EVALUATION OF CONTEMPORARY PHYSICAL ACTIVITY TRACKING TECHNOLOGIES

[1]REEM ALTAMIMI, [2]GEOFF SKINNER

[1,2]Faculty of Science and Information Technology, University of Newcastle, Australia
E-mail: [1]Reem.Altamimi@uon.edu.au, [2]Geoff.Skinner@newcastle.edu.au

Abstract— Active living is a way of life that promotes health and active behavior. Technology in modern life can either act as a barrier for active living or facilitate this lifestyle, depending on which technology people choose to use in their everyday lives. Finding a technology that facilitates an individuals' physical workout and motivates and promotes physical activity levels, requires investigation of the current technical options available. Physical activity monitoring technology has a range of types, mechanisms and capabilities. Physical activity trackers are also varied in their way of attachment to individuals' bodies. For example, they can be little devices attached to users' bodies, such as waist-clips or wrist-bands, or they can be applications installed in their mobiles or tablets. This paper is a part of our ongoing research in active living technology. Our path of research seeks to find the most applicable and accurate types of these devices. We aim through the work presented in this research to examine some of the current available physical activity monitors including Fitbit One, Fitbit Flex, Jawbone UP and Health iPhone application. Variation has been observed in physical activity data based on where monitors are held or attached to users' bodies.

Keywords – Activity Monitoring, Physical Activity, Active Living Technology, Fitbit, Jawbone, Health Applications.

I. INTRODUCTION

"Active living" has been defined as a way of life that integrates physical activity into daily routines [1]. Daily physical activity, in any type of physical movements such as sports, exercise or recreation activities, is important to promote a healthy active lifestyle [2]. Adding technology to this term would mean using technology to promote and facilitate physical activity in our everyday lives. One popular example of this kind of technology is physical activity monitoring technology. An exercise monitoring system is a collection of sensors which are attached to a human body in order to measure data resulting from body movement during exercise [3]. Wearable activity trackers have become popular in the last few years. Different monitors have different mechanisms of tracking, calculating, recording and measuring physical movements [3]. These kind of devices have the ability to monitor users' daily physical activity, measuring steps taken, distance travelled, calories burned, stairs climbed and sleep patterns [4]. This ability draws researchers' attention towards the use of these tools in different applications, especially in health context [5].

Wearable sensors are effective tools and commonly used to provide quantitative assessment of human physical activity [6] [7] [8]. They provide opportunities for automatic, long-term methods of assessment for physical activity in a free-living environment [6] [7]. Consequently, these sensors can be adopted in a variety of settings such as healthcare and fitness environments [8]. An interesting utilization of these trackers is the use of these devices as motivators for exercising and increasing levels of physical activity.

As part of our on-going research agenda in active living technologies, we found a growing variety of these technologies in current markets. Based on our aim to integrate an activity tracking device into our previous MySteps framework, the issue of choosing the most appropriate contemporary activity tracking technology is raised. We aim through the work presented in this paper to test the most popular physical activity monitoring technologies and find the one that best suits our application. We specifically look at features like accurate recording, ease of use and applicability in everyday lives. However, to overcome the time limitation, all tests have been done by the principle author. Furthermore, findings are based on this author's observations.

Section 2 provides definitions of physical activity and sedentary behaviour in line with the common trends in this technological era. Section 3 describes how a technological solution helps in the promotion of physical activity levels, followed by a specific overview of physical activity tracking technologies and some previous works that are related to this research. Finally, our contribution, including tests, data, and observations are detailed in the last section.

II. CLARIFYING THE SENSE AND SEDENTARY BEHAVIOUR

Sedentary behaviour refers to the involvement of individuals in seated activities [9] that result in a very little energy expenditure [10]. Examples include screen-based activities, such as watching TV, working on a computer, or playing video games [10]. Physical activity refers to activities that make individuals physically move, and accelerate their breath and heart beats [9]. Physical activity has been classified based on its intensity as sedentary, light, moderate, vigorous and high [11]. Light intensity refers to physical activity that is not associated with obvious change of breath rates, such as home and

office duties [11]. Moderate intensity of physical activity refers to activity that requires physical effort while allowing individuals to speak, such as fast walking or riding a bike [9] [11]. In contrast, vigorous intensity requires more physical effort. Individuals are hardly able to speak and experience fast breathing, such as in jogging and many other organized or competitive sports [9] [11].

It has been reported that the amount of time spent in sedentary activities as well as the number of youth engaged in these activities, have both increased in the past years [12]. This trend is likely to increase as technology advances, which is a serious cause for concern as there is strong evidence for links between TV viewing and obesity, increased fat mass, higher BMI, and decreased academic achievement [12].

III. TECHNOLOGY AND PHYSICAL ACTIVITY

Information and communication technologies (ICTs) have been applied and exploited in different areas based upon users' needs. The rapid increase of technology advancement has facilitated the use of technology as well as personalized its use. For example, the availability of home Internet access facilitates online media usage, which expanded from 74% to 84% between 2004 and 2009 [13]. Internet technology has been utilized to deliver a huge array of information, knowledge, programs and innovations for different age groups. The vast majority of US teens are using the Internet daily for different purposes such as playing games, communicating with friends and seeking information [14].

Computer-based interventions have become widely used for the purpose of health promotion. The term eHealth has become increasingly common, and refers to the use of emerging information and communication technology, especially the Internet, to improve or enable health and health care [15]. There are many interactive eHealth interventions which have been designed for physical activity and behavioural change [16]. Technology-based programs targeting behavioural treatments such as weight management through promoting healthy behavior including diet, exercise and social support have also been developed [17]. Along the path of research in promoting and maintaining levels of physical activity, a variety of interventions have been proposed and applied. In 1998, a study reviewed researchers' findings in media-based physical activity interventions up to that

period [18]. Researchers had suggested the use of mass-media campaigns, print media and/or telephone based programs, and other information and communication technology approaches in order to promote levels of physical activity [18]. Results showed that mass media campaigns were able to reach large numbers of community members and promoted awareness and interest in exercising, but had little effect on physical activity behavioural change. In contrast, interventions which were based on print media and/or telephone were more effective in encouraging physical activity behavioural change in the short term [18]. Other studies proposed the use of persuasive technology to promote healthy behaviour [17]. They supported the development of persuasive technologies to encourage regular participation in physical activity, using goal-setting strategies in order for individuals to live healthy lifestyles [19]. UbiFit, Houston and Fish 'n' Steps systems are all examples of persuasive technology that were developed with the aim to encourage changes in physical activity behaviour [19] [20] [21]. Applying goal-setting strategies in persuasive technology has been demonstrated as an effective way to enhance physical activity behavioural change [19]. Using Internet and mobile phone technology in physical activity programs has also been evaluated [22]. A 9-week test, using a system of Internet, email and mobile phone behavioural change, along with a wrist-worn physical activity monitor, was conducted. With 77 participants, results demonstrated the effectiveness of using Internet and mobile phone technology in increasing and maintaining levels of physical activity in healthy adults [22]. Another 3-week field trial of technology using mobile phones and pedometers to encourage physical activity among teenage girls also supported the use of technology in this context [23].

Technology-based intervention for the purpose of physical activity promotion should be effective, especially among teenage populations [23] whose levels of physical activity have declined at this age [24] while their use of technology has increased [25]. However, there are some considerations worth mentioning in designing the technology to encourage physical activity. Firstly, this technology should give users appropriate credit for their physical activity. There is a problem with currently available activity tracking technologies in that they do not record all types of physical activity. For example, pedometer devices can track steps taken walking or running but cannot monitor activities such as swimming and cycling. Therefore, designers should consider the most common physical activities undertaken by their targeted users [20]. Secondly, technology should allow users to access information regarding their past and current physical activity levels with respect to their goals [20]. Thirdly, technology should include features, such as the ability to share data with friends, which support socializing and communication and which may enhance motivation [20] [23]. In relation to this point, adding some kind of beneficial peer pressure through a form of competition would have a positive effect while minimizing the development of any harmful peer pressure [23]. Furthermore, features such as receiving persuasive text messages that encourage physical activity would be a good motivator [23]. Additionally, in developing

technology that encourages physical activity, designers should be aware of the practical constraints of users' lifestyles. For example, if technology requires a physical device to be carried or worn, the everyday implications of this should be considered in the design of the device. Finally, the technology should provide reasonable goals that encourage a sustainable increase in physical activity [20].

IV. PHYSICAL ACTIVITY MONITORING TECHNOLOGY

4.1. Overview

A variety of activity monitoring technologies has been developed over the past decades. A recent study in 2014 illustrated the timeline of activity device development, starting from 1920, when the accelerometer was invented, until 2014, when new lifestyle smartwatches and fitness monitors were released [5]. In 2013, the physical activity monitors that gained around 97% of market share were Fitbits, Jawbone Ups and Nike FuelBands. Fitbit devices were the top-selling choice [26]. Each of these devices has a different capability, usability, functionality and measurements. Therefore, they are varied in their accuracy [5]. Furthermore, their methods of setting up, connecting with web or phone applications, synchronising data, connecting with other applications, battery length and customer support are varied [5]. They also have different ways to be worn or attached to human bodies. For example, some are designed as wristbands, where others can be clipped in users' belts, clothes or shoes [5] [6]. The accuracy of measurements is also affected by the location where sensor is worn [6]. For example, in order to measure whole-body movement, sensors are commonly placed in the waist area. The reason behind the use of this location is the proximity of the body's waist to the centre of mass of the whole human body. Therefore, it might be a good place to accurately detect the majority of human motions [6]. Furthermore, attaching wearable activity detectors to this area is easy and has a minimum of carrying discomfort [6].

4.2. Previous Studies

Much literature has used activity monitoring devices in their investigations [20] [21] [27] [28] [29] [30]. For example, pedometers are a popular monitoring device that have been utilized in eHealth interventions for the assessment of levels of physical activity. They have been used to track and record users' steps over a day [5]. Pedometers were also the first monitor used by health consumers [5]. In recent years, other new lifestyle activity monitors have been released to consumers in markets which had also started to be investigated and analysed by researchers [4] [5] [31] [32].

A study in 2011 has assessed the validity of a wristwatch, Smarthealth watch, as a heart rate monitor during rest and exercise in different intensities [27]. Results showed that a wristwatch is a valid monitor of heart rate during standing, walking and jogging. This would suggest that it is a handy tool for exercise intensity monitoring compared to the other methods that use chest straps to monitor the heart rate. However, the Smarthealth watch lost its validity in higher treadmill speeds (running). The reason behind the watch's inability to detect heart rates in higher intensity exercise may relate to the upper body parts involvement, which makes it hard to be detected via watch band [27].

Another study examined the accuracy of hipwear pedometers in measuring step counts, distances travelled and energy expenditure during treadmill walking at different speeds [28]. Results showed that the pedometer is a valid tool in the measurement of steps taken. Furthermore, step count recording is not affected by monitor placement position around the hip. However, pedometers are inaccurate in their assessment of distance travelled and energy expenditure in speed controlled conditions [28]. The daily step recordings of two sensors have also been compared either using different types of sensors (a pedometer and an accelerometer) [29], or the same sensor with different brands [30]. The two sensors were worn simultaneously in the same period under free-living conditions [29] [30]. A sample of 135 adolescent girls wore the two motion sensors on their waist for a one-week period. The aim of the study was to assess the step counts recorded by each device and to compare their outputs. Results showed a significant variability of step count recordings between the two motion sensors [29]. Furthermore, pedometers underestimated the step counts in individuals who spent greater time in lightintensity physical activity within free living environments [30].

4.3. Related Works

Different websites have evaluated physical activity tracking technologies based on customer reviews [33] [34], but a lack of published works in this regard has been found. However, in the last few years, many researchers have started to evaluate and assess the contemporary wearable activity tracking technologies used for the purpose of health and fitness [4].

Based on our knowledge, the first study in evaluating the most popular market activity monitoring technologies was published in 2013 [4]. Its evaluation included Fitbit Devices (Ultra, One, Zip), Nike+ bands (Fuelband, Sportsband), iPhone Move app and Mechanical Pedometer. This evaluation was based on the direct testing and application of these tools. The results showed that themost accurate steps recorded with the smallest margin of error (equal to 1%) was Fitbit [4]. Fitbit has other key features, including its API and Bluetooth connectivity. However, clip-in Fitbit devices are easy to drop and lose. On the other hand, in term of battery life, ease of wear and portability, it has been noticed that Fitbit and Nike+

monitors are more convenient in everyday lifestyles [4]. In 2013, another study tested the validity and reliability of Fitbit One monitors in a controlled environment using a treadmill device [31]. With a sample of 30 healthy adults, two 'Fitbit One' monitors were placed on the hips and one in the pocket during walking at five different speeds on a treadmill. The aim of the test was to assess the accuracy of Fitbit One in recording step count and distance travelled while walking on a treadmill at different speeds and placements of wear. Results demonstrated the validity and reliability of Fitbit One in recording step count for all treadmill walking speeds. However, the Fitbit One monitor was inaccurate in calculating the distance travelled as there was a significant difference between the criterion output of the treadmill and each Fitbit One monitor. Furthermore, the different placements of the Fitbit One monitor, whether on the hips or in the pocket, had no effect on the output of steps taken and distance travelled as recorded by the monitor [31]. In 2014, another study analysed five recent popular activity monitoring technologies: Nike Fuel Band, Fitbit Flex, Fitbit One, Jawbone UP and Basis[5]. In their evaluation, they considered usability, privacy and security aspects of these common activity monitors as well as a number of physiological and psychological parameters. Their investigation of these activity monitors were based on Nurse Practitioners' (NP) perceptions and patient implications. This study concluded that the usability of activity monitoring devices depends on individuals' needs; goals and condition [5].

A recent study in 2015 evaluated the top trading 2013 market fitness trackers, including Fitbit One, Jawbone UP and Nike+ Fuelband [32]. This work was based on the analysis of Amazon.com customer reviews of these devices. The ability of these devices to count steps, distance travelled and calories burned were assessed based on user satisfaction ratings. Different user insights were recorded. For Fitbit One, some users liked the email reminders warning of low battery charges, the ease of setting up and syncing the data as well as the ability of syncing Fitbit data with many other apps. Others reported the annoying issue of requiring the dongle to sync the data to PC or Mac, and the ease of dropping and losing this device because of its size and method of attachment to users. For Jawbone UP band, users recorded the silent vibrating alarm, Power Nap, Idle Alert and Jawbone UP app as good features. Others complained about the manual change of sleep-awake mode, the accuracy of sleep data, the customer service and the inability to sync the data wirelessly. Some users found that wearing the Jawbone UP band on their ankles would increase the accuracy of the trackers' data. Nike+ Fuel bands were motivating tools based on their NikeFuel score feature. However, they did not accurately track users' steps [32].

V. EVALUATION OF THE CURRENT TRACKERS

For the purpose of our ongoing research, we sought to find the best applicable physical activity tracking technology to be integrated with our framework. Tests have been done using our own trackers. These trackers include Fitbit One, Fitbit Flex, Jawbone UP, and Mobile Health App. Fitbit One is a small instrument that can be clipped inside users' clothes, such as in pockets or belts. Fitbit Flex and Jawbone UP are both bracelets being worn on users' wrists. Health App is an iPhone application where the phone needs to be carried during activities to track users' movements. Fitbit One has a small screen where users can instantly check their physical data, whereas Fitbit Flex data needs to be synchronized to Fitbit app in order to be read. Jawbone UP data is also displayed via a smartphone application after data synchronization. Health App is a free iPhone application that gives an easy-to-read dashboard of users' health and fitness data. The idea of choosing these trackers is to have different types of trackers being worn in different body locations in order to find the most suitable type and the most accurate one. The data that was collected from this test is free and simple, and not aimed to be analysed. Rather, different observations were recorded after these tests. Other structured tests with formal data analysis will be published in the near future.

5.1. Tests

Tests have been conducted over three weeks. In the first week, the author put on Fitbit One, Fitbit Flex and Jawbone UP from the morning until sleep time. For five days, with normal daily routines such as office-work, some walking and shopping, and some household chores, trackers recorded different results (Table 1). Except day 5, besides the daily routine, a 6 km distance walk was done.

Table1: Trackers' data for Week1

	Day	Steps	Distance
Fitbit One	Day 1	3897	2.64
Fitbit Flex		5692	3.85
Jawbone UP		5070	3.6
Fitbit One	Day 2	7252	4.91
Fitbit Flex		10018	6.78
Jawbone UP		10986	7.8
Fitbit One	Day 3	6423	4.35
Fitbit Flex		10013	6.81
Jawbone UP		11448	8.2
Fitbit One	Day 4	4665	3.16
Fitbit Flex		6123	4.15
Jawbone UP		6653	4.8
Fitbit One	Day 5	11590	7.85
Fitbit Flex		12724	8.61
Jawbone UP		13175	9.5

In the second week, four types of physical activity monitors were used, including Fitbit One, Fitbit Flex, Jawbone Up and Health iPhone app. These monitors were used to track walking activity over a specific distance. Based on iPhone Maps application, the walking route was determined and the distance was calculated. For five days, different routes with different distances were chosen. The results of the trackers are recorded in Table 2.

Table2: Trackers' data for Week2

	Day	Steps	Distance
Fitbit One	Day 1 3 km	4140	2.8
Fitbit Flex		4136	2.8
Jawbone Up		4127	3.04
Health App		3961	2.93
Fitbit One	Day 2 1.3 km	2037	1.40
Fitbit Flex		2013	1.36
Jawbone Up		2073	1.5
Health App		2003	1.48
Fitbit One	Day 3 850 m	1137	0.77
Fitbit Flex		1093	0.74
Jawbone Up		1117	0.8
Health App		1050	0.79
Fitbit One	Day 4 3.8 km	5408	3.69
Fitbit Flex		5383	3.64
Jawbone Up		5461	4.1
Health App		5210	3.98
Fitbit One	Day 5 2.84 km	4968	3.49
Fitbit Flex		4114	2.79
Jawbone Up		4119	3.1
Health App		4900	3.62

Several other activities were done in Week 3. On day 1, 2 and 3, walking on a treadmill with four trackers was set up. On day 4, the data was collected after a 30-minute scooter riding using Fitbit One, Fitbit Flex and Jawbone UP. On day 5, Fitbit One and Jawbone UP only were used to record physical data after about 45 minutes of soccer play. On day 6, the steps were counted manually and the results were compared with the output of the three tracking types. All data from this week is shown in Table 3.

Table3: Trackers' data for Week3

	Day	Steps	Distance
Fitbit One	Day 1 Treadmill data (2.5km)	3633	2.46
Fitbit Flex		3495	2.37
Jawbone Up		3553	2.6
Health App		3447	3.09
Fitbit One	Day 2 Treadmill data (3.4km)	4756	3.24
Fitbit Flex		4676	3.17
Jawbone Up		4679	3.5
Health App		4662	4.82
Fitbit One	Day 3 Treadmill data (3km)	4201	2.85
Fitbit Flex		4102	2.77
Jawbone Up		4139	3.1
Health App		3907	4.58
Fitbit One	Day 4 30 minutes Scooter Riding	2064	1.4
Fitbit Flex		2542	1.72
Jawbone Up		3358	2.5
Fitbit One	Day 5 Soccer Play	4876	3.30
Jawbone UP		5060	4.1
Fitbit One	Day 6 Manual Counter (1155 Steps)	1164	0.78
Fitbit Flex		1157	0.79
Jawbone Up		1160	0.70
Health App		1120	0.82

5.2. Discussion

In the first week, we particularly sought to make a comparison between the different trackers on normal days. As cannot be held mobile phones all the time with all activities, we ruled out the use of mobile phone applications. Three trackers had been used, including Fitbit One, Fitbit Flex and Jawbone UP. The author observed that wrist-band trackers always recorded more steps and distances walked than waistclip trackers during this week. This observation was true even when trackers had the same manufacturer (Fitbit One and Fitbit Flex). The reason behind this difference would be that jobs that depend on hand movements were more frequently undertaken than jobs that depend on whole body movements. Examples include kitchen work such as cleaning, cooking and washing. This may support the concept of waist-based trackers having the ability to detect whole body movements [6]. However, there was no standard body movement value that can be compared with our first week's results in order to determine the most accurate tracker. Therefore, there is no evidence to declare that Fitbit One showed the most accurate results. Nevertheless, our test demonstrates the differences between physical activity data depending on tracker location on individuals' bodies. The data also depends on the type of physical activity that users performed.

Unlike in the 1st week, during the second week, we aimed to compare the results of the trackers Study on Evaluating the Contemporary Active Living Technologies with a standard value. We used Maps Application to determine the route and the distance that was followed. Each day had a different route and a different distance. After walking each day, we compared the distance of each tracking device with the distance specified by Maps. Based on the collected data, on most days, wrist-band trackers recorded the nearest distance value to the standard distance. The difference between the standard distance value and the distance recorded by waist-clip and mobile app trackers was slightly higher, but also

minor. Following a structured type of exercise such as walking, as in this week's activity, should give a clear view of the accuracy of the physical activity detector. This point has been taken into consideration for our further investigation of activity tracking technologies.

In week 3, for the first three days we compared the distance output of a treadmill with distance recorded by the four trackers. The distance walked on each day was different. Based on the results of this activity, we found that Jawbone UP recorded the most approximate results and Health App recorded the most disparate results. For Fitbit trackers, Fitbit One was more accurate than Fitbit Flex. The difference in results here may not relate to the fact of where the tracker is attached to the user's body. It might depend on the tracker's mechanism to calculate the distance walked.

In scooter riding and soccer play, Fitbit trackers recorded less steps and distance output than Jawbone UP tracker. On the last day of this week, the author used a manual counter for step count while walking and compared it with the trackers' output. After counting 1155 steps, the most approximate results were recorded by Fitbit Flex (1157) followed by Jawbone UP (1160). The least accurate tracker in this activity was mobile Health App. Data from this week cannot be generalized or provide any valid finding as it is random and minimal. The idea was just to observe and decide which activity was best to follow for further investigation to find out the most accurate tracker.

Based on author observation, while sitting on a chair and moving legs only, the waist-clip tracker did not record any steps. In contrast, moving the hands without entire body movement led to a greater step count on wrist-band trackers. Therefore, assessing trackers that accurately measure the amount of physical activity in everyday routines is challenging. Instead, performing a structured type of physical activity and having a standard value to compare with could be a valid method to find the most accurate physical activity monitor. For example, in the last week's activity of treadmill walking, we obtained data from a walking activity with a specific distance to compare with. The distance walked calculated by each tracker can be compared with the treadmill distance output. Results of this activity showed that Jawbone UP band gave approximate results whereas Fitbit trackers (One and Flex) underestimated the physical data. In addition, Health app overestimated the distance walked compared to the distance showed by the treadmill. This finding inspired our interest to investigate more and do a further test which will be published in the near future.

CONCLUSION

While there was a lot of research into tracking technologies in the past, little has been conducted for the new design trackers released in recent years. In this paper, the authors observed a clear variation in different kinds of physical activity trackers based on their types and where they attach to human bodies. In addition, finding the most appropriate tracker requires determining the right type of physical activity and finding the best way it can be accurately monitored. The work presented in this paper helped us to determine the next step in this testing process, which will be based on a specific type of physical activity and determine the best monitor to accurately track it.

Physical activity monitors are a promising technological tool in motivating and facilitating active lifestyles. The recent rapid development of this technology warrants interest, testing and investigation by academics including ourselves, as part of our research into active living technology. For the purpose of integrating such tools into our future framework for active living technology for youth, we aim through this work to start investigating the current available popular devices. Some fundamental tests have been conducted using our own trackers and are detailed in this paper. This testing aims to record some observations in order to construct a more structured experiment whose results would help in determining the best available technology in tracking and monitoring levels of physical activity. We are planning in the near future to publish tests and data analysis and provide valid results that demonstrate the most accurate monitoring device in tracking a specific type of physical activity. Our findings after this step will help in the construction of a framework that integrates the best available technologies to facilitate active living in the young generation.

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