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Review

Smart devices and healthy aging

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Abstract. Chronic diseases, such as cardiovascular disease, cancers, chronic respiratory diseases, diabetes mellitus, and neurodegenerative disorders represent major global health problems to society, and their incidence and prevalence continue to increase. Chronic diseases share common risk factors, including socio-economic factors and co-morbidities and, importantly, their risk increases with age. The silent transition from health to disease with a late onset of symptoms can delay treatment and interventions. Healthcare-systems must thus evolve proactive rather than purely reactive approaches to care once symptoms appear. Many self-tracking technologies (based on wireless biosensors) are readily available to the general public that monitor and record personal bio-related data. These biosensors may be wearable, implanted in the body or installed on a device. The aim of this review is to discuss the current market and proven utility of wrist-worn devices, in improving and maintaining a healthy lifestyle. Optimizing the technological opportunities for monitoring good health has the potential to empower people and help many enjoy a high quality of life.

Keywords: Smart devices, health self-monitoring

1. Introduction

Chronic diseases listed by World Health Organization (WHO), including cardiovascular disease (CVD), cancers, chronic respiratory diseases, diabetes mellitus (DM), and neurodegenerative disorders represent a major global health problem [1–3]. Such chronic diseases are key contributors to the global health burden, are a leading cause of mortality worldwide, and are increasing in incidence and prevalence [1–4]. Chronic diseases share common risk factors, including socio-economic factors and co-morbidities and are closely associated with aging [1–3, 5]. The links between over-nutrition and/or nutrient scarcity with overweight/obesity, hypertension, stroke, coronary heart disease, diabetes and cancer are well established [6, 7]. Characteristic diets observed in those affected by chronic diseases typically include low consumption of cereals and vegetables and high consumption of meats and saturated oils/fats. This type of diet, combined with a sedentary lifestyle and increased exposure to tobacco and alcohol, has contributed to the rapid increase of chronic diseases over recent decades.

The challenge for health-care professionals and researchers in the 21st century is to understand the complexity of chronic diseases and the silent transition from a healthy to diseased state due to a late onset of symptoms, which can delay treatment and effective intervention. As a society, we need to shift toward a model of disease prevention: healthcare and medicine must evolve a proactive system that moves away from a purely reactive approach to care once the symptoms appear. Indeed, many individuals do pay attention to their bodily functions and sensations, diet, body weight, drug consumption and

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exercise patterns, in an attempt to achieve optimal health or help manage an ongoing illness or disease. Self-tracking devices have helped encourage such proactive health-care behaviors, and have long been recommended as good practice in personal healthcare [8]. The implications of self-tracking on concepts such as self-identity, social relations and embodiment have gained interest over recent years. This interest stemmed in part from increasing coverage in the mass media of the potential for new digital technologies to facilitate self-tracking in novel, fashionable ways. In the most modern conception, self-tracking devices typically refer to wireless bio-sensors, medical instruments or equipment that are accessible to the general public to monitor and record personal bio-related data. Such wireless bio-sensors may be wearable, implanted in the body or even installed in homes, cars, workplaces and other environments [8–11]. Some healthcare applications and services are digitally availability through mobile device applications. In this regard, the integration of wireless medical sensor networks and radio-frequency identification (RFID) technology to healthcare systems has helped drive the advancement and sophistication of self-monitoring capabilities.

Patient-centered activity monitoring for the self-management of chronic health conditions has proven effective in the post-surgical recovery of patients with cardiac diseases or diabetes [12], but smart devices for self-monitoring also have the potential to support health in everyday living to *prevent* the insurgence of chronic diseases. The aim of this review is to highlight the current market offer, potential and proven utility of smart devices (in particular wrist bands) in prolonging the functional and cognitive capacity of the general population. Optimizing opportunities for good health has the potential to empower people, particularly the elderly, to enjoy an independent and high quality of life, with great social and economic benefits.

2. Smart devices: A growing market

The elderly population represents a huge untapped market for technology companies producing smart devices. According to 2010 US census data, $\sim$13% of the US population is aged $\geq$65 years; this percentage is estimated to increase to $\sim$19% by 2030 [13]. An area of technological invention that holds particular promise for this age group is wearable technology (wearables). Wearables are currently used by >20% of US citizens. Many wearables encourage and support healthy lifestyles, such as smart wear developed by top brands to help optimize workout routines. Wearables that foster healthy aging and independent living, such as nanotechnologic "smart clothes" that monitor health and remind subjects to take their medications, have the potential to fill the wardrobes of the elderly. In fact, market analysts predict that medical applications will soon account for the largest share in the smart textile industry, reaching $843 million by 2021 [14].

Wearables, such as activity trackers, are a good example of the Internet of Things (IoT), which is the network of physical devices, home appliances, and other items embedded with electronics, software, sensors, actuators, and have network connectivity to enable these objects to collect and exchange data. The healthcare IoT market segment is poised to hit $117 billion by 2020, and currently involves big industrial players such as IBM, Cisco, Microsoft, Google, Amazon, and GE. Thousands of devices and gadgets are available that have the potential to help one live a healthier mental, physical and emotional life [15, 16], but it is beyond the scope of this review to discuss them all. Popular application choices include those that monitor sleep quality (Pebble Time and the Android Sleep App), blood pressure (Nokia's Withings watch and Viatom's CheckMe™), exercise (Gymwatch® fitness tracker) and that aid meditation (InteraXon's Muse™ head band) and stress reduction (PIP). Here, we focus exclusively on the wrist-worn trackers for sleep, calorie intake and fitness, as a proof-of-concept that smart devices can help maintain a healthy span in the general population.

Fitbit® is the best known fitness tracker brand on the market, and it comes in many forms. Fitbit® is a touch-screen wristwatch that not only tracks steps and sleep, but also alerts the user to incoming phone calls and text messages, monitors heart rate with a built-in optical heart-rate monitor and tracks outdoor activity via GPS. Fitbit® is easy to use and connects the user to a wider community that shares the same activities and allows them to compete in a playful manner. Other widely used wrist-worn trackers include the Xiaomi MI Band 2, Garmin Vivosmart 3, Samsung Gear Fit2 and the Apple Watch S1. Table 1 summarizes the features of these devices (including steps, calories, distance, clock, sleep tracker, wireless, battery/charge lasts, continuous hearth rate, GPS tracking, multi-sport detector, music control, style or mode of wearing and price) and economic indicators

Table 1
Main features of wrist-worn devices, average price and sales (indicative, based on Amazon online US market

Most popular health monitoring devices	Fitbit Charge 2	Xiaomi Mi Band 2	Garmin Vivosmart 3	Samsung Gear Frt 2	Apple Watch SI	Others
Steps	Yes	Yes	Yes	Yes	Yes	
Calories	Yes	Yes	Yes	Yes	Yes	
Distance	Yes	Yes	Yes	Yes	Yes	
Clock	Yes	Yes	Yes	Yes	Yes	
Sleep Tracker	Yes	Yes	Yes	Yes	No	
Wireless	Yes	Yes	Yes	Yes	Yes	
Battery/Charge lasts	7–10 Days	20 Days	6 Days	3 Days	l8h	
Continuous Hearth rate	Yes	Yes	Yes	Yes	Yes	
GPS Tracking	Yes	Yes	No	Yes	No	
Multi-sport	Yes	No	No	Yes	Yes	
Music Control	Yes	No	Yes	Yes	Yes	
Style	Wristband	Wristband	Wristband	Wristband	Smartwatch	
Price*	$148.95	$36,98	$139.99	$177.99	$276.55	
Fourth Quarter 2016 Units Shipped**	6.5	5.2	2.1	1.9	4.6	13.6
Fourth Quarter 2016 Market Share**	19.2	15.2	6.2	5.6	13.6	40.1
Fourth Quarter 2015 Units Shipped**	$.4	2.6	2.2	1.4	4.1	10.3
Fourth Quarter 2015 Market Share**	29%	9.10%	7.60%	4.70%	14.10%	35%
Year-Over-Year Growth**	–22.70%	96.20%	–4%	37.90%	13%	32.10%

*Amazon online US market. **All products Fibit, Xiaomi, Garmin, Samsung, Apple and other.

(such as the number of units sold, the market share and the year-over-year growth), based on the Amazon online US market. Fitbit® achieves the most units sold and has the biggest market share worldwide, there is large variation in price between the various available devices (Table 1).

3. Impact of smart devices on healthy aging

Commercial self-monitoring wrist-worn devices are increasingly popular in both the consumer and medical markets. In 2015, 232 million wearable electronic devices were sold worldwide, and sales increased by 18.4% in 2016 [17]. With this increase in popularity, behavioral change interventions are becoming more evident [18–22]. However, with their increasing popularity, questions as to the validity, accuracy and reliability of these devices become increasingly more important. A recent study evaluated such commercially available devices for clinical purposes [23]. Here, four activity trackers and one sleep tracker were evaluated based on step count validity, in a cohort of 22 healthy volunteers asked to complete a walking test [23]. The study found that some self-monitoring devices are better suited than others for measuring step count at slow walking speeds. The Fitbit® and the Garmin Vivofit 2 showed the lowest average systematic error percentage; however, the standard deviations of the Fitbit® were significantly lower than the Garmin Vivofit 2, making this device the most reliable for use in slow-walking populations [23]. Another study examined the accuracy of heart rate and energy expenditure measures made at different exercise intensities by three popular wrist-worn activity monitors [24]. A cohort of 62 participants wore the Apple Watch, Fitbit®, or Garmin Forerunner 225 and their validity was assessed using a heart-rate chest strap and a metabolic cart. The participants completed a 10-minute seated baseline assessment; separate 4-minute stages of light-, moderate-, and vigorous-intensity treadmill exercises; and a 10-minute seated recovery period. The highest measurement error for all devices occurred during the light and moderate physical activity stages [24]. The Apple Watch provided the most accurate measure of heart rate, followed by Fitbit® and then the Garmin Forerunner 225 [24]. Although these results seemed to indicate the most favorable outcomes for the Apple Watch, this device measured significantly lower heart rates during light and moderate physical activity compared to the other devices. Fitbit® produced reasonably accurate results during moderate physical activity but measured lower heart-rate readings during vigorous physical activity compared to the other devices. Finally, Garmin Forerunner 225 read accurately during vigorous physical activity but measured significantly higher heart rate readings at all other intensities compared to the other devices [24].

Several randomized controlled trials on the utility of these popular wrist-worn activity trackers, and in particular Fitbit®, on health outcomes across various age ranges of the general population have been conducted or are ongoing. The list below is not intended to be exhaustive but highlights the potential range of applications of wrist-worn devices on improving a healthy lifespan.

3.1. Completed trials

A randomized controlled trial by Smith Lillehei et al. compared the effectiveness of lavender (*Lavandula angustifolia*) and sleep hygiene versus sleep hygiene alone on sleep quantity and quality, and aimed to determine whether any positive effects of lavender could be sustained for 2 weeks [25]. The study cohort included 79 college students with self-reported sleep issues and their usual sleep settings were maintained. The intervention took place over five nights; the experimental group wore a patch with lavender essential oil and the control group wore a blank patch [25]. Sleep quantity was measured using a Fitbit® tracker and a sleep diary, and sleep quality was measured using the Pittsburgh Sleep Quality Index (PSQI) and the NIH Patient-Reported Outcomes Measurement Information System (PROMIS) sleep disturbance short form. The experimental group demonstrated better sleep quality at post-intervention and 2-week follow-up, compared to the control (sleep-hygiene-only) group. Interestingly, sleep quantity did not differ between groups [25]. This study highlighted the utility of wrist-worn smart devices for monitoring certain sleep parameters.

Several clinical trials of tracking food intake or recording the number of steps made per day using a pedometer have resulted in successful weight loss [26, 27]. However, the impact of food management applications on permanent behavioral change toward diet and activity is doubtful [28, 29]. In fact, a randomized clinical trial conducted at the University of Pittsburgh that enrolled 471 participants, found that among young adults with a body mass index between 25 and <40, the addition of a wearable technology device to a standard behavioral intervention resulted in less weight loss over a 24-month period compared to a standard intervention alone [21].

Data suggest that wrist-worn devices are effective because users like them. Another randomized controlled trial assessed the feasibility and efficacy of integrating the Fitbit® tracker with a related website resource, in improving physical activity in postmenopausal women [19]. A cohort of 51 postmenopausal overweight/obese women was randomized to a 16-week web-based self-monitoring intervention or a comparison group. The web-based tracking group received a Fitbit® and an instructional session, and the comparison group received a standard pedometer. All participants were asked to perform 2.5 h/week moderate-to-vigorous physical activity, and the physical activity outcomes were then measured. Interestingly, almost 100% of the web-based tracking group wore the wrist tracker and liked it [19]. The wrist-worn smart device was well-accepted in this sample of postmenopausal women and strikingly, it was associated with increased physical activity at 16 weeks. Relative to baseline, those wearing a Fitbit® increased their number of steps per day by 789 ± 2 [19]. Conversely, those carrying a simple pedometer did not show a significant increase in physical activity [19].

3.2. Ongoing trials

The Australian project Raising Awareness of Physical Activity (RAW-PA) aims to study the impact of Fitbit® Flex on the daily physical activity levels (moderate to vigorous intensity) of 300 teenagers [30]. Specifically, RAW-PA is a 12 week multi-component intervention that will examine whether a wearable activity tracker combined with behavior change resources is effective at promoting physical activity in inactive adolescents who are attending schools in socioeconomically disadvantaged areas [30]. RAW-PA is anticipated to provide insights into how such technologies are used by adolescents, which at present is unclear.

A German clinical trial is evaluating the effectiveness of two web-based interventions in initiating and maintaining regular physical activity in adults aged 65–75 years compared to a delayed intervention group [31]. The participants have been randomly assigned to one of three study arms: a) participants receive access to a web-based intervention for 10 weeks, which allows them to track their weekly physical activity (subjective self-monitoring); b) participants receive access to the web-based intervention for 10 weeks and in addition, will track their physical activity using Fitbit® (objective self-monitoring); c) participants receive access to the intervention implemented in the first study arm after completion of the 12-week follow-up in the other two groups (delayed intervention). Using an integrated approach (including community meetings and psychological assessment), it is hoped that this study will provide answers regarding the effectiveness of web-based interventions in promoting the maintenance of regular physical activity in persons aged 65–75 years [31].

The DOREMI project (Decrease of cOgnitive decline, malnutRition and sedEntariness by elderly empowerment in lifestyle Management and social Inclusion), coordinated by Prof. Oberdan Parodi (CNR, Milano), combines multidisciplinary research in the areas of serious games, social networking, Wireless Sensor Network, activity recognition and contextualization and behavioral pattern analysis [32]. By recording and monitoring information about the use of adopted lifestyle protocols, DOREMI aims to track user performance over long periods and provide early warning of signs of malnutrition and physical and cognitive deterioration. The DOREMI system utilizes four core technologies and three applications. These technologies include: "Smart Carpet", a Wii-based balance board for daily weight assessment; an Android tablet containing the three applications; a wrist-worn DOREMI bracelet that collects patient metrics and sends them to a centralized home-based station; and ∼10 environmental home-installed sensors to assess life-style habits and level of socialization. Each application focuses on a specific aging-related issue: fitness, cognition via a series of games, and diet. In a revolutionary approach, clinicians can remotely check the diaries and, if necessary, modify the participant's habits to promote health (in accordance with the general guidelines promoted by project) [33]. A pilot study cohort included 32 people aged between 65 and 80 years, who participated in 3-month trial in either the UK or Italy. These participants were characterized in terms of their physical activity (including daily steps/meters travelled measured with the DOREMI bracelet), hemodynamic and biochemical parameters (including blood pressure, lipid profile and glycemic index), caloric intake and balance at baseline and at the end of the trial. In addition, they were stimulated to perform an indoor physical activity protocol monitored by the DOREMI bracelet, invited to fill in a diet e-diary to receive nutritional advice provided by an expert, and tested for balance (via the DOREMI smart balance board. The DOREMI system has been tested for 3 years and the project was recently completed; we are now awaiting the publication of its first results. Thus far, DOREMI participants at both UK and Italian test sites reported an overall increase in physical activity and a significant improvement in hemodynamics and in dietary habits.

The VISTERA project, powered by the European Institute for Systems Biology and Medicine (EISBM), aims to encourage the transition from reactive to proactive methods of health and wellness management based on the principles of Systems P4 (Predictive, Preventive, Personalized and Participatory) Medicine [35, 36]. The study, based in France (and in collaboration with other European partners) uses individual active engagement in healthcare monitoring techniques, such as: participant follow-up over time, participants access to a comprehensive dataset, data analysis using advanced computational tools and participant access to a personalized dashboard for health and wellness coaching [34]. Over the course of the project, self-measurements of heart and respiration rate, sleep quality, weight, blood pressure and calorie uptake will be made using wrist-worn devices. By monitoring the participants over a long period of time, it is hoped that actionable recommendations to maintain health and wellness can be made, and early detection warnings of events indicative of risk or transition to disease can be provided. The expectation of the VISTERA Project is that by monitoring up to billions of individuals over the next 25 years will trigger a reversal of the escalating costs of healthcare management and drug and diagnostic development in just one generation. All partners of the VISTERA Project are committed to respect the privacy of the participants and will implement stringent measures to ensure compliance with national and international regulations on personal data protection. This project is very ambitious and still in its infancy.

4. Conclusions and perspectives

Wrist-worn smart devices have clinical utility, but they are under-utilized in the healthcare industry. People wanting to use technology to live a healthier life are rushing to buy a wearable. We advocate that wearables are an excellent option to help take control of health and life style at the individual level. However, wearables can currently only show data, which will not be actionable if it is not known how and what should be changed. Wearables should not completely replace the traditional methods of scoring mental, physical and emotional health parameters, but should be complementary. Self-monitoring helps people understand how their own body works, and encourages vigilance about health. At the clinical level, incorporating smart wearable sensors into the routine care of patients with a chronic disease could enhance physician-patient relationships, increase the autonomy and involvement of patients in their own healthcare and provide novel remote monitoring techniques that will revolutionize healthcare management and spending, especially in the elderly.

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In loving memory of Prof. Domenico Vinciguerra (1937–2015).

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