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Antti Alamäki, Elina Nevala, John Barton,
Joan Condell, Karla Muñoz Esquivel, Anna Nordström,
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Wearable Technology Supported Home Rehabilitation Services in Rural Areas

– Emphasis on Monitoring Structures and Activities of Functional Capacity

KARELIA UNIVERSITY OF APPLIED SCIENCES

Publications of Karelia University of Applied Sciences
B, Handbooks and Article collections: 58

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HANDBOOK

KARELIA UNIVERSITY OF APPLIED SCIENCES
JOENSUU 2019

Publication series: B, Handbooks and Article collections: 58

Editor in chief: Kari Tiainen

Layout: Pasi Tikka, Osuuskunta Mekastamo

Authors:

Alamäki Antti (MSc)[1], Nevala Elina (MSc)[1], Barton John (Industry Projects Team Leader, Wireless Sensor Network Group)[2], Dr. Condell Joan[3], Dr. Muñoz Esquivel Karla[3], Prof. Nordström Anna[4], Tedesco Salvatore (Research Engineer)[2], Dr. Kelly Daniel[3] and Dr. Heaney David[3]

[1] Karelia University of Applied Sciences, Finland, Reasearch, Development and Innovation activities (RDI) & Physiotherapy Education
[2] Tyndall National Institute, University College Cork, Ireland
[3] Magee Campus, Ulster University, UK
[4] Department of Public Health and Clinical Medicine, Umeå University, Sweden and School of Sport Sciences, The Arctic University of Norway, Tromsø, Norway

Corresponding Author:
Antti Alamäki, MSc, Project manager in Sendoc, Karelia University of Applied Sciences, Joensuu, Finland, antti.alamaki@karelia.fi

ISBN 978-952-275-283-3
ISSN-L 2323-6914
ISSN 2323-6914

Joensuu, Finland, 2019

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1 Introduction

The sustainability of modern healthcare systems is under threat. – the ageing of the population, the prevalence of chronic disease and a need to focus on wellness and preventative health management, in parallel with the treatment of disease, pose significant social and economic challenges. The current economic situation has made these issues more acute. Across Europe, healthcare expenditure is expected to rice to almost 16% of GDP by 2020. (OECD Health Statistics 2018). Coupled with a shortage of qualified personnel, European nations are facing increasing challenges in their ability to provide better-integrated and sustainable health and social services. The focus is currently shifting from treatment in a care center to prevention and health promotion outside the care institute.

Improvements in technology offers one solution to innovate health care and meet demand at a low cost. New technology has the potential to decrease the need for hospitals and health stations (Lankila et al., 2016. In the future the use of new technologies – including health technologies, sensor technologies, digital media, mobile technology etc. - and digital services will dramatically increase interaction between healthcare personnel and customers (Deloitte Center for Health Solutions, 2015a; Deloitte Center for Health Solutions 2015b).

Introduction of technology is expected to drive a change in healthcare delivery models and the relationship between patients and healthcare providers. Applications of wearable sensors are the most promising technology to aid health and social care providers deliver safe, more efficient and cost-effective care as well as improving people's ability to self-manage their health and wellbeing, alert healthcare professionals to changes in their condition and support adherence to prescribed interventions. (Tedesco et al., 2017; Majumder et al., 2017). While it is true that wearable technology can change how healthcare is monitored and delivered, it is necessary to consider a few things when working towards the successful implementation of this new shift in health care. It raises challenges for the healthcare systems in how to implement these new technologies, and how the growing amount of information in clinical practice, integrates into the clinical workflows of healthcare providers. Future challenges for healthcare include how to use the developing technology in a way that will bring added value to healthcare professionals, healthcare organizations and patients without increasing the workload and cost of the healthcare services. For wearable technology developers, the challenge will be to develop solutions that can be easily integrated and used by healthcare professionals considering the existing constraints.

This handbook summarizes key findings from clinical and laboratory-controlled demonstrator trials regarding wearables to assist rehabilitation professionals, who are planning the use of wearable sensors in rehabilitation processes. The handbook can also be used by those developing wearable sensor systems for clinical work and especially for use in home-type environments with specific emphasis on elderly patients, who are our major health care consumers.

2 The Background of the SENDoc project

The SENDoc project (Smart Sensor Devices fOr rehabilitation and Connected health) will assess monitoring sensors technical, clinical and social acceptability aspects and their impact on patients, on health and care delivery, and on rural communities (SENDoc, 2019). It is an international project, comprised of four partners. The lead partner is Ulster University (Northern Ireland, UK) and the other partners are: Tyndall Institute/University College Cork (Ireland), Västerbotten County Council (VLL)/Umeå University (Sweden) and Karelia University of Applied Sciences (Finland). The SENDoc project aims to introduce the use of wearable sensor systems in ageing communities in northern remote areas. Each partner has an associate partner in healthcare. The associate partner of Karelia UAS is Siun sote (North Karelia´s Joint municipal Authority, Social and Healthcare 2019). This project is funded by the Northern Periphery and Arctic Programme (NPA 2018). For developing this Handbook, SENDoc team members have sifted through 220 pieces of research and other literature in order to collect information about wearables in clinical rehabilitation work. In the future, the SENDoc team will launch publications about developing the use of such equipment in a variety of settings.

3 What is considered as Home Rehabilitation and Remote Rehabilitation

Rehabilitation services are fundamental and play an integral role in patient flow across the health care continuum. The provision of effective rehabilitation services requires a diverse range of health professionals, services and external care facilitators to work together and needs to acknowledge that the rehabilitation process is not a linear process. Rehabilitation needs to be introduced early on in the patient's recovery pathway and be individually re-evaluated and redefined over time. As such, wearables introduce a possibility to be used for assessment and rehabilitation at different points during the patient rehabilitation journey such as acute care setting to the sub-acute care setting and ultimately the patient's return to the community and home environment. In the rehabilitation process, two distinct areas need to be acknowledged, home and remote rehabilitation.

Home rehabilitation is a term which does not have a unique definition. There are observed differences in definition according to countries and areas, timelines of activities, target groups and especially goals. However, what brings all together is the conception of home or home-like environment. The following table (1) explores the concept of Home Rehabilitation in some NPAP member countries.

Table 1. Home rehabilitation in selected NPAP countries

COUNTRY	**HOME REHABILITATION** **Home or home-like conditions**
UNITED KINGDOM	A recent concept is reablement – "short-term intervention". Reablement aims at assisting users to re-attain self-assurance and relearn self-care skills, reduce needs for longer-term support, and increasing independence (Glendinning et al., 2010) A philosophy of reablement is being created by Health care providers. The focus is to give an unclouded view and strategy for home rehabilitation services (DH-TCS Programme, 2009).
IRELAND	Home care packages (HCP) are available for elderly living in communities, who are also in-patients at critical hospitals or at risk of admission to long-term care. HCP also targets elders in long-term care, who might come back to the community with support (Citizensinformation.ie, 2013). The model of the National Clinical Programme for Rehabilitation Medicine (NCPRM) recommends for example, a person-centered approach to service delivery, equitable access to services, 3- level model of service delivery across managed clinical rehabilitation networks, but the official model has not yet been approved or implemented (Health Service Executive, Ireland 2018).
SWEDEN	The direct translation of home-rehabilitation concept "vardagsrehabilitering" is everyday rehabilitation. The core concepts behind it are: Fellowship, participation, and sense of purpose and meaning-making. The municipalities are responsible for organizing home-based rehabilitation and they organize it differently (Condelius et al., 2011; Emilsson 2009; Pettersson & Iwarsson 2015).
FINLAND	There is no definition of home rehabilitation in general, since it covers a wide range of care and rehabilitation services, but the main objective is implementing them at least in partially in people`s own houses or home-like conditions (Forss, 2016). One example of Finnish home rehabilitation services can be Siun Sote Home Rehabilitation Services - which is based on ICF (International Classification of Functioning, Disability and Health) , and GAS (Goal Attainment Scaling) – are: 1. Elderly health and social services advisory clinic 2. Home Care Supporting Home Rehabilitation 3. Multidisciplinary Home Rehabilitation (Mönkkönen 2017)
NORWAY	A goal-directed, individualized, multidisciplinary and time-limited home-based form of rehabilitation for elders living in their own homes. The goal is not to avoid or postpone institutional care, but to enable older adults to participate in meaningful activities in their homes and communities (Tuntland 2017)

Cochrane et al. (2016) defines criteria of home-based rehabilitation:

- Participants must have an identified need for formal care and support, or be at risk of functional decline
- The intervention must be time-limited and intensive (multiple home visits)
- The intervention must be delivered in the home setting (or in the local community)
- The intervention must focus on maximizing independence

Home-based rehabilitation has proved effective in a few studies (Glendinning et al., 2010; Cochrane et al., 2016; Tessier et al., 2016). However, the impact of the time period employed for rehabilitation on specific groups of people is unknown, i.e. it has not been quantified yet. A similar situation is observed about the cost-effectiveness and the outcomes of reablement. As a result, further research is required to validate the actual effectiveness of rehabilitation delivered at home like environments (NICE guideline, 2017).

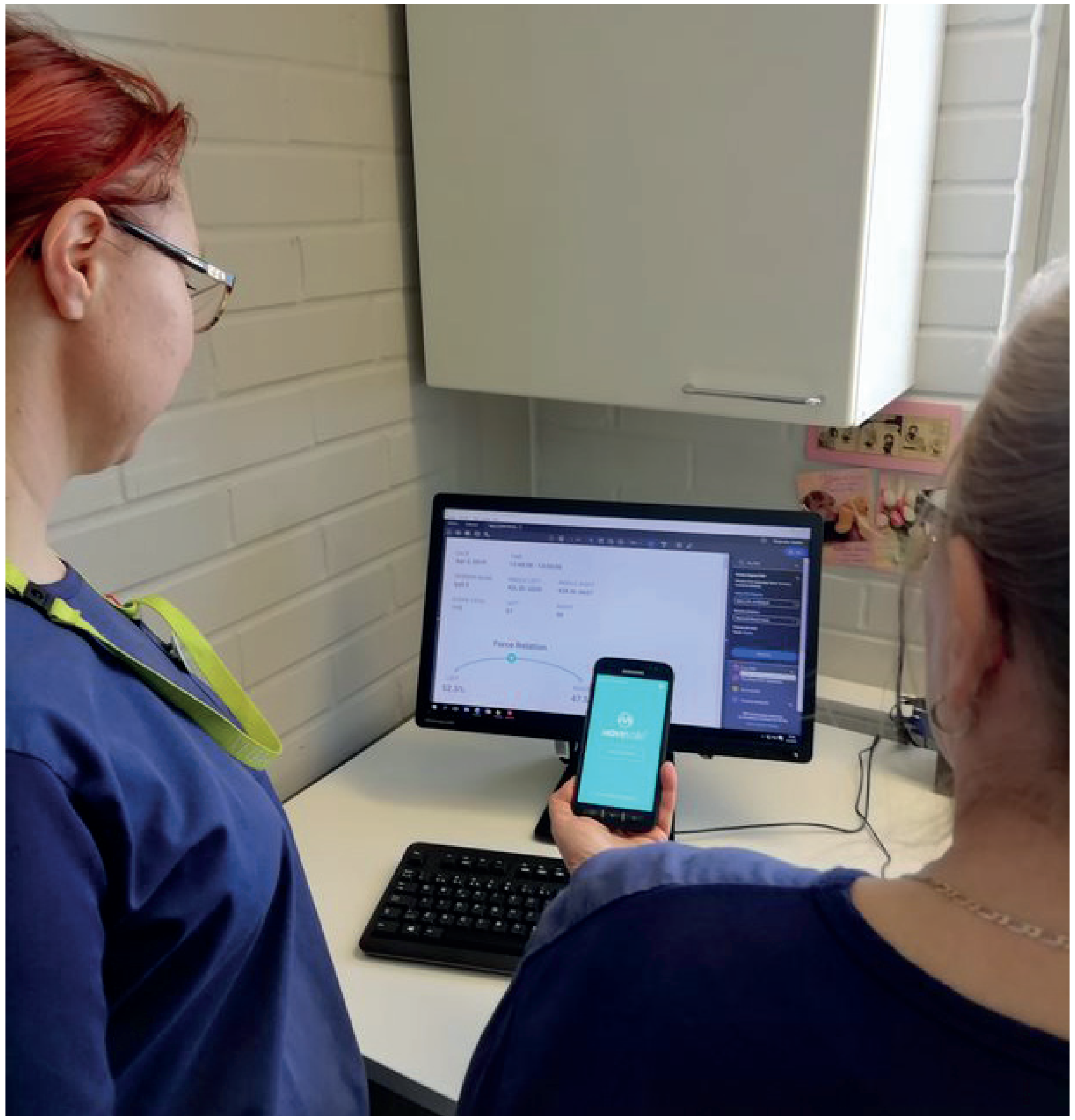
REMOTE REHABILITATION

Some of the problems related to patient access to rehabilitation or physicians might be solved with the help of remote rehabilitation, monitoring and measuring exercise. This kind of monitoring with smart sensor devices is still underutilized, even though they have shown to be accurate and have clinical utility and usage. Rehabilitation processes or routine outpatient care could be extended or replaced with this kind of monitoring and measuring. (Appelboom et al., 2014). There are usually three key issues when enabling remote monitoring with wearable sensor systems: hardware for sensing and data collection of physiology and movement, communications hardware and software to transfer the data to a remote center and data-analysis for clinically relevant information (Patel et al., 2012). The regular use of remote rehabilitation is still low, although it has been developed since the beginning of the 2000s (Salminen et al., 2016).

Remote rehabilitation is a wide and not established term and is referred to in several terms such as net therapy, telehealth, virtual rehabilitation or mobile rehabilitation, but all of these terms are too narrow to describe it in general. Remote rehabilitation must be controlled by professionals, and it has a clear goal from the beginning to the end, as with other rehabilitation periods. In remote rehabilitation, you can use various remote technology applications in rehabilitation, for example, phone, mobile phone, computer, phone and computer sharing, and television applications. (Salminen et al., 2016).

Remote rehabilitation can be divided into synchronous and asynchronous categories. Synchronous category means that clients and service providers are connected in real-time. This kind of remote rehabilitation can include for example counseling, assessment, rehabilitation or rehabilitation monitoring via phone or video connection or the internet. It can be implemented individually or by a group. Asynchronous remote rehabilitation is, for example, supportive online material, training programs provided independently by the client or the games that are used by the client on their own. (Keck & Doarn, 2014). Combining synchronous and asynchronous methods in remote rehabilitation is very common and this mixed model is also good for combining face to face rehabilitation and remote rehabilitation. (Salminen et al., 2016). 77 % of studies in speech therapy use these mixed models (Keck & Doarn, 2014).

In Finland, remote rehabilitation and other remote services and their use are instructed, monitored, and supervised by The National Supervisory Authority for Welfare and Health (Valvira). These remote services can include e.g. examination, diagnosis, monitoring, treatment, treatment decisions or recommendations of a patient are based on, for example, video or information transmitted via web or smartphone. Both private sector and public healthcare have to follow these regulations related to remote services provided. (Salminen et al., 2016). Remote rehabilitation from the Swedish perspective is not an established term. Rehabilitation, in general, is managed both in situ at a rehabilitation center at health-care facilities and similar and as well at home (or remote from the rehabilitation center). With the use of technology, the in-situ rehabilitation may, in some cases, be exchanged by remote rehabilitation and then words such as e-health or digitalization within the health domain are more current. (RICE ICT-enablers of sustainable digitalization). In Ireland, an eHealth strategy (eHealth Ireland 2013) has now been published which sets out how eHealth could benefit the Irish healthcare delivery system and a proposed roadmap of how eHealth can be implemented within an outcomes-based delivery system. Tele-health and tele-medicine are mentioned in a number of places but there is not any mention of rehabilitation in the entire document.



4 Key aspects of Usability and Utility using wearable sensors

4.1 USABILITY, UTILITY AND SYSTEM ACCEPTABILITY IN GENERAL

A product which can be used by specified users to accomplish specified goals with **effectiveness**, **efficiency**, and **satisfaction** in a specified context of use is defined as usability. Effectiveness signifies accuracy and completeness with which users achieve specified goals, efficiency is how the resources are used in relation to the effectiveness, and satisfaction means positive attitude towards the use of the product and freedom from discomfort (ISO 9241-11, 1998).

System acceptability (Figure 1.) signifies that the system is good enough to fulfill all the needs and requirements for the user. A combination of social acceptability and practical acceptability is the overall acceptability of the system. **Usefulness** means the system can be used to attain the desired goal and it can be divided into the categories of utility and usability. Utility is whetherthe functionality of the system can do what is needed and usability tells how well users can use that functionality. Usability applies to all aspects of systems with which a person may interact. (Nielsen 1993). The five usability attributes are explained in more detail in Figure 2.

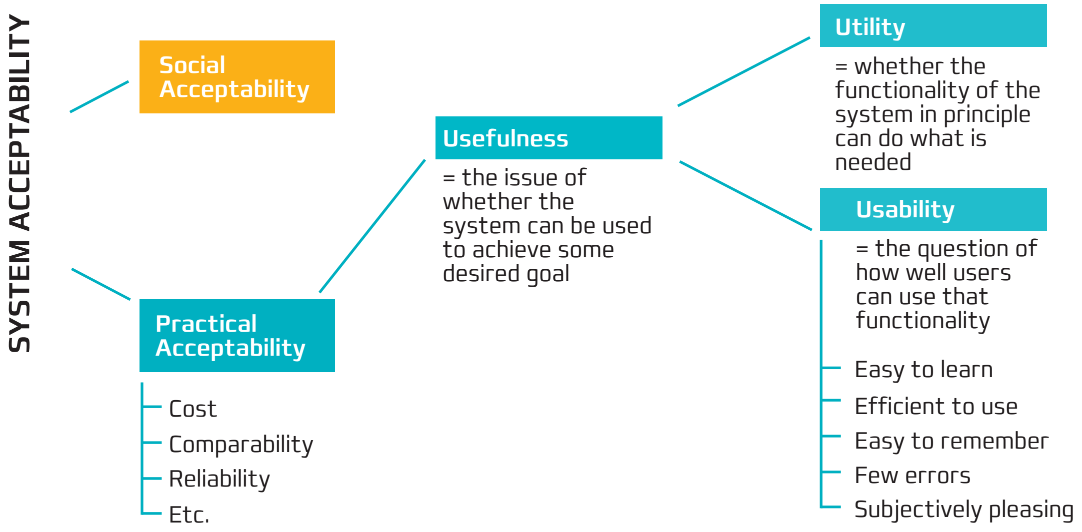


Figure 1. System acceptability modified from Nielsen´s "A model of the attributes of system acceptability" (1993).

FIVE ATTRIBUTES WHICH ARE USUALLY ASSOCIATED WITH USABILITY:

Learnability:	The system should be easy to learn so that the user can rapidly start getting some work done with the system
Efficiency:	The system should be efficient to use, so that once the user has learned the system, a high level of productivity is possible
Memorability:	The system should be easy to remember, so that the casual user is able to return to the system after a period of not using it, without having to learn everything all over again
Errors:	The system should have a low error rate, so that users make few errors during the use of the system, and if they do make errors they can easily recover from them. Further, catastrophic error must not occur
Satisfaction:	The system should be pleasant to use, so that users are subjectively satisfied when using it because they like it

Figure 2. The five components of usability (Nielsen, 1993).

An important thing is that the usability assessment evaluates certain users and certain tasks, and they are defined. Usability can be measured by having a number of test users using the system to perform agreed tasks or it can be measured in the real environment so that the users are doing their usual tasks (Nielsen, 1993). Both tests in the laboratory and field are valuable methods for product and system evaluation. Usually, tests in the laboratory are usable when the product reaches the predefined usability criteria. Field studies can tell something about the acceptability of the product, e.g. Will the product be used in real life environment? (Maguire, 2001).

Usability is a function of the context in which the product is used, so it is not relevant to talk just about the usability of a product. For instance, changing the relevant aspect of the context of use can change the usability of the product. The quality of use of an overall system is a broad approach, which takes into account the context. The advantage of this kind of approach is that it concentrates on the real purpose of a product and the product is usable to real users, in real tasks, and in the real environment. (Bevan & Macleod, 1994).

Every new product or system will be used in **a particular context**, and it will have users from certain characteristics. These users will have specified goals and wish to accomplish different everyday tasks. The product or system will also be used in a certain range of technical, physical and social environments, which can affect its use. (Maguire, 2001). Usually, the context in usability research has three first-level attributes: user, task and environment (Bevan & Macleod 1994; ISO 9241-11, 1998). Second and third levels are divided differently in these classifications. Table 2. presents one of these classifications of the context of usability (Bevan & Macleod 1994).

Table 2. One example of the classification of the context in usability (Bevan & Macleod 1994).

USERS	TASK	ENVIRONMENT	
Personal details User types Audience and secondary users	Task breakdown Task name Task goal Task frequency Task duration Frequency of events Task flexibility Physical and mental demands Task dependencies Task output Risk resulting from error	**Organisational Environment** **Structure** Hours of work Group working Job function Work practices Assistance Interruptions Management structure Communications structure Remuneration	**Technical Environment** **Configuration** Hardware Software Reference materials
Skills & Knowledge Product experience System knowledge Task experience Organisational experience Training Keyboard & input skills Qualifications Linguistic ability General knowledge	**EQUIPMENT**	**Attitudes & culture** Policy on use of computers Organisational aims Industrial relations	**Physical Environment** **Workplace conditions** Atmospheric conditions Auditory environment Thermal environment Visual environment Environmental insatability
Personal attributes Age Gender Physical capabilities Physical limitations and disabilities Intellectual ability Attitude Motivation	**Basic description** Product identification Product description Main application areas Major functions **Specification** Hardware Software Materials Other items	**Job design** Job flexibility Performance monitoring Performance feedback Pacing Autonomy Discretion	**Workplace design** Space and furniture User posture Location **Workplace safety** Health hazards Protective clothing & equipment

4.2 USABILITY OF WEARABLE SENSORS

According to Hartman (2014), there are several challenges when designing wearable electronics. The author emphasizes the importance of being aware of the dynamics and rugged context of the human body since the circuit has to be translated into this context. The five features that make an electronic product wearable are: Comfort (e.g. to wear: Its size, weight and shape), placement (i.e. consider how the body moves), durability (i.e. it can stand: wearing, washing and repairs), aesthetics (i.e. how it looks) and usability (i.e. comfortable to use). The latter can be broken down using the following questions: Does it function as intended?; Do the electronics work as expected? Does it make for a "good", "satisfying" or "successful" user experience? Figure 3. presents what should be considered when implementing new systems for rehabilitation use.

ONE SHOULD KEEP IN MIND WHEN IMPLEMENTING NEW SYSTEMS AND APPLICATIONS FOR REHABILITATION USE (E.G. MEASURING GAIT)

1. Requirements for a good system

Systems should be able to measure everywhere

In gait over a hundred gait cycles is needed to ensure that the collection represents real-life conditions

Reporting should help the immediate clinical decision making

Reporting should keep the patient ´ s involved, and in that way enhance empowerment

Feedback through different senses (using also augmented reality) could be a viable solution

An innovative system should serve, not only for assessment, but also for treatment. For example, a device assisting to attain decision making while practicing

Immediate reporting is one key factor for attaining acceptance within rehabilitation professionals

The outcome of the system must be problem specific and clinically meaningful

A minimum number of sensors supports time efficiency, moderate pricing, and comfort

Comfort must be perceived by both patients and users of the system. Otherwise, despite the effectiveness, the system will not be adapted for clinical practice.

2. System should be expandable because rehabilitation is multi-factorial entity

3. System should be validated because rehabilitation is evidence-based

Figure 3. Framework for the development of new systems for rehabilitation (Cutti et al., 2015)

Steins et al. (2014) found that accelerometric-based technology is mainly utilized in laboratory settings and that there is a clear need to translate research findings and novel methods into practice. A systematic review by Bergmann & McGregor (2011) points out that patients and clinicians prefer wearable sensors to be compact, embedded and simple to operate and maintain. Body-worn sensors must not replace a health care professional or it shouldn`t affect subjects' daily behavior. Majumder et al. (2017) came to the conclusion that wearable systems should be affordable, easy-to-use, un-obtrusive, and inter-operable among various computing platforms. There should be a minimum number of sensors, but the most important clinical information should not be lost. Equipment should be more lightweight, with more processing capacities, smaller in size, and gain higher usability (Zong-Hao Ma et al., 2016).

4.3 SPECIAL FEATURES OF USABILITY AMONG ELDERLY USERS

New technology used by the elderly should be reliable, easy to understand, learn and use without extensive training. These technology devices must have simple interfaces and demand fewer user skills. However, older people want clear and printed instructions (Golant, 2017) and still, they rely heavily on traditional information channels, for example, radio, television, news, papers, and libraries (Delello & McWhorter, 2015).

When focusing on designing technology for elders, Johnson and Finn (2017) speak about making technology "useful and usable for everyone", since no one must be a disadvantage. Poor usability of devices and user interfaces causes distraction from the actual user's experience and impacts elders more frequently and gravely than young adults. However, other users that have a similar experience to elders are: low tech literacy individuals, second language learners and low vision/impaired people.

In their work, Johnson and Finn (2017) focus on the online creation of Web/online content. However, some of the guidelines discussed can be transferable to design of other technological products. In this work, it was highlighted that as part of providing accessibility to elders, products targeting them must be easy, enjoyable, productive and attractive to use. The authors´ highlight that elders have greater task-domain knowledge (i.e. know-how) than younger adults and adequate design may use this as an opportunity (i.e. giving elders a manner to apply their know-how). Also, authors provide several guidelines according to the age problems and needs that elders might have, which they classify in 7 groups: Vision, motor control, hearing and speech, cognition, knowledge, search and attitude.

5 The basic components in wearable sensor systems in home rehabilitation

5.1 THE TYPICAL COMPONENTS OF WEARABLE SENSOR SYSTEM

Enabling remote monitoring with wearable systems involves usually three component parts: hardware for sensing and data collection of physiology and movement; communication hardware and software to transfer the data to a remote center; and data-analysis for clinically- relevant information (Patel et al., 2012). These sensor systems can include varying numbers of components; sensor system unit/units, communication modules and signal processing units.

The most commonly used wearable sensors are activity trackers or small sensor units that contain accelerometers, gyroscopes, and magnetometers. Measuring equipment can be also integrated into textile fibers, clothes or elastic bands.

The sensors measure motion, physiology and posture and this data is transmitted to a nearby processing unit using a suitable communication protocol (for example Bluetooth). The processing unit (for example a smartphone, tablet computer or computer) contains the sensor systems software which applies algorithms to the raw data to extract clinically relevant information. (Majumder et al., 2017). For example, Figure 4 introduces one sensor system called G-WALK. In this system, there is one sensor, which is attached to the waist with a belt. This sensor is able to establish a connection via Bluetooth to a tablet computer. The computer is running software, which performs the data processing and translates data into understandable measurements, information, and graphics to be displayed to the end-users.

Components of this sensor system:

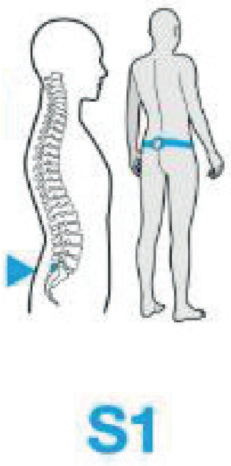
- » Wireless inertial sensor
- » Belt (+ extension)
- » Bluetooth dongle
- » Bluetooth extension cable
- » USB Charge Cable
- » G-Studio Software
- » Transport bag

Included protocols:

» Run, TUG Test, Jumps, 6 Minutes Walking test, Turn Test, Walk+, Free Test

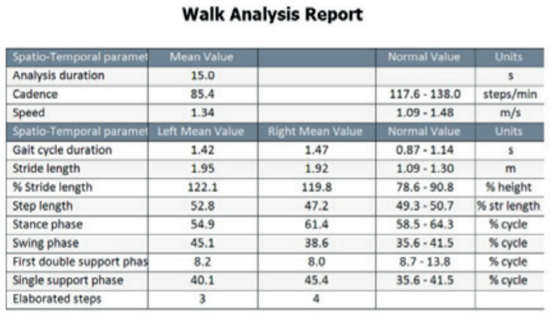
Main features of the wireless inertial sensor:

- » Weight: 37g
- » Wireless inertial sensor includes: triaxial accelerometer with multiple sensitivities, triaxial Gyroscope with multiple sensitivities, triaxial Magnetometer, GPS receiver
- » Battery: rechargeable via USB, 8 hours of autonomy
- » Connectivity: Bluetooth® 3.0, class 1
- » Works in real-time/ Batch mode
- » Memory: Internal Flash from 256MB (in Sensor Fusion mode up to 8h of contiunuous data recording)



...The sensor sends all data to a computer connected via Bluetooth; at the end of each analysis an automatic report containing all the parameters recorded during the test, is displayed.

...This evaluation, which is essential in the field of rehabilitation, helps physicians and specialists to assess patient conditions and quantify the efficacy of treatments and/or rehabilitation therapies..



Walk Analysis Report

Spatio-Temporal paramet	Mean Value		Normal Value	Units
Analysis duration	15.0			s
Cadence	85.4		117.6 - 138.0	steps/min
Speed	1.34		1.09 - 1.48	m/s
Spatio-Temporal paramet	Left Mean Value	Right Mean Value	Normal Value	Units
Gait cycle duration	1.42	1.47	0.87 - 1.14	s
Stride length	1.95	1.92	1.09 - 1.30	m
% Stride length	122.1	119.8	78.6 - 90.8	% height
Step length	52.8	47.2	49.3 - 50.7	% str length
Stance phase	54.9	61.4	58.5 - 64.3	% cycle
Swing phase	45.1	38.6	35.6 - 41.5	% cycle
First double support phas	8.2	8.0	8.7 - 13.8	% cycle
Single support phase	40.1	45.4	35.6 - 41.5	% cycle
Elaborated steps	3	4		

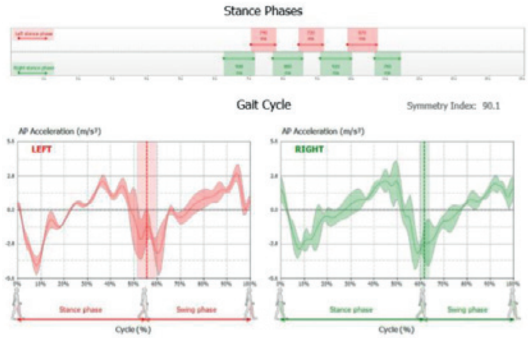


Figure 4. One example of inertial sensor system (BTS Bioengineering corp. 2018).

5.2 TECHNICAL CHALLENGES IN WEARABLE SENSOR SYSTEMS

Wireless Communications

A major problem involved in employing wearable technologies in Medicine is the use of wireless communication protocols for the transmission of data to nearby devices and software control (Tabibu, 2017). There are a number of issues with wireless communications, particularly when applied to a wearable context.

According to Omre (2010), wireless electronics monitors, which are worn in the body, might reduce health care costs. The author speaks specifically of technology that connects to the Internet and mobile phone infrastructure, technology that can reduce or avoid the patient's visit to a hospital. These technologies operate in the 2.4 GHz electromagnetic spectrum, which is unlicensed. According to Omre (2010), the requirements needed for widespread adoption of these wireless connectivity technology are:

a) Interoperability (communication among products of different manufacturers)
b) Low-cost power operation (ensuring operation of medic equipment for months/years on coin-cells e.g. low maintenance and cost)
c) Customized software (medical optimized and data transmission according to medical authorities)
d) Compatibility (coexist with other transceivers without electromagnetic interference)
e) Transmission (secure enough to protect confidentiality)
f) Relay information to remote health practitioners (sensors must connect through the internet or with mobile networks).

Bluetooth low voltage is the first technology that meets all of the above requirements.

Omre (2010) lists the four wireless technologies currently available for medical purposes, which are: Wi-Fi, ZigBee, Classic-Bluetooth and Bluetooth low energy. Medical equipment using any of these requires to be approved by the custodians of the standards, i.e. this guarantees that the equipment can communicate independently from the manufacturer.

Wi-Fi is a technology employed in LANs (Local Area Networks) to connect computers and operates at 300 Mbps in the 2.4 GHz band. However, the latter depends on the region. It has about 30 m of the indoor range. The disadvantages of Wi-Fi - when employed in medical operations – are a relative expense and power consumption (bulky batteries that require recharging frequently).

ZigBee is a wireless technology maintained by the ZigBee Alliance (an alliance of commercial companies). This is a low-power technology, which range is about 100 meters maximum. Modern versions of this technology can operate from coin-cell batteries. It regularly operates in the 2.4 GHz band, but also can operate in other bands. The disadvantage of ZigBee is that its 250 kbps bandwidth makes data transmission 4 times slower when compared with Bluetooth low energy. Also, data transmission demands considerable battery power (requiring big batteries or shortening the life of small batteries). ZigBee cannot connect directly with the mobile or internet infrastructure.

Classic-Bluetooth is based on a standard maintained by an organization of commercial electronics companies known as Bluetooth Special Interest Group (SIG). It operates in the 2.4 GHz band and has a range of bandwidth – depending on its version - from 1 to 24 Mbps. Its range is up to 30 m and is currently used in medical products. The disadvantage of Classic-Bluetooth is high power consumption, which decreases battery life to a few tens of hours, which is a limitation to achieve continuous medical monitoring. SIG created a “Health Device Profile” (HDP) software with the main objective of improving the performance of Classic-Bluetooth when transmitting data in medical applications – requested by medical authorities, a “one-size-fits-all” solution to serve all varieties of medical products. As a result, HDP needs high battery power and memory.

Bluetooth low energy is available in two different implementations: a) single mode and b) dual mode. The former are radio communication units, which are compact, and are included in medical monitors, which size is about tens of millimeters (extremely low power consumption, i.e. they can run months/years on coin-cell batteries). The latter are radio communication devices, which are included in mobiles, PCs, and headsets, i.e. these are able to communicate with single-mode devices. SIG is developing HDP software for Bluetooth low energy. There are several customized HDPs (i.e. profiles for fitness and medical applications: blood pressure, weight scale, glucose, pulse, temperature, heart rate, oximeter, pedometer, cycle cadence, speed, distance, battery status and simple remote control) for a given application or applications, which reduce the energy and memory required. A Bluetooth low energy device would therefore be more cost-effective and power-efficient than a Classic-Bluetooth device. To avoid electromagnetic interference (EMI), Bluetooth low energy uses a frequency-hopping spread spectrum interference avoidance scheme, i.e. When initiating a connection, the two transceivers transmit on one of three available fixed-channels and if no signal is received, it will try the other two channels, which is more effective than scanning the whole band. So, it is able to fix communication in a matter of milliseconds and specifies that the corrupted channel not be used again (In a 2.4 GHz band, Bluetooth low energy hops 37 dynamic data channels). Bluetooth low energy has an advanced encryption standard-128 algorithm like Classic-Bluetooth and is the standard used in the US. Also, it is resilient to tracking transmitting devices, since it uses a random device address that changes often.

Channel Overcrowding

Currently, most wireless solutions are based on 2.4 GHz (Eroglu, 1998), which has **high water absorption content when placed directly on body areas**, in addition to relying on the use of chip antennas which while physically small, require large ground planes to operate effectively and also **suffer greatly from human-body interaction**. This includes Wi-Fi and the popular Bluetooth (BT) wireless protocol, which has proliferated in mobile phones and the vast majority of wearable devices to come to the market. Figure 5 below shows an illustration of the band congestion at 2.45GHz (Wi-Spy, 2017).

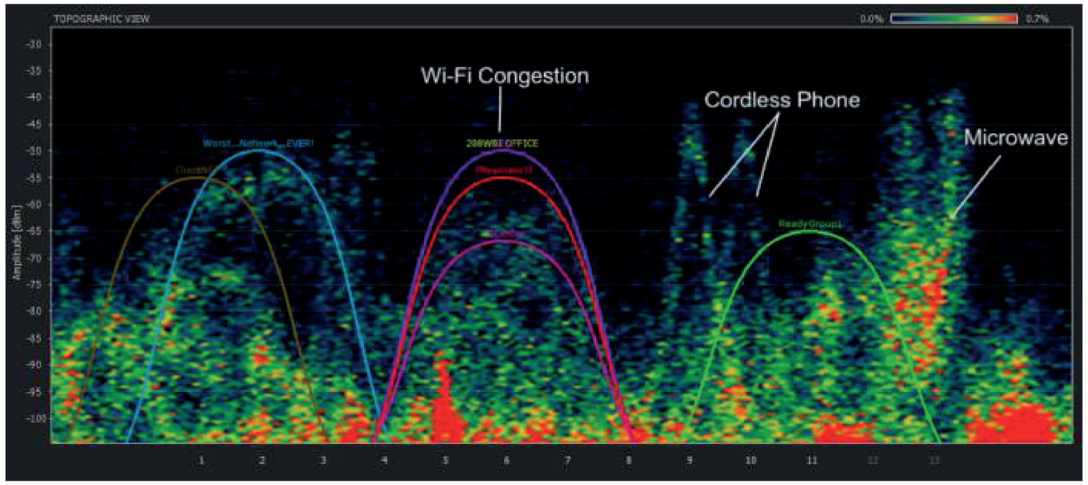


Figure 5. Illustration of 2.45 GHz Band Congestion.

More and more people are carrying wearable devices and competing for bandwidth. In 2020, the number of connected devices per person is expected to be 6.58, resulting in about 50 billion connected devices in total. (Statista, 2019). Many, if not most, of these will operate in the 2.45GHz band. Therefore as an alternative to the 2.45 GHz band, the use of lower frequency license-free bands such as the Industrial Scientific and Medical (ISM) bands is of great interest in terms of potential performance improvements. In particular, the use of sub-GHz solutions and specifically at the 900 MHz ISM bands is of key interest to evaluate the potential for **reduced human body effects, decreased band congestion, enhanced transmission range, improved quality-of-service** and **lower DC power requirements** for wireless data transfer.

Body Attenuation

A proliferation of BT devices exists that are not optimized for on-body wearable wireless devices using the 2.4 GHz frequency bands. These performance effects include antenna detuning. This effect is illustrated in Figure 6 (a) and (b) showing that the presence of the human body leads to significant detuning compared to the free-space case and this in turn results in a large degree of RF power reflection from the antenna. (Di Serio, 2018).

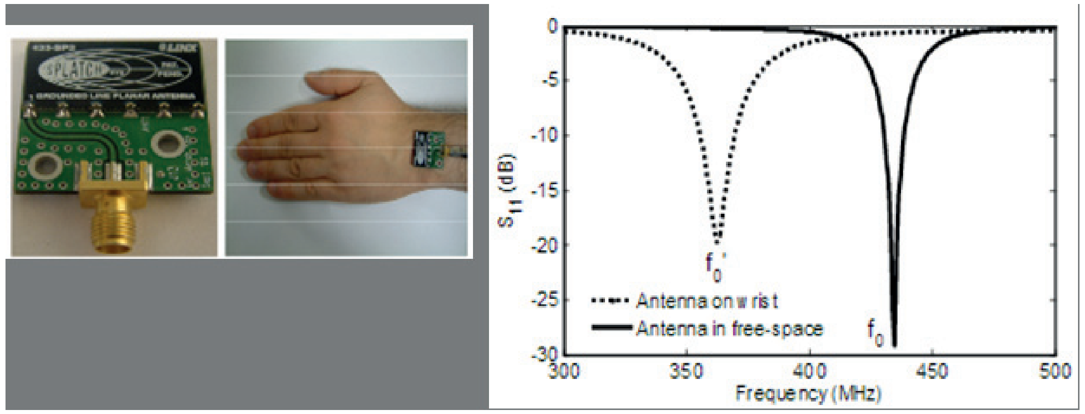


Figure 6 (a). Test antenna assembly and antenna on human wrist (b) Antenna detuning caused by human wrist.

Hence, if the antenna is not properly designed to compensate for this, there will be performance issues. The off the shelf commercial chip antennas vastly underperform in these applications and can lead to connection problems or loss of data. The addition of RF absorption effects results in significant RF attenuation and hence the wireless device requires more DC power to transmit the signal, resulting in decreased battery lifetime for the wireless device.

The low transmission power and small-sized antennae of wireless sensor devices can cause reduced signal to noise ratios that cause a higher bit error rate and reduced quality-of-service as well as a reduction in the reliable coverage area. However, reliable data transfer of data in medical monitoring and Wireless Body Area Network (WBAN) systems is crucial in a large number of applications.

Security

Even though wearable technology has developed rapidly, there are challenges that require more research and development. The biggest concern is related to the privacy and security of the sensitive medical information of the user. Further development of algorithms is needed to confirm highly secured communication channels in existing low power, short-range wireless platforms. (Majumder et al., 2017). Data must be encrypted and under access control to be private and all data collected must be relevant. These issues have been highlighted with the implementation of the General Data Protection Regulation (GDPR, 2016).

Data Protection Regulation

Another risk that must be managed when employing wearable technologies in medicine is data storage and data processing since both can be currently outsourced to the cloud. The problem is related to privacy and data security from the cloud provider and the client's perspective. (Schukat et al., 2016). From the provider's viewpoint, the security of the infrastructure must be addressed, the client's data and applications must be protected. From the client's viewpoint, access to the data and services in the cloud must be restricted.

Arriba-Pérez, Caeiro-Rodríguez & Santos-Gago (2016) discuss several interoperability issues involved using wearables in real life environments, such as the available operating systems and sensors, the diversity of devices, problems related to the data models and the different options available to transfer data from wearables to third-party servers. Two approaches – wearable data transfer and warehouse data transfer – are employed to transfer data from wearables. The former is employed when data is taken directly from wearable sensors and the later takes data from the warehouse. Warehouse data transfer has various disadvantages, the most important is its inability to collect real-time data from the device. Data transfer can be completed within several days. In comparison, a wearable data transfer can take place at the precise period in time. In addition, some processing is performed over the data at the proprietary warehouse with summarization purposes. Therefore, raw data can only be attained from wearable data transfers. However, it is important to observe that current wrist wearable devices can have problems of memory size, since this is usually very limited, so frequent data transfers are necessary. Other types of sensors should have memory capacity themselves as a backup for connection problems.

The EU General Data Protection Regulation (GDPR) (GDPR, 2016) replaces the Data Protection Directive 95/46/EC and was designed to harmonize data privacy laws across Europe. Its main objective is to protect and to empower all EU citizens' data privacy and to reshape the way organizations across the region approach data privacy. Key articles about the GDPR aim to strengthen and enhance eight Data Protection rules, which can be summarized as follows:

1. Obtain & process the information fairly (consent)
2. Keep it for one or more specified and lawful purposes
3. Use and disclose only in ways compatible with these purposes
4. Keep it safe and secure
5. Keep it accurate and up-to-date
6. Ensure that it is adequate, relevant and not excessive
7. Retain it no longer than is necessary for the purpose(s)
8. Give a copy of his/her personal data to any individual on request

Under GDPR, any organization must be able to demonstrate **compliance** with these principles.

Furthermore, it is important to address issues such as poor battery life (Majumder et al., 2017; Hooge, 2015) which is obviously coupled with the Wireless issues and the complex design of user experiences, which are also currently observed when using wearable technologies in the fashion field (Hooge, 2015).

6 Choose a suitable sensor system for your rehabilitation purpose

In the last 15 years a large variety of sensor types has been developed. Some of them are under development or are developed for research purposes only, while others are available for off the shelf purchase.

6.1 EXAMPLES OF TECHNICAL, PHYSIOLOGICAL, AND BIOMECHANICAL WEARABLE SENSOR SYSTEMS

The following tables contain different types of measuring systems that can be included in the wearable sensor box (Table 3) and systems that are related to diagnostics and monitoring of physiological measures (Table 4). In addition, various e-textiles (electrical textiles) have been developed that enables the textiles to perform sensing and/or actuating functions (McLaren et al., 2016).

Table 3. Different types of measuring systems that can be included in the wearable sensor box.

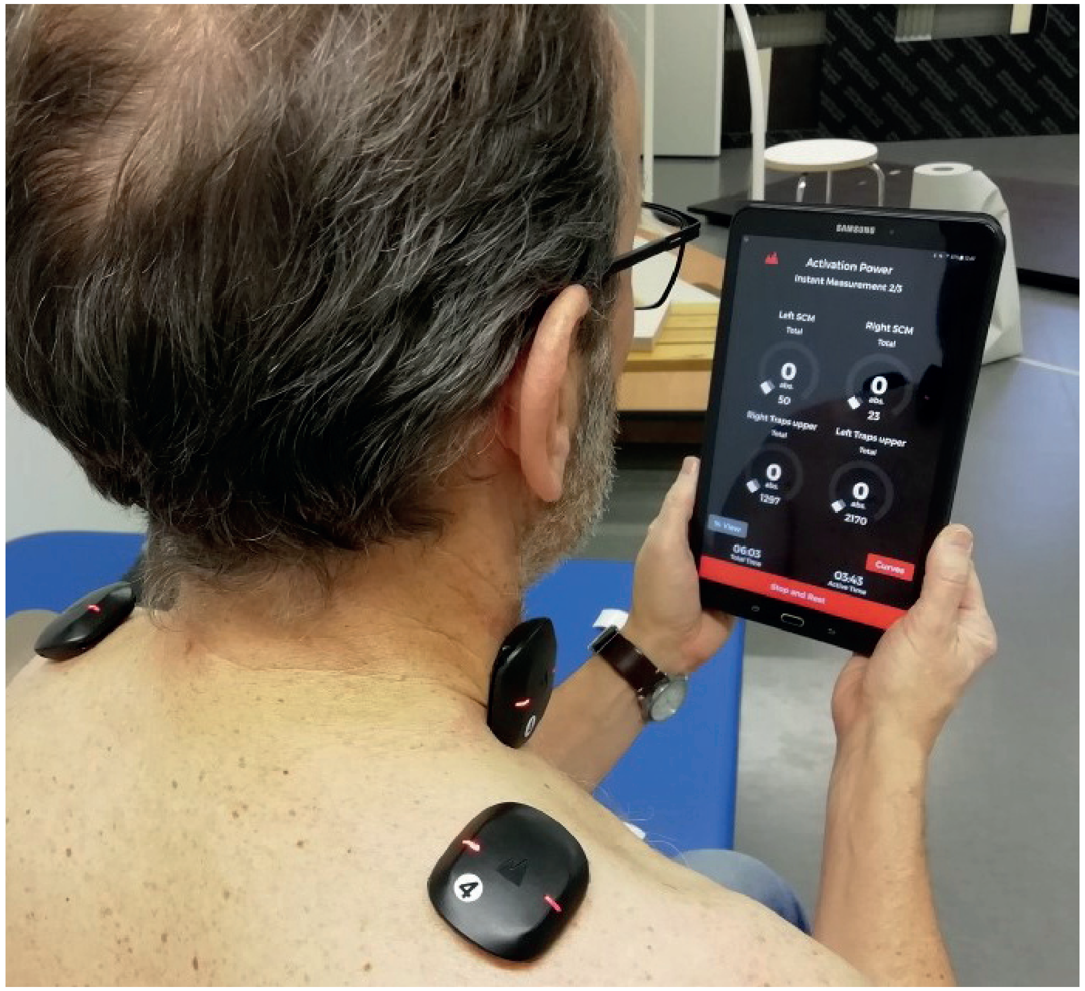
DEVICE/SYSTEM/INSTRUMENT:	MEASURES:	USED FOR EXAMPLE:
Accelerometer	Linear acceleration of X, Y and Z movements in 3D space	To measure human motions, e.g. gait parameters such as stance and swing phases
Gyroscope	Angular velocity, extent and rate of rotation in 3D space	To measure object´s orientation
Magnetometer	Direction: absolute angular movements in relation to the magnetic field	Can be used as compass and also can be utilized 3D movements
Barometer	Pressure	Is used analyzing contact forces
Altimeter	Height compared to sea level	Measured vertical movements e.g. moving in stairs
Global Position System (GPS)	Position and distance travelled	Can measure e.g. walking distance, have connections analysing activity of person and used also in security alert systems
Force Myography (FMG)	Captures the expansion/ contraction of the large muscle	Connection to activity and force production of muscle
Force meter	For example, a plantar force sensor measures force or pressure of contact, so force or pressure is the physical quantity informed	Measuring mats & insoles, different techniques can be used

Table 4. The systems related to diagnostics and monitoring of physiological measures.

DEVICE/SYSTEM/INSTRUMENT:	MEASURES:
Electrocardiogram (ECG or EKG)	Enables to monitor heart functions: Pulse, Interbeat Interval and Heart Rate Varaibility, Oxygen Saturation
Electroencephalogram (EEG)	Enables to monitor electrical activity of the brain
Electrodermal Activity (EDA) Galvanic Skin Response (GSR) Skin Conductance (SC)	Enables to measure skin conductance, which is connected to various activities - for example autonomous nervous system activity
Electromyogram (EMG)	Enables to monitor skeletal muscle/motor unit activities
Photoplethysmograph (PPG)	Employs to detect changes in blood volume in microvascular beds of tissue, measurements takes place on the skin surface
Skin temperature and body temperature (tympanic membrane)	
Respiratory Rate	

6.2 EXAMPLES OF WEARABLE SENSOR SYSTEMS USED IN ANALYSIS AND MONITORING AREAS OF FUNCTIONAL CAPACITY ACCORDING TO THE ICF

ICF is International Classification of Functioning, Disability and Health and its purpose is to provide a common language for disability. Any health condition can be described by using ICF classification and it provides a scientific, operational basis for describing, understanding and studying health and health-related states, outcomes, and determinants. It is also a multi-perspective, a bio-psycho-social approach, which is reflected in the multidimensional model classifying functioning and disability (World Health Organization WHO, 2013). Adopting an ICF-mindset in the use of wearable sensors (for measurements and analyses) and combining it with other taxonomies for equipment and methods, may assist different professionals to achieve an enhanced understanding of each other and may provide more specific and sensitive results in that direction (Figure 7).



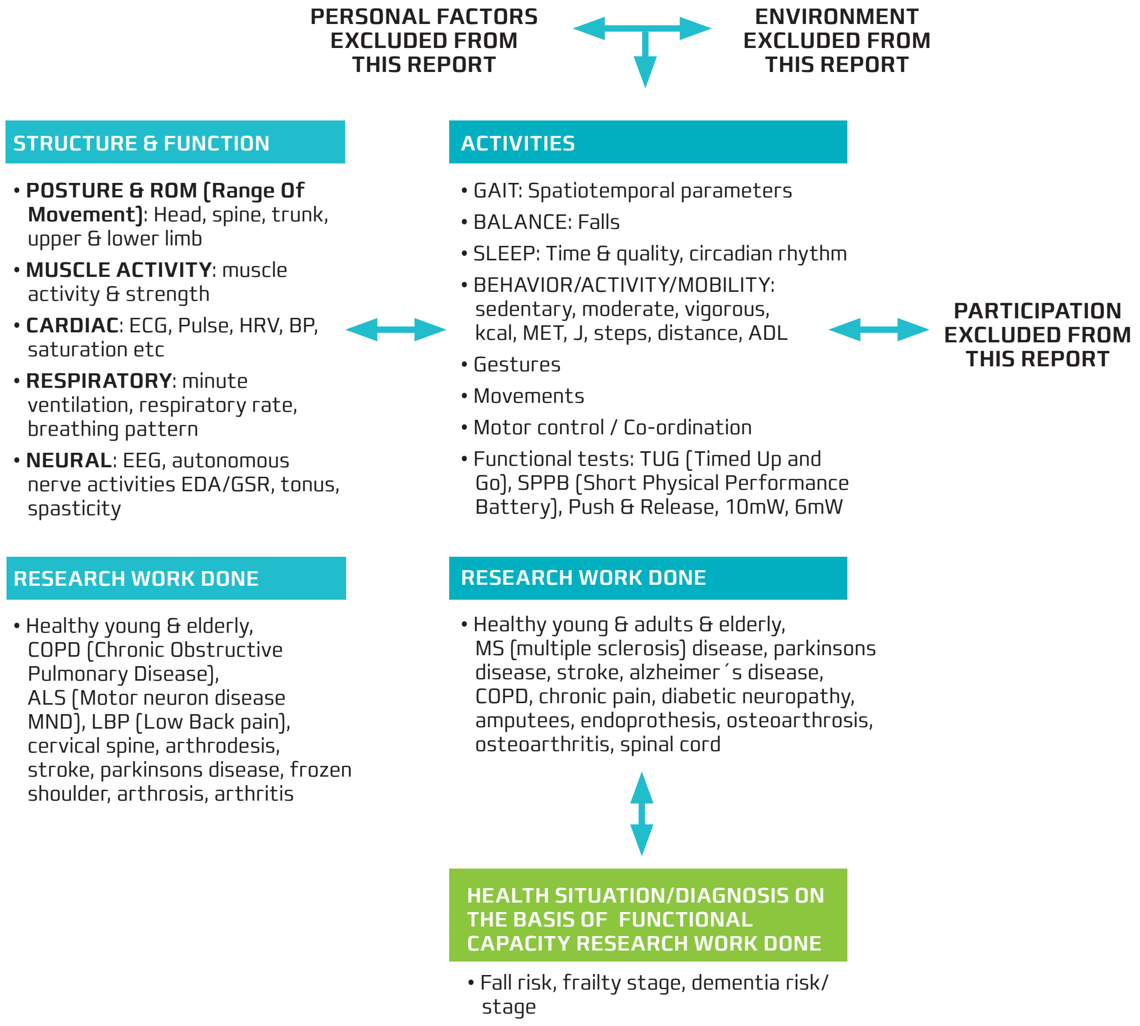


Figure 7. Wearable Measures and Monitoring of Functional Capacity (ICF Frame) (World Health Organization WHO, 2013).

6.2.1 Structure and Function

Mental Functions – Structures of the Nervous System

The following measurements are connected directly or indirectly to measure or diagnose activities related to the functioning of the nervous system: EEG, Heart rate variability (autonomous nervous system), ENMG, Electrodermal activity (EDA Sympathetic nervous system) and Galvanic skin response (GSR - Sympathetic nervous system) (Majumder et al., 2017).

Alzheimer disease and dementia are examples of detection or diagnostic of neural structure problems. By analyzing daily activities and motion using triaxial accelerometers on ankles for three days, it is possible to discern unlabeled Alzheimer disease from healthy people with 91% accuracy. This kind of monitoring reached a higher rate than the Cohen-Mansfield Agitation Inventory. (Kirste et al., 2014).

Cardiovascular, Hematological, Respiratory and Immunological Functions - Structures of Cardiovascular, Immunological and Respiratory Systems:

ECG, pulse, blood pressure, heart rate variability, respiratory rate, skin temperature, photoplethysmograph, oxygen saturation, minute ventilation, respiratory rate, and breathing pattern, activity and air quality are measurements connected directly or indirectly to measure or diagnose problems within the cardiovascular and respiratory systems.

Neuromusculoskeletal and Movement-related Functions – structures Related to Movement

Upper limb structure & activities

In real rehabilitation working life the ability to use and change of functions of the upper limb is one factor in ADL and working abilities. Simple aspects, that can be measured and monitored with wearables, are the range of movement of all the upper limb joints. Together with velocity and acceleration of hand movements, these are connected to stiffness symptom and co-ordination of hands and fingers. Measuring and monitoring upper limb movement's changes can be beneficial in cases of stroke, Parkinson´s disease, hand and upper limb surgery, rheumatoid arthritis, shoulder region problems, CRPS (Complex Regional Pain Syndrome), and Carpal tunnel syndrome. Position and movements of shoulder girdle and scapula in relation to lower parts of the upper limb would need new tools. Muscle strength is usually easy to measure and monitor with traditional equipment, but for example, spasticity and tremor are problematic without sensors or heavier ENMG studies.

Wearable technologies, which measure the finger and hand joint angles, can be divided into six categories: flex sensor based, accelerometer based, vision-based, hall-effect based, stretch sensor based and magnetic sensor based. At the present time, flex sensors and accelerometers are the most promising technologies. Flex sensor technology provides the best accuracy and lifetime whilst accelerometer-based technology provides the best performance and cost (Rashid & Hasan, 2018).

Spasticity of the upper limb with stroke patients might be possible to measure and analyze with wearable sensors. A wearable sensor system can capture clinically relevant features in the clinical environment from elbow spasticity during stretch-reflex testing (McGibbon et al., 2013). Concerning **constraint-induced therapy of stroke** upper-limb the web-supported-therapy program, which uses wearable sensors and a graphical user interface, was feasible and supported the home exercise program. With this kind of supported therapy program, upper limb functions improved. There were also reported positive effects on self-efficacy, confidence to use the affected arm, and body image. There are three key issues why telehealth should be augmented to conventional stroke rehabilitation: it enables stroke patients to experience a greater intensity of therapy, it provides intensity without additional therapist time and minimizes the costs, and it makes rehabilitation more accessible. (Burridge et al., 2017). In chronic stage, post-stroke, remote VR-based motor training for upper limb, may effectively induce motor gains and neuroplastic changes (Ballester et al., 2017).

People with **frozen shoulder** might benefit from rehabilitation where WIMU sensors and virtual reality techniques are combined (Lee et al., 2016). Lorussi et al. (2016) developed a new bi-articular model of **scapula-humeral kinematics and measures** using data from wearable sensors.

Several wearable sensor-based "glove-type" equipment has been developed to measure movement and posture of fingers. Challenges related to sensor-based gloves are the comfort, durability, cost-effectiveness, donning or removal, and measurement repeatability. (Simone & Kamper, 2005). A wearable glove-type sensor system can measure accurately: movements of flexion, extension, adduction, and abduction of fingers and thumb joints. This kind of glove-system can concurrently detect movement patterns, and measure angles of multiple fingers (Condell et al., 2011). **Thumb carpometacarpal joint movements** have been difficult to measure accurately. Preliminary studies related to this are Kim, Lee & Park (2016), Shin et al. (2016), Zheng et al. (2016).

Lower limb structure & activities

Qualitative and quantitative assessment is typically divided into clinimetrics, balance analysis, and gait analysis in rehabilitation. Simple kinematic and kinetic measures using for example goniometers and different muscle force measuring equipment are a simple and reliable device. There are some aspects in the lower limb assessment which are easily measurable with traditional clinical equipment (muscle strength, ROM and movements of hip, knee and talocrural joint), but there are also others, which require more complicated laboratory tests (ROM and movements of patella, subtalar joint, tibiofemoral rotation position, spasticity, etc.). Indexes, rating scales, questionnaires, and observational forms are used for example monitoring experienced functional capacity or supporting diagnostics.

Gold-standard technology adopted in gait analysis for quantitative movement analysis includes camera-based motion analysis, pressure sensitive walkaway or insoles, instrumented treadmills, and force platforms. Despite the achieved high performance, their application is constrained by costs, access to specialist motion labs, as well as the practicality of application for larger patient/subject groups. A viable alternative is represented by the adoption of small-size low-cost, wearable sensing units whose consideration for lower-limbs monitoring during rehabilitation.

Wearable sensors have been used in a great number of applications, such as navigation systems, activity classification, augmented reality systems, and so on (Walsh et al., 2014; Scheurer et al., 2017), and biomechanics, in particular, has achieved significant progress from the adoption of this technology (O'Flynn et al., 2015; Tedesco, et al., 2016).

Typical groups of persons who can benefit from wearable sensors in their clinical practice include persons with motor impairment associated with a number of conditions, such as orthopedic injuries, arthrosis, stroke, cerebral palsy, MS, Parkinson's, and so on, all of them requiring long rehabilitation periods.

Structure and activities of head and spine

Identifying accurately positions like head or cervical spine anteversion, differentiated ROM and movements of the upper and lower part of the cervical, thorax and lumbar spine, sacrum and pelvis posture, and movements, can benefit from new wearable sensor tools. These types of musculoskeletal problems is the main reason for therapeutic visits in developed countries. More specific detailed numeric data, in line with clinical tests, would help to show the impact of therapies, exercise, and rehabilitation, in inflammation- (eg. ankylosing spondylitis), structural based (arthrodesis) or in movement control disorders of the trunk.

Some neurological conditions like ALS and Cervical Dystonia symptoms and control of head and neck could be followed with sensor-based monitoring. (Theobald et al., 2012; Jasiewicz et al., 2007; Duc et al., 2014; Duc et al., 2013; Yim et al., 2017; Pancani et al., 2017).

Using two validated inertial wearable sensors to measure a range of movement, acceleration and angular velocity with persons of arthrodesis of the cervical spine and healthy persons showed excellent sensitivity and specificity (Duc et al., 2013). A wearable inertial system can present accurate results from the cervical range of movements and angles compared to an optoelectronic reference system (Duc et al., 2014).

Lower Back

Changes of the spine and pelvic control of movements or movement restrictions are typical in **Low Back Pain (LBP)**. They can be one factor to LBP, or the restrictions can be caused by LBP. Wearable sensor technologies have become more common for the quantitative assessment of human movement and it is a promising alternative to movement analysis in laboratory environments. It enables movement analysis in real-life settings. Many types of sensors have been used to assess spine kinetic and kinematics: electrogoniometers (3/22), strain gauges based sensors (2/22), textile piezoresistive sensor (1/22) and accelerometers with gyroscopes and magnetometers (15/22). In most studies, the researchers used two sensor units, and the measured outcomes were lumbar spine actions (in the sagittal plane – angles), the range of motion, angular velocity, joint moments and forces. (Papi et al., 2017).

When **the movements and postures of people with or without LBP** were compared using comprised of two wireless movement sensors (triaxial accelerometer, triaxial gyroscope, and a magnetometer), there was no significant difference between groups in lumbar lordosis. However, there were considerable differences in people with or without LBP in lumbar flexion, right lateral flexion and trunk lateral flexion ROM and lumbar contribution to the lumbo-pelvic rhythm. (Laird, Kent, & Keating, 2016). The short and long period results in LBP can be improved by adding wearable sensor-based biofeedback therapy training to usual therapy activities. (Kent, Laird & Haines. 2015).

6.2.2 Activities and participation

Mobility / Activity / Activities of Daily Living

Mobility, activity, and activities of daily living are general expressions, which should be specified when analyzing elements of those for rehabilitation purposes. There are controversial findings in researches about the accuracy and feasibility of different sensor systems. Commonly those systems are developed for sports and wellbeing purposes. Also, the target group – like the elderly and disabilities – have an impact on accuracy and usability. General physical activity is a concept that is considered to have an impact on many health and quality of life-related aspects. Age, health issues, functional capacity, psychological and social factors and work, leisure time and environmental factors have an effect on it. Commonly physical activity is connected with energy expenditure (kcal, J, metabolic equivalent MET). Evaluations have been calculated from heart rate and other physiological changes. The Number of steps (pedometers) and a relationship between moving and resting times (accelerometers), and measures of distance moved with GPS, have been used to analyze and measure physical activity and the intensity levels of it. Correlation between those measures and activity and health can be argued, and it is dependent on what is the parameter considered to be the golden standard. In ICF point of view in rehabilitation and research, it is best to use the terms of real measures. (Serra et al., 2017; Innerd et al., 2015; Trost et al., 2014).

General activity - Elderly

The use of inertial motion detectors for measuring, monitoring and analyzing senior citizen’s physical activity has been reported in several studies in the literature. With older people, the use of wearable sensors can have constraints. Therefore, an objective, clinically relevant and accurate assessment is still a topic of discussion. Different approaches to monitoring and measuring aspects and phenomena of physical activity have been employed. Settings, approaches, and sensors are mainly well described and their validity and acceptability reported (Tedesco et al., 2017).

Sensor placement seems to be one of the key aspects that have an influence on the accuracy of activity recognition. Certain groups of users are under the risk of inaccurate placement or sensor movement during activity - elderly, disabled, injured, children, people evaluating physiotherapy or sports exercisers (Yurtman et al., 2017).

Rosenberger et al. (2016) compared nine wearable devices for accuracy in 24 hours of activity measurement. Error rates varied from 8,1-16,9% for sleep, 9,5-65,8% for sedentary behavior, 19,7-28% for light-intensity physical activity, 51.8-92% for moderate-to-vigorous physical activity and 14,1-29,9% for steps. The conclusion is that there are not enough accurate devices to capture the activity data for entire 24-h, but it must be the goal of the future.

Pedometers are commonly used to evaluate a person's general activity level and to motivate them to be more active. A recurring question has been the accuracy of the measures especially owed to sensor placement and walking speed. Results showed that especially when the walking speed gets slow enough, the accuracy diminishes under a very low level. When walking speed is under 2.16 km/h (0.6 m/s, 1.24 mph), sensors cannot be reliably used to measure physical activity. The use of pedometers with elderly people is very much questionable (Ehrler, Weber, & Lovis, 2016).

General activity - neurologic & musculoskeletal

Godinho et al. (2016) presented a systematic review about monitoring technologies to assess characteristics and their validity monitoring **Parkinson's disease**. From 22 wearable devices, 38 non-wearable devices, and 13 hybrid devices, only 9 devices were recommended to be used.

Circadian rhythm/sleep

There is a growing interest in monitoring circadian rhythm and sleep characteristics in wellbeing, health and in rehabilitation, due to connections with several health issues. One of the risk factors is cardiovascular problems, and in the last 10-15 years, a connection to dementia has been identified.

Paavilainen et al. (2005a; 2005b) came to the conclusion that Vivago provides a valid system for monitoring sleep/wake patterns and the overall well-being of a demented elderly both in institutions and at home. Vivago proved to be more sensitive to low-intensity activities when compared to traditional Actigraphs, which are better in high-intensity activities. (Lötjönen et al., 2013). A multisensor sleep tracker ŌURA ring was compared against polysomnography whilst measuring sleep and sleep stages. Results showed that variables for sleep onset latency, total sleep time and wake after sleep onset were not different when comparing ŌURA and PSG results. ŌURA ring had a 96 % sensitivity to detect sleep (EBE analysis). It also had an agreement of 65 %, 51 %, and 61 % when detecting "light sleep", "deep sleep" and REM sleep respectively. These first results are promising, but further development and validation are necessary. (de Zambotti et al., 2017).

Balance and Gait

Most research and literature concerns kinetic and the kinematic analysis of standing, balance, and gait with wearable sensor systems. The problems of spatiotemporal parameters of gait (e.g. quality) and balance are connected to fall risk but also other health conditions like frailty and dementia. Falls lead to huge expenses to communities: the amount of first time and second-time surgery, need of a home and institutional care and even increased the death rate. We have already a clear vision about spatiotemporal and muscle force parameters that are excellent to measure, monitor and exercise in order to avoid falls. Some research on cost-effectiveness has been done, but more is needed. For example, the surgery and treatment caused by falls were 1.85 times more expensive than the costs of preventive exercise-based interventions (Hektoen et al., 2009).

Several wearable sensor systems have been developed and used to measure, analyze and monitor gait and balance. Monitoring those parameters can enhance the feeling of security and eases the fear of falling for persons with increased risk of it. Sensor systems allow measurement of new parameters not possible with other equipment. These new parameters are measure and monitor gait and balance in real life conditions for a longer period, turning, the height of the foot, propulsion, all three (X, Y, Z) force directions, gait initiation, raising up, etc. Balance and gait have been monitored in several pieces of research for different health and age groups and health conditions (Table 5). There are several possibilities in the home and remote rehabilitation to monitor and exercise those quality parameters of function with wearable sensors. Extra qualitative information to clinical functional capacity tests (TUG, Sit to Stand, Push and Release) can be achieved with wearable sensor systems.

Table 5. Relevance of monitoring of Gait and Balance for multiple conditions

Balance	Gait
Fall Risk: COM Sway- Direction of sway, amount of sway, distance travelled, mean distance from COP, sway in semi-tandem position, Hip sway (pre-frail) CTSIB (Clinical test for sensory interaction in balance)	**Elderly:** Pre-Frail - Change in double support phase, reduced cadence, increased step width variability and double support, steps/day (pre-frail) **Discriminating non, pre and frail:** Gait speed, stride length, double support duration **Fall risk:** stepping height, gait symmetry, fall detection, step during turning
	MS (Multiple Sclerosis): Gait speed- discriminating factor, all spatiotemporal parameters
	PD (Parkinson ´ s disease): Specific- gait initiation, step climbing, stepping height, turning all spatiotemporal parameters; gait and turning parameters have connection to global cognitive function and processing speed
	Stroke: All kinetic and kinematic analyses, walking speed, symmetry features, weight transfer and symmetry
	Osteoarthrosis of hip and knee: Gait symmetry, walking speed
	Amputees: Gait asymmetry, fall risk, unsuitability of prosthesis

References for example:Thiede et al., 2016; Shcwenk et al., 2016; Hubble et al., 2015; Cutti et al., 2014; Igual et al., 2013; McGinnis et al., 2017; Redfield wt al., 2013; Hafner et al., 2014; Howcroft et al., 2013; Howcroft et al., 2016; Trojaniello et al., 2014; Bonora et al., 2015; Munoz-Organero et al., 2016; Kobsar et al., 2017; Rapp et al., 2015; Liikavainio 2010.

Hollmann et al. (2011) have categorized reference values of 23 gait parameters for older adults (+70). These reference values can be utilized by researchers and clinicians for assessing and interpreting gait dysfunctions in aging persons. Howcroft et al., (2017) defined a feature selection for elderly falls classification using wearable sensors. To avoid high costs and irrelevant feature settings of measurements, walking 7.62 m with pressure sensing insoles and tri-axial accelerometers on patients' head, pelvis and left and right shank was compared. The best performing method reached 78% accuracy, 26% sensitivity and 95% specificity with one posterior pelvis accelerometer input. The second method reached a sensitivity of 44%, 74% accuracy, and 83% specificity. The simplest arrangement was to use one accelerometer on the posterior pelvis. Pressure sensing insoles and the use of several accelerometers - in combination with the selection of correct features - improve sensitivity.

One typical part of gait is turning for elderly's normal daily living, is turning. Difficulty in turning can be a contributor of mobility disability and falls. In Mancini et al. (2016) a study found that quality of turning can be measured with wearable inertial sensors. The highest connection to future falls was the increased variability of the number of steps employed to turn.

Gait might be a possible measure to find older patients (55+), who have a risk of frailty syndrome of peripheral artery disease **(pre-frailty)**. Changes in the double-support phase were the most sensitive parameter identifying pre-frail (Thiede et al., 2016). In systematic analysis, gait speed has the highest effect size, to tell the difference between frailty subgroups. Gait parameters variability had the same quality. Key gait parameters connected to prefrailty were: reduced cadence and increased step width variability during habitual walking and increased double support during fast walking (Schwenk et al., 2014). Stride length and double support duration were the best to discriminate three frailty levels **(non–frail, pre-frail and frail)** Walking duration was the most sensitive and physical activity for identifying three frailty levels. None of the balance parameters could do it (Schwenk et al., 2015).

Sensor derived parameters of gait, functional performances, and physical activity are suitable for screening and monitoring pre-frailty or frailty. Outcome variables should be validated in large cohorts and under normal daily living conditions to have robust screening tools for intervention and prevention (Dasenbrock et al., 2016).

Ambulatory assessment and self-management of rehabilitation have been done successfully with a small group (5 persons) of **stroke survivors** using **smart insoles**. Features such as walking speed, heel strike and symmetry were analyzed. Dual motor learning and compensatory strategies were used by participants (Davies et al., 2016). "Tailor-made" smart insoles were used to measure plantar pressure for analyzing **stroke survivors**' gait patterns. With this kind of wearable sensor technology inside an "intelligent shoe" can find four different gait characteristics for stroke patients´: Heel walking Strategy, Planar Stride Strategy, Low Heel Pressure strategy, and Gait Asymmetries (Munoz-Organero et al., 2016).

Functional Tests (ICF/activities/mobility)

Timed Up and Go –test (TUG)

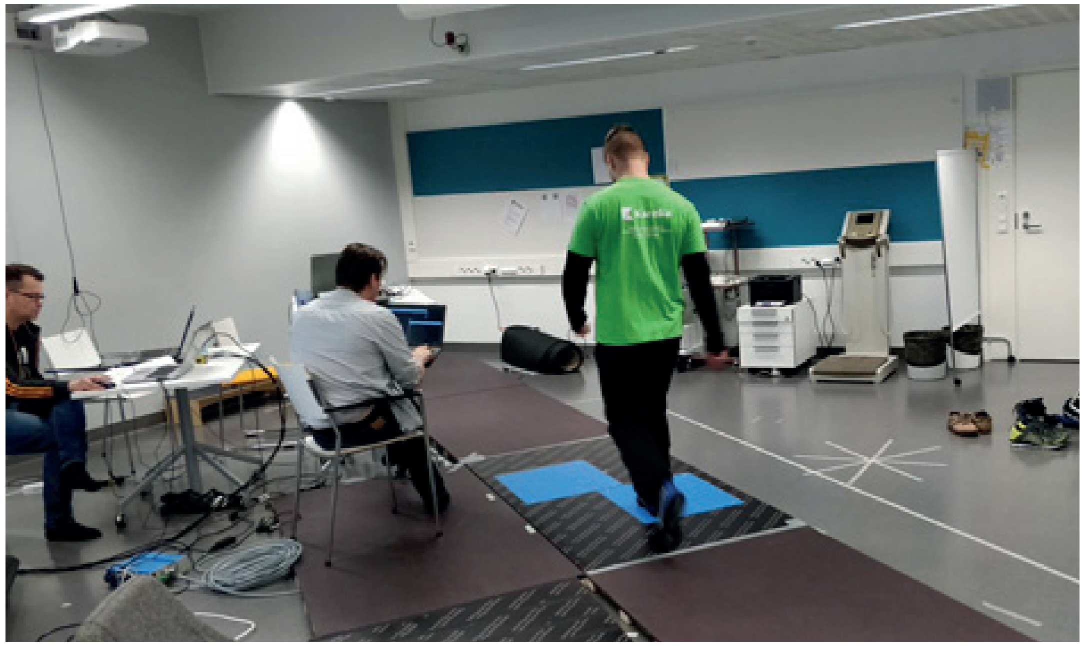
The Timed Up and Go –test indicates the frailty status of elderly people (Savva et al., 2012; Greene 2014) and can be used for identifying frail or non-frail people. As a single measure TUG time accuracy is 71,8%, using inertial sensor 75,2%, and using grip strength alone 77,65%.

Sit to stand -test

Ganea, Paraschiv-Ionescu & Aminian (2012) explored sit-to-stand (SiSt) and stand-to-sit (StSi) in daily activity. Measurement system consisted of three miniaturized inertial units, which were attached on the right shank, right thigh, and the trunk. Monitoring was performed on 40 participants, aged 40 to 82 years old. Each participant was monitored three consecutive days 8h / day. The algorithm was actual data received from a real-world environment. This research tries to show the potential of long-term monitoring for **frail and older people**. Results suggest that they have significantly lower rate of postural transitions, longer sit-to-stand duration, and lower sit-to-stand trunk tilt and acceleration compared to healthy elderly people.

Push and release test

By using 3-inertial sensors, it is possible to measure – quantify – postural responses (stepping latency, time and number of steps to restore stability and initial step length) with persons who have **Multiple Sclerosis**. Sensors were placed on lumbar spine and feet. Correlations of measured parameters were compared to laboratory-based methods. They were from moderate to strong. Compared to healthy persons, MS patients demonstrated a larger number of steps to restore stability and longer time to stability (El-Gohary et al., 2017).



7 What should be considered when implementing wearable sensors to rehabilitation processes

According to our experience of testing different sensor systems in real rehabilitation environments and real home rehabilitation processes, the key factor and problem are by far usability and utility of wearable sensor systems. When choosing a system, test the usability aspect first. In Figure 8. presents a checklist for implementing wearable sensor systems to everyday rehabilitation practices.

- support of the management of rehabilitation organizations
- management´s decision is the use of sensor systems for additional activity or does it replace something
- education for the users
- on the spot support
- development attitude both staff and management
- test usability, think about utility
- timetable for implementation
- selection of the sensor systems (+/-)
    - need/goal of using wearable sensors
    - easy to use for end users
    - selection between a wide range of rehabilitation needs or very specific need
    - the information from the report is clinically usable
- choose accurate, suitable, sensitive and usable wearable sensor system for your goal
- interaction between electronic patient reports and data protection
- analysis of cost-effectiveness

Figure 8. Checklist for implementing wearable sensors to everyday rehabilitation practices.

There has to be a real need for using these wearable sensor systems in rehabilitation practice, for example, to get clinically meaningful additional data. At worst, these new technologies are unexplored, forgotten, or rejected – until they are actually used in human action and thereby become part of a process. (Orlikowski, 2000).

Implementing technologies or devices into everyday rehabilitation practices requires commitment and support of management and the organization. The organization must be clear why there is a need for using new technologies. For example, monitoring the change and impact of rehabilitation on functional capacity, ensuring the correct interventions are done at the right time and right place. Management should demonstrate whether new activity replaces something or is it an additional activity. There is a need for education, the use of software and sensor systems and possible new clinical parameters that can be measured. Rehabilitation staff should have on the spot support available during working hours. Rehabilitation staff should have a development-oriented attitude and understanding. Together management and staff have to consider what are the suitable criteria for implementing new technologies.

The use of these systems and the information they provide aren´t necessarily familiar to physiotherapists working in practice. To date, new wireless technologies and wearable sensors are not part of daily work. Implementing and testing these systems should be the next step.

8 Ethics

Ethics is the systematic study of what is obligatory, forbidden and permissible. Ethics of Technology is ethics applied to technical domains and domains depending heavily on technology. Some few examples where the ethics of technology are concerned to include; the connection of technology to economic interests, the ability to guide the future, the impact on society and the environment and the ability to apply technology for various purposes. In particular, information technology has contributed significantly to people’s lives and the development of society both positively and negatively. Controversial issues have emerged, for example, regarding data copying, storage, and data transfer. Problems related to the control of people and the intrusion of their personal lives have also been problematic. The various problems of information technology ethics (IT ethics) are related, for example, to abuse of technology (e.g. breach of privacy) and to false values (e.g. excessive user guidance in a particular direction). These technology-related ethical issues should not always be looked at with a negative viewpoint. It should also be considered how technology could increase, for example, our self-determination and self-fulfillment. (Leikas, 2008).

Technological development has general and profound implications:

- Huge technical changes can shock social structures and people’s interaction
- Maximizing short-term economic benefits can fundamentally undermine future development conditions
- Some technical solutions may have adverse side effects on our habitat
- The more people are involved in technical solutions, the more fatal the cross-effects may be
- Efficient economic-technical solutions do not necessarily support values that people feel important

The relationship between an aging person and technology is affected by the cultural, economic, political and legal factors associated with the life of each person and can be different in specific age groups and countries. Also, the older generations technological acceptance may change over time towards a generally favorable attitude. Today's oldest generation is not used to using technology so we can talk about the inequality of technology, though it should support equality and justice. (Leikas, 2008).

In the case of elderly people, reconciliation of self-determination and care is often an ethical question. The feeling of aptitude is one part of life management, and it can be increased through technology. For this reason, products and services should be easy to use, the instructions for users should be clear and usage training should be empowered. The sense of security is also one of the core issues in life management. (Leikas, 2008).

9 Cost effectiveness in the use of wearable sensors

The costs to individuals and organizations might be reduced by using wearable sensors in home-based and remote rehabilitation, but cost-effectiveness must be shown in order to attain more wide and continuous use of them. Table 6 summarizes examples of how the use of wearable sensor systems can reduce costs.

Table 6. Possible positive impacts of using wearable sensors in home and remote rehabilitation for the elderly.

Decreased travel expenses • less time used traveling both patient ´ s and rehabilitation staff
More efficient use of work hours, because of no transitions between different places
Better accessibility and provision of rehabilitation services in remote and sparsely populated areas
Right activities at the right time
More accurate measures and monitoring of exercise • more detailed information of results and effectiveness

When remote rehabilitation and exercise are implemented, it is possible to save on travel expenses, and also on working time of the rehabilitation staff. When living in rural and sparsely populated areas, these questions are very important also from an economic point of view. Remote rehabilitation can be more cost-effective in rural areas, providing rehabilitation services for patients/clients who might not have been able to have access to it (Vuononvirta, 2015).

If using new technology and measuring the activity of older people can prevent for example falls and fractures, it will save money and it is economically sensible. The average cost of treatment for a hip fracture in the first year was roughly 30 900€ per person in Finland. If an elderly person ends up permanently in institutional care as a result of a hip fracture, the costs are much higher. (Lonkkamurtuma käypä hoito –suositus, 2017). So, we can say that rehabilitation and safety discharge pay themselves back.

There are still remaining questions related to cost-effectiveness of wearable sensors: What are the economic consequences of not investing in the rehabilitation? What is the balance between the cost of rehabilitation and better outcomes? Would it be more effective if individuals would have the opportunity to access rehabilitation at an earlier point in time? How patients and governmental institution feel about investing in prevention? Contact the correct professional in the right time? For example, self-referral of different healthcare professionals.

10 Summary

Similar efforts in Finland, Sweden, Ireland and UK are focused on decentralizing care; avoiding the access for long-term of elderly patients to acute hospitals; and making it more cost-effective in time and money for the patient and the local authorities. SENDoc outlines the potential of remote rehabilitation in achieving those goals and objectives through the use of wearable technology and sensors. It is always a question whether the data is reliable and necessary and if this can effectively be measured in a traditional way.

There is limited knowledge about the continuous and long-period use of wearable sensors in real rehabilitation processes, particularly in remote and home-based rehabilitation and in sparsely populated areas. Populations or cohorts in the research reviewed were small and mostly they are done in clinical or laboratory settings. The impact of regular use of wearable sensor systems in rehabilitation is not yet known.

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