sports.

Finally, it is relevant to highlight that the development of smart fabrics requires a multidisciplinary approach, in which knowledge of circuit design, smart materials, microelectronics, chemistry, design, and medicine are completely integrated with a solid understanding of fabric manufacturing.

Acknowledgements The authors thank the support of the National Doctorate Scholarship ANID Chile, the year 2019–2022 folio 21190910.

References

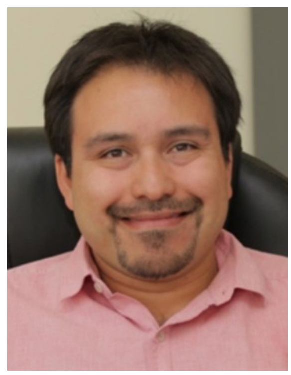
1. "OMS | Datos interesantes acerca del envejecimiento," *WHO*, 2015, Accessed: Oct. 20, 2020. [Online]. Available: http://www.who.int/ageing/about/facts/es/.
2. "OMS | La actividad física en los adultos mayores," *WHO*, 2013.
3. "(No Title)." https://apps.who.int/iris/bitstream/handle/10665/186466/9789240694873_spa.pdf?sequence=1 (accessed Nov. 07, 2020).
4. "Caídas." https://www.who.int/es/news-room/fact-sheets/detail/falls (accessed Nov. 06, 2020).
5. "Discapacidad y salud." https://www.who.int/es/news-room/fact-sheets/detail/disability-and-health (accessed Nov. 07, 2020).
6. Feigin VL et al (2014) Global and regional burden of stroke during 1990–2010: findings from the Global Burden of Disease Study 2010. Lancet 383(9913):245–255. https://doi.org/10.1016/S0140-6736(13)61953-4
7. Lavados PM et al (2007) Stroke epidemiology, prevention, and management strategies at a regional level: Latin America and the Caribbean. Lancet Neurol 6(4):362–372. https://doi.org/10.1016/S1474-4422(07)70003-0
8. Hankey GJ, Jamrozik K, Broadhurst RJ, Forbes S, Anderson CS (2002) Long-term disability after first-ever stroke and related prognostic factors in the Perth Community Stroke Study, 1989–1990. Stroke 33(4):1034–1040. https://doi.org/10.1161/01.STR.0000012515.66889.24
9. P. Chaná, M. Jiménez, V. Díaz, and C. Juri, "Mortalidad por enfermedad de Parkinson en Chile Parkinson disease mortality rates in Chile."
10. G. Alves, E. B. Forsaa, K. F. Pedersen, M. Dreetz Gjerstad, and J. P. Larsen, "Epidemiology of Parkinson's disease," in *Journal of Neurology*, Sep. 2008, vol. 255, no. SUPPL. 5, pp. 18–32, https://doi.org/10.1007/s00415-008-5004-3
11. D. J. Reinkensmeyer and M. L. Boninger, "Technologies and combination therapies for enhancing movement training for people with a disability," *Journal of NeuroEngineering and Rehabilitation*, vol. 9, no. 1. 2012, https://doi.org/10.1186/1743-0003-9-17.
12. Mertz L (2020) E-textiles for health monitoring: off to a slow start, but coming soon. IEEE Pulse 11(3):20–24. https://doi.org/10.1109/MPULS.2020.2993663
13. "OMS | Dispositivos y tecnologías de apoyo a las personas con discapacidad," *WHO*, 2016, Accessed: Nov. 09, 2020. [Online]. Available: http://www.who.int/disabilities/technology/es/.
14. P. Alvial, "Uso de tecnología en rehabilitación." Accessed: Nov. 09, 2020. [Online]. Available: www.redclinica.cl.
15. Trung TQ, Lee NE (2016) Flexible and stretchable physical sensor integrated platforms for wearable human-activity monitoring and personal healthcare. Adv Mater 28(22):4338–4372. https://doi.org/10.1002/adma.201504244
16. E. Torres Alonso *et al.*, "Graphene electronic fibres with touch-sensing and light-emitting functionalities for smart textiles," *npj Flex. Electron.*, vol. 2, no. 1, 2018, https://doi.org/10.1038/s41528-018-0040-2.
17. Y. Kim *et al.*, "Flexible textile-based organic transistors using graphene/Ag nanoparticle electrode," *Nanomaterials*, vol. 6, no. 8, Aug. 2016, https://doi.org/10.3390/nano6080147.
18. S. Choi *et al.*, "Highly flexible and efficient fabric-based organic light-emitting devices for clothing-shaped wearable displays," *Sci. Rep.*, vol. 7, no. 1, Dec. 2017, doi: https://doi.org/10.1038/s41598-017-06733-8.

19. Roach DJ et al (2019) Long liquid crystal elastomer fibers with large reversible actuation strains for smart textiles and artificial muscles. ACS Appl Mater Interfaces 11(21):19514–19521. https://doi.org/10.1021/acsami.9b04401
20. Koyama S, Sakaguchi A, Ishizawa H, Yasue K, Oshiro H, Kimura H (2017) Vital sign measurement using covered FBG sensor embedded into knitted fabric for smart textile. J Fiber Sci Technol 73(11):300–308. https://doi.org/10.2115/fiberst.2017-0046
21. E. Kańtoch (2018) “Recognition of sedentary behavior by machine learning analysis of wearable sensors during activities of daily living for telemedical assessment of cardiovascular risk,” *Sensors (Switzerland)*, vol. 18, no. 10. https://doi.org/10.3390/s18103219.
22. Manogaran G et al (2019) Wearable IoT smart-log patch: an edge computing-based Bayesian deep learning network system for multi access physical monitoring system. Sensors 19(13):3030. https://doi.org/10.3390/s19133030
23. Esfahani MIM, Nussbaum MA (2018) A ‘smart’ undershirt for tracking upper body motions: task classification and angle estimation. IEEE Sens J 18(18):7650–7658. https://doi.org/10.1109/JSEN.2018.2859626
24. Gao W, Ota H, Kiriya D, Takei K, Javey A (2019) Flexible electronics toward wearable sensing. Acc Chem Res 52(3):523–533. https://doi.org/10.1021/acs.accounts.8b00500
25. Lee Y et al (2017) Biomechanical design of a novel flexible exoskeleton for lower extremities. IEEE/ASME Trans Mechatronics 22(5):2058–2069. https://doi.org/10.1109/TMECH.2017.2718999
26. Hegde N et al (2018) The pediatric SmartShoe: wearable sensor system for ambulatory monitoring of physical activity and gait. IEEE Trans Neural Syst Rehabil Eng 26(2):477–486. https://doi.org/10.1109/TNSRE.2017.2786269
27. Yang L et al (Jul. 2018) Towards smart work clothing for automatic risk assessment of physical workload. IEEE Access 6:40059–40072. https://doi.org/10.1109/ACCESS.2018.2855719
28. Patel SV, Cemalovic S, Tolley WK, Hobson ST, Anderson R, Fruhberger B (2018) Implications of thermal annealing on the benzene vapor sensing behavior of PEVA-graphene nanocomposite threads. ACS Sensors 3(3):640–647. https://doi.org/10.1021/acssensors.7b00912
29. Y. J. Hong *et al.*, “Multifunctional wearable system that integrates sweat-based sensing and vital-sign monitoring to estimate pre-/post-exercise glucose levels,” *Adv. Funct. Mater.*, vol. 28, no. 47, Nov. 2018, doi: https://doi.org/10.1002/adfm.201805754.
30. Li S et al (2015) Cloth-based power shirt for wearable energy harvesting and clothes ornamentation. ACS Appl Mater Interfaces 7(27):14912–14916. https://doi.org/10.1021/acsami.5b03680
31. A. Dabrowska and A. Greszta, “Analysis of the possibility of using energy harvesters to power wearable electronics in clothing,” *Advances in Materials Science and Engineering*, vol. 2019. Hindawi Limited, 2019, doi: https://doi.org/10.1155/2019/9057293.
32. W. Gong *et al.*, “Continuous and scalable manufacture of amphibious energy yarns and textiles,” *Nat. Commun.*, vol. 10, no. 1, Dec. 2019, doi: https://doi.org/10.1038/s41467-019-08846-2.
33. H. Y. Chung, Y. L. Chung, and C. Y. Liang, “Design and implementation of a novel system for correcting posture through the use of a wearable necklace sensor,” *JMIR mHealth uHealth*, vol. 7, no. 5, May 2019, doi: https://doi.org/10.2196/12293.
34. S. J. Park and C. H. Park, “Suit-type wearable robot powered by shape-memory-alloy-based fabric muscle,” *Sci. Rep.*, vol. 9, no. 1, Dec. 2019, doi: https://doi.org/10.1038/s41598-019-45722-x.
35. Tong JK, Huang X, Boriskina SV, Loomis J, Xu Y, Chen G (Jun. 2015) Infrared-transparent visible-opaque fabrics for wearable personal thermal management. ACS Photonics 2(6):769–778. https://doi.org/10.1021/acsphotonics.5b00140
36. Han P, Zhang X, Qiao J (2016) Intrinsically conductive polymer fibers from thermoplastic trans-1,4-polyisoprene. Langmuir 32(19):4904–4908. https://doi.org/10.1021/acs.langmuir.6b01333
37. Pu X et al (2016) Wearable self-charging power textile based on flexible yarn supercapacitors and fabric nanogenerators. Adv Mater 28(1):98–105. https://doi.org/10.1002/adma.201504403
38. G. Postolache, H. Carvalho, A. Catarino, and O. A. Postolache, *Smart clothes for rehabilitation context: technical and technological issues*, vol. 22. 2017.
39. L. Wang, “Recognition of human activities using continuous autoencoders with wearable sensors,” *Sensors (Switzerland)*, vol. 16, no. 2, 2016, https://doi.org/10.3390/s16020189.
40. Z. Wang, Z. Yang, and T. Dong, “A review of wearable technologies for elderly care that can accurately track indoor position, recognize physical activities and monitor vital signs in real time,” *Sensors (Switzerland)*, vol. 17, no. 2, 2017, doi: https://doi.org/10.3390/s17020341.
41. D. Dias and J. P. S. Cunha, “Wearable health devices—vital sign monitoring, systems and technologies,” *Sensors (Switzerland)*, vol. 18, no. 8, 2018, doi: https://doi.org/10.3390/s18082414.
42. Priya A, Kumar A, Chauhan B (2015) A review of textile and cloth fabric wearable antennas. Int J Comput Appl 116(17):1–5. https://doi.org/10.5120/20425-2741
43. Gonçalves C, da Silva AF, Gomes J, Simoes R (2018) Wearable e-textile technologies: a review on sensors, actuators and control elements. Inventions 3(1):1–13. https://doi.org/10.3390/inventions3010014
44. M. Frydrysiak and L. Tesiorowski, “Health monitoring system for protecting elderly people,” in *2016 International Multidisciplinary Conference on Computer and Energy Science, SpliTech 2016*, Aug. 2016, pp. 1–6, doi: https://doi.org/10.1109/SpliTech.2016.7555935.
45. K. S. Patel and S. S. Patel, “Method and apparatus for safety using inflated bags through smart sports clothes,” in *Proceedings - 2nd International Conference on Computing, Communication, Control and Automation, ICCUBEA 2016*, Feb. 2017, pp. 1–4, doi: https://doi.org/10.1109/ICCUBEA.2016.7860135.
46. K. Nesenbergs and L. Selavo, “Smart textiles for wearable sensor networks: review and early lessons,” in *2015 IEEE International Symposium on Medical Measurements and Applications, MeMeA 2015 - Proceedings*, Jun. 2015, pp. 402–406, doi: https://doi.org/10.1109/MeMeA.2015.7145236.
47. L. Gonzales *et al.*, “Textile sensor system for electrocardiogram monitoring,” in *2015 IEEE Virtual Conference on Applications of Commercial Sensors (VCACS)*, Mar. 2015, pp. 1–4, doi: https://doi.org/10.1109/VCACS.2015.7439568.
48. A. C. M. Fong, B. Fong, and G. Hong, “Short-range tracking using smart clothing sensors : AA case study of using low power wireless sensors for pateints tracking in a nursing home setting,” in *2018 IEEE 3rd International Conference on Communication and Information Systems, ICCIS 2018*, Feb. 2019, pp. 169–172, doi: https://doi.org/10.1109/ICOMIS.2018.8645003.
49. Guo Y et al (2018) All-fiber hybrid piezoelectric-enhanced triboelectric nanogenerator for wearable gesture monitoring. Nano Energy 48:152–160. https://doi.org/10.1016/j.nanoen.2018.03.033
50. Fischer M, Renzler M, Ussmueller T (Jul. 2019) Development of a smart bed insert for detection of incontinence and occupation in elder care. IEEE Access 7:118498–118508. https://doi.org/10.1109/access.2019.2931041
51. H. K. Dow, I. J. Huang, R. Rieger, K. C. Kuo, L. Y. Guo, and S. J. Pao, “A bio-sensing system-on-chip and software for smart clothes,” Mar. 2019, doi: https://doi.org/10.1109/ICCE.2019.8662101.
52. C. C. Hsiao, R. G. Lee, S. C. Tien, Y. Y. Feng, and S. F. Huang, “Early clinical prognosis for high-risk chest pain patients using

smart textiles," *Biomed. Eng. - Appl. Basis Commun.*, vol. 27, no. 6, Dec. 2015, doi: https://doi.org/10.4015/S101623721550057X.
53. W. Y. Lin, H. L. Ke, W. C. Chou, P. C. Chang, T. H. Tsai, and M. Y. Lee, "Realization and technology acceptance test of a wearable cardiac health monitoring and early warning system with multi-channel MCGs and ECG," *Sensors (Switzerland)*, vol. 18, no. 10, Oct. 2018, doi: https://doi.org/10.3390/s18103538.
54. R. I. W. K. H. Ohfwurfduglrjudsk, "Iru Wkh (Oghuo \ % Dvhg Rq 6Pduw & Orwkhv," pp. 478–482, 2018.
55. M. Martinez-Estrada, R. Fernandez-Garcia, and I. Gil, "A wearable system to detect urine leakage based on a textile sensor.," Oct. 2020, pp. 1–3, doi: https://doi.org/10.1109/fleps49123.2020.9239554.
56. M. J. Rodrigues, O. Postolache, and F. Cercas, "Physiological and behavior monitoring systems for smart healthcare environments: a review," *Sensors (Switzerland)*, vol. 20, no. 8. MDPI AG, Apr. 02, 2020, doi: https://doi.org/10.3390/s20082186.
57. Tian M, Lu Y, Qu L, Zhu S, Zhang X, Chen S (2019) A pillow-shaped 3D hierarchical piezoresistive pressure sensor based on conductive silver components-coated fabric and random fibers assembly. Ind Eng Chem Res 58(14):5737–5742. https://doi.org/10.1021/acs.iecr.9b00035
58. Katayama K, Chino S, Koyama S, Ishizawa H, Fujimoto K (2020) Verification of blood pressure monitoring system using optical fiber sensor -tracing sudden blood pressure changes-. J Fiber Sci Technol 76(2):79–87. https://doi.org/10.2115/fiberst.2020-0008
59. Lim SJ, Bae JH, Jang SJ, Lim JY, Ko JH (2018) Development of textile-based pressure sensor and its application. Fibers Polym 19(12):2622–2630. https://doi.org/10.1007/s12221-018-8813-8
60. S. Majumder, T. Mondal, and M. J. Deen, "Wearable sensors for remote health monitoring," *Sensors (Switzerland)*, vol. 17, no. 1. MDPI AG, Jan. 12, 2017, doi: https://doi.org/10.3390/s17010130.
61. Y. H. Lu and C. C. Lin, "The study of smart elderly care system," in *8th International Conference on Information Science and Technology, ICIST 2018*, Aug. 2018, pp. 483–486, doi: https://doi.org/10.1109/ICIST.2018.8426110.
62. C. C. Lin, C. Y. Yang, Z. Zhou, and S. Wu, "Intelligent health monitoring system based on smart clothing," *Int. J. Distrib. Sens. Networks*, vol. 14, no. 8, Aug. 2018, doi: https://doi.org/10.1177/1550147718794318.
63. Takamatsu S, Yamashita T, Murakami T, Masuda A, Itoh T (2018) Meter-scale flexible touch sensor using projection capacitive measurement technique and fabric electrode for human position detection. Sensors Mater 30(12):3039–3051. https://doi.org/10.18494/SAM.2018.2173
64. Hu X et al (2020) Multiscale disordered porous fibers for self-sensing and self-cooling integrated smart sportswear. ACS Nano 14(1):559–567. https://doi.org/10.1021/acsnano.9b06899
65. Y. Zhang, M. Tian, L. Wang, H. Zhao, and L. Qu, "Flexible Janus textile-based electroosmotic pump for large-area unidirectional positive water transport," *Adv. Mater. Interfaces*, vol. 7, no. 13, Jul. 2020, doi: https://doi.org/10.1002/admi.201902133.
66. F. Zeng, P. Siriaraya, D. Choi, and N. Kuwahara, "Textile EEG cap using dry-comb electrodes for emotion detection of elderly people," 2020. Accessed: Oct. 27, 2020. [Online]. Available: www.ijacsa.thesai.org.
67. I. Hrga, "Wearable technologies: between fashion, art, performance, and science (fiction)," *Tekstilec*, vol. 62, no. 2. University of Ljubljana, pp. 124–136, 2019, doi: https://doi.org/10.14502/Tekstilec2019.62.124-136.
68. A. Albrecht *et al.*, "Over-stretching tolerant conductors on rubber films by inkjet-printing silver nanoparticles for wearables," *Polymers (Basel).*, vol. 10, no. 12, 2018, doi: https://doi.org/10.3390/POLYM10121413.
69. X. Tao, T. H. Huang, C. L. Shen, Y. C. Ko, G. T. Jou, and V. Koncar, "Bluetooth low energy-based washable wearable activity motion and electrocardiogram textronic monitoring and communicating system," *Adv. Mater. Technol.*, vol. 3, no. 10, Oct. 2018, doi: https://doi.org/10.1002/admt.201700309.
70. S. Shahidi and B. Moazzenchi, "Carbon nanotube and its applications in textile industry–a review," *Journal of the Textile Institute*, vol. 109, no. 12. Taylor and Francis Ltd., pp. 1653–1666, Dec. 02, 2018, doi: https://doi.org/10.1080/00405000.2018.1437114.
71. T. Chittenden, "Skin in the game: the use of sensing smart fabrics in tennis costume as a means of analyzing performance," *Fash. Text.*, vol. 4, no. 1, Dec. 2017, doi: https://doi.org/10.1186/s40691-017-0107-z.
72. Leśnikowski J (2016) Research on poppers used as electrical connectors in high speed textile transmission lines. Autex Res J 16(4):228–235. https://doi.org/10.1515/aut-2016-0025
73. Dai M, Xiao X, Chen X, Lin H, Wu W, Chen S (Dec. 2016) A low-power and miniaturized electrocardiograph data collection system with smart textile electrodes for monitoring of cardiac function. Australas Phys Eng Sci Med 39(4):1029–1040. https://doi.org/10.1007/s13246-016-0483-5
74. C. Schaude and G. J. Mohr, "Indicator washcloth for detecting alkaline washing solutions to prevent dermatitis patients and babies from skin irritation," *Fash. Text.*, vol. 4, no. 1, 2017, https://doi.org/10.1186/s40691-017-0092-2.
75. C. Zeng, H. Wang, H. Zhou, and T. Lin, "Heat transfer in directional water transport fabrics," *Fibers*, vol. 4, no. 4, 2016, https://doi.org/10.3390/fib4040026.
76. McCann J (2016) Sportswear design for the active ageing. Fash Pract 8(2):234–256. https://doi.org/10.1080/17569370.2016.1215118
77. Y. C. Huang, J. H. Chen, G. Y. Chen, and K. F. Tung, "Smart sportswear design for down syndrome patients," in *Advances in Intelligent Systems and Computing*, 2020, vol. 1202 AISC, pp. 847–855, https://doi.org/10.1007/978-3-030-51194-4_109.
78. P. C. Huang, C. C. Lin, H. J. Hsieh, W. C. Chen, and H. H. Chiang, "Development of health care system based on smart clothes," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2020, vol. 12193 LNCS, pp. 78–88, https://doi.org/10.1007/978-3-030-49913-6_7.
79. S. Uran and J. Geršak, "Smart clothing to increase safety of people with dementia," in *IOP Conference Series: Materials Science and Engineering*, Dec. 2018, vol. 460, no. 1, https://doi.org/10.1088/1757-899X/460/1/012047.
80. Lou CW, Shiu BC, Lin JH, Chang YJ (2015) Development and characteristic study of woven fabrics for intelligent diapers. Technol Heal Care 23(5):675–684. https://doi.org/10.3233/THC-151008
81. Oks A, Katashev A, Eizentals P, Pavare Z, Balcuna D (2019) Application of smart sock system for testing of shoe cushioning properties. IFMBE Proceedings 68(3):861–864. https://doi.org/10.1007/978-981-10-9023-3_155
82. J. Jia *et al.*, "Conductive thread-based textile sensor for continuous perspiration level monitoring," *Sensors (Switzerland)*, vol. 18, no. 11, Nov. 2018, doi: https://doi.org/10.3390/s18113775.
83. S. Palamutcu and I. Goren, "Functional textile preferences of elderly people," *Mediterr. J. Soc. Sci.*, vol. 6, no. 2S5, pp. 279–285, 2015, https://doi.org/10.5901/mjss.2015.v6n2s5p279
84. Havelka A, Tichý M, Soukup R, Nagy L (2018) Application of hybrid heating textile structures in clothing for seniors. Vlakna a Text 25(4):26–30
85. M. Normann, T. Grethe, K. Zöll, A. Ehrmann, and A. Schwarz-Pfeiffer, "Development of 2D and 3D structured textile batteries processing conductive material with Tailored Fiber Placement (TFP)," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 254, no. 7, 2017, https://doi.org/10.1088/1757-899X/254/7/072016

86. R. Atakan *et al.*, "Design of an electronic chest-band," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 254, no. 7, 2017, https://doi.org/10.1088/1757-899X/254/7/072002.
87. E. F. Waldhör, B. Greinke, P. Vierne, K. Bredies, and P. Seidler, "E-textile production of wearable ambient notification devices," *DIS 2017 Companion - Proc. 2017 ACM Conf. Des. Interact. Syst.*, pp. 309–312, 2017, doi: https://doi.org/10.1145/3064857.3079181.
88. M. Raad *et al.*, "An IOT based wearable smart glove for remote monitoring of rheumatoid arthritis patients," in *BIOSIGNALS 2019 - 12th International Conference on Bio-Inspired Systems and Signal Processing, Proceedings; Part of 12th International Joint Conference on Biomedical Engineering Systems and Technologies, BIOSTEC 2019*, 2019, pp. 224–228, https://doi.org/10.5220/0007573302240228.
89. V. Viegas, J. M. Dias Pereira, O. Postolache, and P. S. Girão, "Application of force and inertial sensors to monitor gait on legacy walkers," *Acta IMEKO*, vol. 7, no. 4, pp. 33–41, 2018, https://doi.org/10.21014/acta_imeko.v7i4.575.
90. Ogasawara T, Matsunaga K, Ito H, Mukaino M (2018) Application for rehabilitation medicine using wearable textile 'hitoe.' NTT Tech Rev 16(9):6–12
91. C. Hayashi, Y. Enokibori, and K. Mase, "Harmless line-oriented sensing point reduction for non-categorical sitting posture score," *UbiComp/ISWC 2017 - Adjun. Proc. 2017 ACM Int. Jt. Conf. Pervasive Ubiquitous Comput. Proc. 2017 ACM Int. Symp. Wearable Comput.*, pp. 61–64, 2017, doi: https://doi.org/10.1145/3123024.3123083.
92. M. C. Farrell and C. A. Shibao, "Morbidity and mortality in orthostatic hypotension," *Autonomic Neuroscience: Basic and Clinical*, vol. 229. Elsevier B.V., Dec. 01, 2020, doi: https://doi.org/10.1016/j.autneu.2020.102717.
93. R. Granberry, J. Abel, and B. Holschuh, "Active knit compression stockings for the treatment of orthostatic hypotension," *Proc. - Int. Symp. Wearable Comput. ISWC*, vol. Part F1305, pp. 186–191, 2017, doi: https://doi.org/10.1145/3123021.3123065.
94. M. J. Magalhães, S. T. De Magalhães, and K. Revett, "Enhancing elderly mobility through IoT using textiles: a review," *Smart City 360 2016 - 2nd EAI Int. Summit*, pp. 1–10, 2017, doi: https://doi.org/10.4108/eai.14-2-2017.152284.
95. K. Guan, M. Shao, and S. Wu, "A remote health monitoring system for the elderly based on smart home gateway," *J. Healthc. Eng.*, vol. 2017, 2017, doi: https://doi.org/10.1155/2017/5843504.

Valeria P. Bravo graduated in 2013 as an industrial designer at the University of Talca, Chile. She has a M.Sc. in Industrial Design and Product Development at the University of Girona, Spain, in 2011, and M.Sc. in ergonomics at the University of Concepción, Chile, in 2015. Currently, she is a PhD student in Engineering Systems at the University of Talca, Chile. Since 2015, she has lectured at the University of Talca, Curico, Chile, teaching Industrial Civil Engineering. Her research interests include vibration systems, wearable devices in clothing, and smart fabrics focused on health care. Moreover, she has participated as a panelist in conferences, and she has published some research articles related to ergonomics, design, engineering, and health.



Javier A. Muñoz received the Eng. degree in electronic engineering (with First Class Hons.) and the M.Sc. and D.Sc. degrees in electrical engineering from the University of Concepcion, Concepcion, Chile, in 2007, 2009, and 2012, respectively. Since April 2011, he has been with the University of Talca, Curico, Chile, where he is the actual Dean of the Faculty of Engineering. He is currently teaching in the areas of dynamic systems, and his research interests include microinverters for photovoltaic integration to the grid. He has published more than one hundred papers in conference proceedings and around 30 papers indexed in Web of Science.