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Validation of Contemporary Physical Activity Tracking Technologies through Exercise in a Controlled Environment

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***Abstract*—**Extended periods engaged in sedentary behavior increases the risk of becoming overweight and/or obese which is linked to other health problems. Adding technology to the term 'active living' permits its inclusion in promoting and facilitating habitual physical activity. Technology can either act as a barrier to, or facilitate this lifestyle, depending on the chosen technology. Physical Activity Monitoring Technologies (PAMTs) are a popular example of such technologies. Different contemporary PAMTs have been evaluated based on customer reviews; however, there is a lack of published experimental research into the efficacy of PAMTs. This research aims to investigate the reliability of four PAMTs: two wristbands (Fitbit Flex and Jawbone UP), a waist-clip (Fitbit One), and a mobile application (iPhone Health Application) for recording a specific distance walked on a treadmill (1.5km) at constant speed. Physical activity tracking technologies are varied in their recordings, even while performing the same activity. This research demonstrates that Jawbone UP band recorded the most accurate distance compared to Fitbit One, Fitbit Flex, and iPhone Health Application.

***Keywords*—**Fitbit, Jawbone UP, mobile tracking applications, physical activity tracking technologies.

I. Introduction

SPENDING numerous hours engaged in sedentary behavior such as watching TV, playing video games and other screen-based activities may increase the risk of becoming overweight and obesity [1]. This health issue is linked to other health problems such as cardiovascular disease, diabetes, and cancer. Furthermore, childhood obesity is also associated with social and psychological problems such as depression and low self-esteem [2], [3]. Families, schools and communities are all responsible for preventing an epidemic, and have the opportunity to facilitate active lifestyles, by reducing the amount of screen time and increasing the levels of physical activity among young people [1]. Time at school can positively affect behavior, increasing the time spent in moderate to vigorous physical activity [4]. Physical education at schools and community recreation programs should receive attention because of their significant impact on the promotion of physical activity [5].

In order to promote a healthy life style, health institutions recommend a nutritious diet, regular physical activity and limited screen-based activities [1]. Minimizing the time spent on sedentary activities may help in decreasing the risk of poor health [6]. The current guidelines suggest a maximum of two hours a day as a screen time limit for children aged between 5 and 18 years [6]. Increasing physical activity and decreasing sedentary behavior has social, emotional and intellectual benefits [6]. For example, it reduces anti-social behavior, assists in the development of physical skills, and improves self-esteem and confidence [6]. Regular participation in physical activity is strongly recommended as it is linked to improved health outcomes and motor skills [7] and reduced risks of many diseases [6], [8].

Health institutions have set guidelines for physical activity for children and adolescents to be at least 60 minutes of moderate-to-vigorous physical activity per day [9], [10]. Adults aged between 18 and 64 should accumulate 150 to 300 minutes of moderate physical activity or 75 to 150 minutes of vigorous physical activity per week [6], or at least 150 minutes of moderate- to vigorous-intensity aerobic physical activity per week [10]. However, it has been reported that participation in physical activity has declined [11] across age groups between childhood and adolescence and has continued to decline with age [12]. For example, the time spent on moderate to vigorous physical activity drops significantly in children aged 12-15, compared to children aged 6-11, and had a further drop among adolescents aged 16-19 [12]. A study in the US showed that only 42% of children met the recommendation of 60 minutes physical activity [12]. Furthermore, the adherence to physical activity recommendations was common in only 6-8% of adolescents, and less than 5% among adults [12]. Apart from age, physical activity also differs between weekdays and weekends as a result of the differences in locations and therefore affects the intensity of daily physical activity [4].

Different barriers have been identified that can discourage children and adolescents from engaging in physical outdoor activities. This in turn impacts on their levels of physical activity. These barriers include unsafe neighborhoods [5] or poor weather conditions. More complex social barriers include lack of time and energy for children to play outside or a lack of parental time and energy for facilitating children's exercise [13]. It has been reported that sedentary behaviour has become more common, especially among adolescents [11].

The number of steps taken by a person is an essential measurement in quantifying daily physical activity [14], [15]. The recommended daily steps for children and adolescents is

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12,000 steps for girls and 15,000 steps for boys [16], and 10,000 steps for adults [15]. A large number of steps leads to greater health benefits [15]. The literature specifies the steps per day scale for each age group and links this specification to time spent engaged in moderate-to-vigorous physical activity [17], [18]. For example, the daily recommendation of 60 minutes of moderate to vigorous physical activity is equivalent to?? 10,000 - 14,000 steps/day in preschool children, 13,000 - 15,000 steps/day in male school children, 11,000 - 12,000 steps/day in female school children, and 10,000 - 11,700 steps/day for adolescents [17]. Furthermore, the daily recommendation of 30 minutes moderate to vigorous physical activity in healthy older adults is associated with approximately 7,000-10,000 steps/day [18]. It has been demonstrated that advising the exact number of 10,000 steps per day leads to a greater walking volume compared to the recommendation to walk briskly for 30 minutes [19].

Reaching the recommended amount of daily steps (10,000 steps) for adults can be achieved through a variety of daily activities including walking and other sports and home activities [15]. Measuring the numbers of daily steps is possible with the available variety of PAMTs; for instance a pedometer is one of the most common tools used by researchers for this purpose and has been tested under free-living [20], [21] and controlled [14] conditions. A pedometer is a motion sensor device that is able to record individuals' physical daily steps, and is able to measure the intensity of physical activity [20].

Recording objective measurements of physical activity is made possible through the use of electronic motion sensors [20], which are considered to be an effective tool for measuring the daily steps of adolescents. However, different factors affect the validity of motion sensor devices, such as targeted population and the type, intensity and accessibility of physical activity [20]. The accuracy and reliability of motion sensors in recording movement data are important factors that have been considered in the literature. For example, researchers have agreed that the accuracy of a physical activity monitoring device is affected by the intensity of activity and walking speed [14], [22]. Some studies have also reported that higher intensity exercise reduces the ability of wrist band monitors to detect the wearer's pulse [22]. Others have revealed that low walking activity speeds are not accurately recorded by monitors in terms of distance [23] and energy expenditure [14]. In contrast, the concept of accuracy may differ with the new released physical activity tracking devices. Many PAMTs have been released in recent years. For example, Fitbit trackers are new tracking technology released in recent years and which have gained popularity in markets. A recent 2014 study showed that the step counting of the Fitbit monitor was valid and reliable at multiple walking speeds [23].

As part of our on-going research agenda in active living technology adaption and use, we found a growing variety of PAMTs on the markets. Based on our primary aim to integrate an activity tracking device into our previous 'MySteps' framework, the issue of choosing the most appropriate contemporary activity tracking technology was raised. While there is much literature that has assessed the validity and reliability of physical activity monitors, such as pedometers and accelerometers, little experimental work has been done with the new generation of activity tracking technology. We aim through the work presented in this paper to test the most popular PAMTs and to identify the one that best suits our application. This work assessed the reliability of some of the current available physical activity monitors: Fitbit One, Fitbit Flex, Jawbone UP and Health iPhone application for recording the distance travelled. Our objective was to investigate the tracking devices in their ability to record distance travelled while walking a specific distance on a treadmill at constant speed. We further looked at features like accurate recording, ease of use and applicability in everyday lives. The concept of wearing multiple devices concurrently is supported by other physical activity research [20], [23], [24]. In line with protocols outlined in previous literature, our assessment of physical activity trackers, presented in this paper, has been done.

This paper starts with a brief background of the influence of technology on physical activity. Section III provides a specific overview of physical activity tracking technologies followed by review of the previous literature on related work in the assessment of the new generation of physical activity trackers. Section V describes our contribution in this study including research questions, the experimental test, trackers used, methods followed, data and analysis, and results and findings. Our future direction is briefly provided at the end.

II. Influence of Technology on Physical Activity

The world of technology has rapidly advanced over the last decade. This development includes a list of different commonplace technologies such as smartphones, tablets and wearable technologies [25]. Young people enjoy using technology and digital devices, and are highly proficient Internet users and online explorers. Close to nine in ten US teenagers are internet users [26]. Examples of Internet use include playing games online, making purchases, communicating with friends, sharing links, photos and videos, getting news, and seeking information [26], [27]. The proportion of Australian households with access to the internet at home increased, from 64% in 2006-07 to 79% in 2010-11 [28]. Most reported using the Internet daily [28]. Based on a recent report published in 2015, 92% of teens report going online daily [27]. The advancement of technology has facilitated the use of Internet. For example, smartphones - with their convenience and constant access features – facilitate constant and daily use of Internet [27]. It has been reported that teens who do not access the Internet via their mobile devices are going online less frequently [27]. Information and communication technologies are widespread amongst young people [26], [27].

Technology-based interventions have become widely used for different purposes, including health promotion [29]. There are many eHealth interventions which have been designed for physical activity and behavioural change [29]. Research in promoting and maintaining levels of physical activity, proposed and have applied a variety of interventions [30]-[34]. Different technologies have been used for physical activity promotion including PAMTs such as pedometers and accelerometers, Global Positioning Systems (GPS), Geographic Information Systems (GIS), interactive video games, persuasive technology, and Internet-based physical activity interventions [35].

A variety of activity monitoring technologies have 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 [36]. Wearable PAMTs have become popular in the last few years. Different monitors have different mechanisms of tracking, calculating, recording and measuring physical movements [37]. These kind of devices have the ability to monitor users' daily physical activity, measuring the steps taken, distance travelled, calories burned, stairs climbed and the wearer's sleep patterns [24]. These monitors have been utilized in eHealth interventions for the assessment of levels of physical activity. They also have been investigated as motivational tools for physical activity and exercising. The literature suggests that the use of physical activity monitors such as pedometers is associated with significant increases in physical activity [38]. Furthermore, integrating physical activity monitors with self-guidance interventions may be an effective strategy to promote physical activity in middle-aged or older individuals [39].

Accelerometer-based technology is also a type of PAMTs. This technology records body acceleration and provides data related to physical movement such as frequency, duration, intensity, and patterns of movement [35]. The literature reports that this technology has been utilized in describing the levels of physical activity among different age groups [12]. A variety of new physical tracking devices have been developed based on accelerometer technology in tracking and recording body movements [35].

The effectiveness of using new lifestyle wearable monitors along with short message service (SMS) text-messaging has prompted an increase in physical activity in overweight and obese adults [40]. A recent study in 2015 demonstrated that Fitbit One was able to achieve a small increase in moderate to vigorous physical activity from baseline to week-6 follow-up among a sample of overweight and obese adults [40]. However, using both Fitbit One and three daily SMS-based prompts to undertake physical activity were associated with increased physical activity in the first week only. This effect was not sustained until the end; indeed it was lost by Week 2 of the 6-week intervention [40].

Portable GPS technology is also reported on in the literature to track a specific activity by calculating a geographic location and providing information, such as altitude, distance and time [35]. GIS technology has also been used by researchers in the field of physical activity [4]. A study in New Zealand used GPS, GIS and accelerometer technologies to describe the location and intensity of daily physical activity among adolescents [4]. Integrating GIS with GPS and accelerometer technologies has offered significant help for collecting adolescents' data and understanding the possible factors that affect physical activities of this population, including the location, duration and intensity of physical activity [4].

Active video gaming technology has also been reported as a motivation for exercising and increasing levels of physical activity [35], [41]. Researchers have widely utilized this technology within the context of physical activity motivation and promotion [42]-[44]. 'Exergames' have been developed with the primary aim of motivating people to exercise by providing a safe, entertaining and engaging fitness experience [45]. Moreover, interactive technology-based interventions have the potential to be harnessed in health fields [30], [34]. A study in the area of physical activity promotion supports the argument for the effectiveness of using interactive hand-held computer technology especially over the early behavioural adoption period among underactive adults [30].

In order to promote levels of physical activity, a variety of mass-media campaigns have been successfully applied, including print media and/or telephone based programs, and other information and communication technology approaches [31]. Others supported the development of persuasive technologies to encourage regular participation in physical activity [32]-[34]. Such technologies have been developed as a system that combines different technologies for the purpose of behavioral change. For example, UbiFit and Houston are systems that are based on the union of a mobile application and a physical activity monitoring device [32], [46], [33], whereas Fish'n'Steps is a social computer game with a monitoring device [34].

Internet-based physical activity interventions have been the subject of a wide range of researchers [47]-[50]. While some research reports reveal that there is a limited evidence of the effectiveness of Internet-based interventions designed to promote physical activity [47], others agree that Internet– and Website–based physical activity interventions have a significant effect [48]. A recent literature review of Internet– and Website–based physical activity interventions has shown that 44 of 72 reviewed studies (61.1%) reported significant increases in physical activity [48].

Internet and web-based interventions have been investigated for the purpose of delivering physical activity behaviour change [49]. Using the Internet and a web delivery mode targeting physical activity behaviour may have the potential of wide-scale promotion of physical activity. Furthermore, it includes attractive features, such as being accessible at anytime and anywhere with an acceptable cost [47], [49]. In general, Internet and web-based interventions have positive behavioural outcomes on physical activity [49]. Using greater than 5 interactive intervention elements such as e-mail, chat sessions, discussion groups and online coaches and videos can also encourage a further positive change in physical activity compared to those with five or fewer contacts [49]. However, this mode of delivery is challenging in terms of long term engagement and retention of participants [49].

Using Internet and mobile phone technology in physical activity programs has been comprehensively evaluated. For instance, a 9-week test, using a system of Internet, email and mobile phone behavioural change, along with a wrist-worn physical activity monitor, demonstrated the effectiveness of using such technology in increasing and maintaining levels of physical activity in healthy adults [50]. Using mobile phones and pedometer technology to encourage physical activity among teenage girls is also supported in this context [13].

III. Physical Activity Trackers

A. Physical Activity Types

Many efforts have been made to develop physical activity guidelines for different age groups including children, youth, adults and the elderly [10]. Health organizations around the world are all agreed on the benefits of physical activity for people's health. Individuals of all age groups should be encouraged to participate in daily physical activity that is enjoyable and safe [10]. Walking is an effective method of increasing individuals' levels of physical activity [51], [52]. Walking 10,000 steps for adults is translated to about 8 kilometers or 5 miles, and it burns 300 to 400 calories [15]. Interventions delivering physical activity promotion are more effective if integrated with walking promotion and provide motivation for physical activity [52]. Research shows that walking programs that integrate physical activity monitors such as pedometers resulted in an increase of individual's step count [53].

A motion sensor such as accelerometer is able to detect dynamic movement in whoever wears the device [54]. So far, studies have used this type of activity to assess the accuracy and reliability of motion sensors in measuring the data related to this physical activity such as number of steps [23], [55]-[63]. For these studies, walking activity has either been outdoors in a specific-distance track [55], [56], [61], [63] or indoors on a treadmill [23], [56]-[59], [61]-[63]. Walking on a treadmill is a type of physical activity that can be monitored using physical activity trackers. Researchers have investigated the validity and reliability of activity trackers by monitoring people wearing these devices and walking on a treadmill [23], [57]-[59], [61]-[63]. Simulating actual walking behavior by changing the walking velocity during a trial (variable-speed treadmill condition) has also been conducted [62].

Based on the effect of walking on levels of physical activity, and the ability of physical activity trackers to effectively monitor this type of activity, walking was selected as the physical activity used in this study. This study aims to examine the reliability of four popular trackers while performing a walking activity. This research followed the procedures outlined in previous research that investigated the accuracy of motion sensor devices while walking on a treadmill [23], [57]-[59].

B. Physical Activity Monitors

Physical activity monitors are used within different contexts and for different purposes. This kind of technology is used in fields of obesity prevention and treatment, sports, fitness and performance enhancement training, and other health-related matters [64]. This technology has also been used in the assessment of physical activity levels [12] and it is considered a possible motivating tool for increasing levels of physical activity [38]. Physical activity monitors have been classified into six main categories: pedometers, foot-based monitors, accelerometers, HR monitors, combined accelerometer/HR monitors and multiple sensor systems [64]. Different considerations should be taken when choosing the most suitable wearable monitors for measuring physical activity. Factors that need to be considered include the type of physical activity to be studied, the reasons for conducting the research, the characteristics of the participants, and the shape of the study in terms of resources and time [64].

This study is a part of continuous research into active living technologies for the promotion of physical activity levels. The author seeks to find the most suitable physical activity monitor to be integrated with a previously developed active living framework, called MySteps [65], [66]. The aim of the integrated framework is to manage youth screen time versus physical activity, as well as promoting increased levels of physical activity. The targeted population is adults. The selection of suitable physical activity monitors was based on all of the previous mentioned assumptions. In addition, we aimed to find the most popular, accessible, affordable and applicable tracking technology for adults.

In 2013, the physical activity monitors that had gained around 97% of market share were Fitbits, Jawbone Ups and Nike FuelBands; Fitbit devices were the top-selling choice [67]. In 2015, Fitbit and Jawbone brands were considered to be the best fitness trackers [68], [69]. These two brands are popular among the younger generation, easy to purchase and at a reasonable price. Therefore, we focused on those two brands in our selection. In terms of the applicability features, we aimed to make our selection have three different types of monitors in terms of their ways of attachment to individuals' bodies. We included wrist-band, waist-clip and a mobile application tracker in our selection.

C. Physical Activity Measurements

PAMTs, regardless of their accuracy and reliability, have the ability to measures different components of physical activity. These components include total physical activity, duration, frequency, and intensity of physical activity, sleep and awake activity, different levels of physical activity, estimation of energy expenditure and classification of activities such as walking, jogging and running. Furthermore, they are able to record the steps taken, as well as the speed and distance travelled. Some are also able to recognize posture such as lying, sitting and standing [64].

Step count is a key component of walking [18] and one of the most common measurements in quantifying levels of physical activity [15]. Physical activity trackers are able to calculate the number of steps a person performs during his/her physical movements. Using step counts measurements as a recommendation to walk has a greater effect on completion, compared to the traditional walking instruction of taking a brisk 30-minute walk [19]. An accurate count is needed for determination of an individuals' levels of daily physical activity. Much of the literature has investigated the reliability of pedometers in counting steps [55]-[57], [59], [61]-[63]. Others have also assessed the performance of the step count function using an accelerometer [58], [59], [61]. Using different types of physical activity trackers during the same activity have also been conducted in order to compare the output results [59]-[61]. The accuracy and reliability of pedometers is varied, depending on the internal mechanisms and sensitivity of the model and brand [55], [63]. Furthermore, walking speed affects the accuracy and reliability of pedometers in steps counting [57], [59]-[61], [63]. Pedometers were not as accurate in step counting at slower speeds [57], [59]-[61], [63], but the accuracy is improved at faster speeds [57], [60]. However, reaching a faster speed such as (161 m/minute or 6 miles/hour) causes more errors in recording steps [63]. A recent study in 2014 agreed that slower and faster treadmill speeds both affect the accuracy of pedometers in recording steps count [63]. The accelerometry-based tracking method is a less speed-dependent and more accurate detection of step activity [60], [61]. In the healthy adult population, it has been shown that accelerometer-based devices are valid and reliable for measuring steps [61]. Results from a study which evaluated the activPAL monitor, which contains a uni-axial accelerometer, demonstrated that this monitor is valid and reliable for measuring the number of steps taken, with an absolute value of percentage error of less than 1.2% regardless of walking speed and surface [61]. The appropriateness of the accelerometry-based tracking method has also been demonstrated in patients with slower gait and smaller steps while walking straight-line trajectories of 5 metres or longer [60]. Fitbit One has also been demonstrated as a valid and reliable device in recording step counts, with a percentage relative error below 1.3%, for all treadmill walking speeds [23]. This means that in contrast with pedometers, Fitbit One accuracy in step counts does not decrease at slower walking speeds [23].

Distance travelled is another measurement that is shown by many PAMTs. Previous studies have used this parameter to examine the accuracy of a monitoring device [23], [56], [57]. A distance walked comparison was done after walking a specific distance and wearing different pedometer models simultaneously [56], [57]. While pedometers provided a reasonably accurate estimate of the distance walked, a significant difference in distance walked between pedometers was shown, depending on sensitivity of the model and brand [56]. The stride length, the sensitivity of a pedometer and the accuracy in steps count all affect the distance calculated by the pedometer [57]. Furthermore, the speed of walking is an important factor that should be considered in examining the accuracy of a motion sensor [57]. It has been demonstrated that some pedometer brands were more accurate than others at slow-to-moderate speeds [56]. Pedometers tend to overestimate the distance at slower speeds and underestimate the distance at faster speeds [57]. In terms of distance, it has also been demonstrated that the Fitbit One monitor is inaccurate in measuring distance travelled, particularly at slower walking speeds [23].

Energy expenditure is one of the physical activity measurements that is estimated by many types of physical activity monitors. Accelerometers have been evaluated in the literature regarding their estimation of energy expenditure [70]-[72]. A tracking technology combining a shoe-based activity monitor with accelerometer and pressure sensors has been developed and validated [73]. Using this type of tracking technology led to an accurate prediction of energy expenditure during typical physical activities [73]. The energy expenditure measurements estimated by different wearable activity monitors have been investigated and compared [72]. This comparison included several consumer and research wearable monitors which were demonstrated to display a wide range of accuracy when estimating energy expenditure [72].

In this study, the researcher was only focusing on distance walked measurement and excluding steps taken and energy expenditure. Steps taken and energy expenditure require a valid measurement instrument whereas distance walked requires only the specification of a correct distance. Furthermore, it was predicted that different factors could affect the measurements of steps taken such as the length of person's steps, which varies between people as it may be affected by individuals' height, weight and age, or even by walker's mood and wellbeing. The idea of investigating the accuracy of monitoring devices in measuring distance walked has previously been conducted by researchers [24], [23], [56], [57].

D. Accuracy of PAMTs

Different factors have been suggested that may affect the accuracy of physical activity tracking technologies. The accuracy and reliability of a physical activity tracker depends on the internal mechanisms and sensitivity of each model and brand [55]. Physical activity intensity, which is translated into walking speed in walk activity [61], is an important factor worth investigating. Previous research has examined the effect of walking speed in validation for physical activity monitors [23], [56], [57], [59]-[62]. Physical activity duration in walking activity is determined by a daily total of step numbers, time, or distance [61]. In terms of distance, some revealed that the accuracy of physical activity tracker is decreased significantly as walking distance decreased [60]. The location of where the physical activity tracker is worn on the wearers' body has also been considered in the validation assessment of PAMTs [23], [62], [63]. For example, placement of the pedometer has little effect on validity except for the pants pocket pedometer location [62], [63], which produced a random error equal to 5.8% compared to hip mounting random error which was 1.2% [62]. Researchers have placed pedometers in different body locations, including the waist, chest, armband, a pocket and in a handheld purse while walking at different treadmill speeds. This kind of research has demonstrated that most were accurate when placed at the waist, chest and armband for all walking speeds [63]. However, the accuracy is decreased when some were placed in a pocket or a purse, especially at slower and faster walking speeds [63]. In contrast, the placement of Fitbit One monitor has no effect on the validity and reliability of the device [23]. The reason behind this contrast may relate to the type of the monitoring technology used, so not all trackers are affected by the placement location [23]. The accuracy of a monitor may also appear reliable in one measurement while not in the others. For example, some pedometers are most accurate for assessing steps and less accurate for assessing distance [57].

In the experiment of this research, the author measured the reliability of selected tracking devices with the following constraints. Firstly, the effect of variable speeds on the monitors' accuracy was not considered. Therefore, a constant speed was set throughout the treadmill walking of all trials. Secondly, a fixed distance value was set, which was the same for all the trials in order to have a replicable and comparable set of data and therefore increase the validity of the results. Thirdly, the placement location of each tracking device was considered, as the test included three different wearing based.

E. Features of PAMTs

In order for PAMTs to be a good motivator for physical activity, they should have the suitable features for the purpose. For example, there is a problem with currently available activity tracking technologies in their inability to track all types of physical activity. For example, pedometer devices can record steps taken while walking or running but cannot monitor activities such as swimming and cycling. Consequently, monitors should be able to record the most common physical activities undertaken by their targeted users [33]. Furthermore, having a monitoring technology that saves the users' past record and the current physical activity levels with respect to their goals is recommended [33]. Use of minimal body-fixed instrumentation is also necessary for long-term measurements in everyday life [60]. Beside the accuracy of a physical activity tracker, it should also include activity tracking and feedback and a reminder feature for users to remain active [63].

In recent years, new designs of physical activity trackers have been released. Examples include Fitbit, Jawbone Up and Nike+ trackers. Fitbit trackers are gaining high interest and being one of the top sale trackers [67]-[69]. Fitbit trackers include features, such as its API and Bluetooth connectivity. However, clip-in Fitbit devices are easy to drop and lose because of its size and mode of attachment to users [24], [74]. 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 for everyday lifestyles [24].

Based on user insights, different features were recorded. For Fitbit One, some users positively rate the email reminders 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. Other customers are annoying for requiring the dongle to sync the data to PC or Mac [74]. For Jawbone UP band, users liked the silent vibrating alarm, Power Nap, Idle Alert and Jawbone UP app. Other users do not like the manual change of sleep-awake mode, the accuracy of sleep data, the customer service and the inability to sync the data wirelessly. Nike+ Fuel bands were motivating tools based on their NikeFuel score feature. However, they do not accurately track users' steps [74].

IV. Previous Literature

The literature reports that much work has been done in the area of evaluating physical activity tracking technologies. Work has been varied, based on the technology used and the aspect specifically investigated. Some researchers focused on usability, privacy and security aspects of the common activity monitors as well as a number of physiological and psychological parameters within health context [36]. Others examined the validity and reliability of popular physical activity monitors based on experimental data [23].

Research was conducted in 2013 in order to evaluate the most popular market activity monitoring technologies [24]. The evaluation included Fitbit Devices (Ultra, One, Zip), Nike+ bands (Fuelband, Sportsband), iPhone Move app and a Pedometer. A method of direct testing and application of these tools was applied by wearing multiple devices at the same time while walking a specific distance on a running track. The results showed that the most accurate steps recorded with the smallest margin of error (equal to 1%) was Fitbit [24].

In 2013, a study tested the validity and reliability of Fitbit One monitors in a controlled environment using a treadmill [23]. With a sample of 30 healthy adults, two 'Fitbit One' monitors were placed on the participants: one on the hips and the other 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 the step count and distance travelled while walking on a treadmill at different speeds and placements of wear. The 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 [23].

In 2014, another study analysed five recent popular activity monitoring technologies: Nike Fuel Band, Fitbit Flex, Fitbit One, Jawbone UP and Basis [36]. This investigation was based on Nurse Practitioners' (NP) perceptions and patient implications. This study concluded that the usability of activity monitoring devices depends on the individuals' needs; goals and condition [36].

A recent study in 2015 evaluated the top-trading 2013 market fitness trackers, including Fitbit One, Jawbone UP and Nike+ Fuelband [74]. This work was based on the analysis of Amazon.com customer reviews of these devices. Furthermore a user satisfaction ratings was considered in the assessment of these devices [74]. A review of a total of 3,241 Amazon.com customer reviews of the three tracking bands has been conducted. Statistics resulting from the evaluation described the public satisfaction of devices' performance in terms of steps counter evaluation, distance travelled evaluation and calories burned evaluation. In steps counter evaluation, the three devices recorded a positive satisfaction among the public sentiment, with a significant satisfaction of Fitbit One followed by Jawbone Up and then Nike+ Fuelband. In distance travelled evaluation, Nike+ Fuelband received the most positive satisfaction followed by Fitbit One and Jawbone UP, which both gained similar levels of satisfaction. Regarding calories burned evaluation, both Fitbit One and Jawbone Up recorded relatively high satisfaction while the Nike+ Fuelband had significantly less positive-to-negative mention ratio compared to the two other devices [74].

V. Evaluation Of the popular trackers

A. Problem Statements and Research Questions

This paper reports on on-going research agenda into active living technology. As we planned to integrate physical activity tracking technology into our active living framework, there was a need to find the best available technology in terms of accuracy, reliability and applicability. We aim to address two problems through this research:

- The lack of evaluation of currently available physical activity tracking technologies regarding their ability to record distance walked accurately.
- Physical activity tracking technologies have different methods of attachment to individuals' bodies. Some are worn as wrist-bands and others are attached to users' clothes by being clipped to the chest, waist or shoes. In addition, there are some tracking technologies that take the form of software applications that can be installed on a person's mobile phone or tablet. With this variety of options, the differences in physical activity data showed in each tracker should be assessed.

The following research questions have been specified:

- What is the most reliable physical activity tracking technology that most accurately and reliably records the distance walked?
- Is there a difference in the physical outputs recorded by different activity tracking technologies worn simultaneously in different body locations while walking for a specific distance?

B. Physical Activity Trackers Used

In this research, four PAMTs were used: two wristbands (Fitbit Flex and Jawbone UP), a waist-clip (Fitbit One) and a mobile application (iPhone Health Application) for recording a specific distance walked on a treadmill (1.5km).

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 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 the 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.

Throughout the tests, Fitbit Flex and Jawbone UP were worn on the left wrist, while Fitbit One was attached on the waist. For the iPhone Health App to be used, the iPhone was carried in the right hand while walking on the treadmill. The idea of attaching different trackers at the same time while performing one activity to measure the differences between trackers' output data was inspired from previous literature.

C. Method

With the need to check the devices' reliability and accuracy in recording the distance walked, a specific distance measurement was set as a standard value for comparison. A treadmill walk is a useful type of activity that can be monitored and given a specific distance value. Following the methods reported in other literature [23], the four trackers were tested while walking on a treadmill for a specific distance.

The research took place over 15 days. On each day, three trials were performed (t=45 trials). Each trial was a 1.5km walk on a treadmill and the four PAMTs were worn simultaneously. On each round, the author put on the four devices, started on the treadmill, walked for 1.5 km, stopped the treadmill, and recorded the output of each tracker before resetting the distance and starting over the next trial. By the end of the test period, the distance recorded by each tracker was compared with the treadmill output.

D. Data and Analysis

The data was collected over 15 days for analytic purposes, in order to get valid results of the most reliable device in recording distance walked among the four monitors that were used in this study. The first analysis test was a Shapiro-Wilk W. This test was conducted to see if the outcome variable, distance walked, was normally distributed, so the appropriate parametric or non-parametric test for the differences between each tracker may also be determined.

Based on the results of the Shapiro-Wilks test, the outcome variable "distance walked" is skewed ($W=0.64$, P value <0.0001). The Median = 1.5 km; IQR = 0.1 km; Positively Skewed. The detail of this test is provided in the appendix.

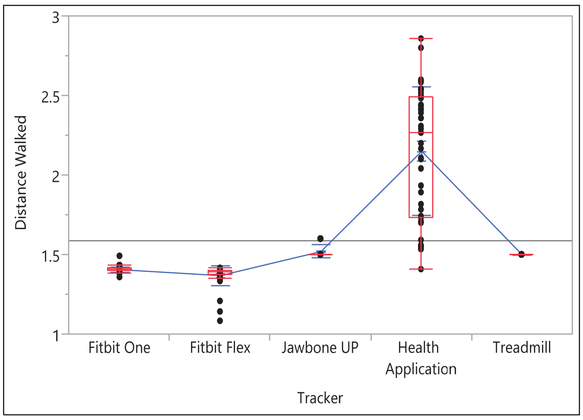

Fig. 1 Boxplots of distance walked by tracker – One-way Analysis

The second test was conducted to see if each tracker was different from each other and different from the treadmill's set distance of 1.5.km. Because the distribution of distance walked is skewed, the use of Kruskal-Wallis Tests (Non-parametric equivalent to ONE-WAY ANOVA) was required. Fig. 1 shows the boxplots of distance walked by each tracker. This figure demonstrates the differences between trackers in recording the distance walked. The variations of the recorded distance in each tracker's output over the whole days of experiment is also shown. Table I gives a specific look at the statistics generated for each tracking device. The mean, median, standard deviation, Interquartile Range of each device is described in the table.

TABLE I
DESCRIPTIVE STATISTICS

Level	Number	Mean	Median	Std Dev	Interquartile Range IQR (Spread)	Shape
Fitbit One	45	1.40844	1.41	0.019881	0.02	+ve Skewed
Fitbit Flex	45	1.37156	1.39	0.065815	0.025	-ve Skewed
Jawbone UP	45	1.52222	1.5	0.042044	0	+ve Skewed
Health App	45	2.15356	2.27	0.401311	0.76	-ve Skewed
Treadmill	45	1.50000	1.5	0.000000	0	

TABLE II
1-WAY TEST, CHI-SQUARE APPROXIMATION

ChiSquare	DF	Prob>ChiSq
201.1951	4	<.0001*

Based on the p value shown in Table II (P value is less than (<.0001)), the tracking devices were different in their distance recordings. Therefore, a further sub-test, using Steel-Dwass method, was conducted in order to show where the differences exist between the trackers, as shown in Table III. Table III specifies the differences between each trackers' data and all other trackers.

E. Results and Discussion

1. Reliability

From the data collected and the statistical analysis, two main results can be drawn. Firstly, there is a clear evidence of differences between the different trackers' output and between each tracker's output and treadmill output, in term of the distance walked. This means that the distance walked recorded by each device was different from the output of the treadmill. In addition, the data recorded from each tracker were different ($p<0.0001$).

TABLE III
STEEL-DWASS TEST RESULTS

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
Jawbone UP	Fitbit One	44.9778	5.325111	8.44636	<.0001*	0.100000	0.090000	0.11000
Jawbone UP	Fitbit Flex	44.9778	5.329868	8.43882	<.0001*	0.120000	0.110000	0.14000
Treadmill	Fitbit One	44.9778	5.137170	8.75536	<.0001*	0.090000	0.090000	0.10000
Treadmill	Fitbit Flex	44.9778	5.142101	8.74697	<.0001*	0.110000	0.100000	0.12000
Health Application	Fitbit Flex	44.7778	5.497497	8.14512	<.0001*	0.890000	0.540000	1.05000
Health Application	Fitbit One	44.1111	5.492021	8.03185	<.0001*	0.870000	0.500000	1.02000
Health Application	Jawbone UP	40.3111	5.339229	7.54999	<.0001*	0.770000	0.390000	0.91000
Treadmill	Jawbone UP	-9.9778	2.998127	-3.32800	0.0078*	0.000000	0.000000	0.00000
Fitbit Flex	Fitbit One	-26.7333	5.433998	-4.91964	<.0001*	-0.020000	-0.030000	-0.01000
Treadmill	Health Application	-42.9778	5.151803	-8.34228	<.0001*	-0.770000	-0.930000	-0.39000

Secondly, it appears that the most reliable tracker was the Jawbone UP because it had a mean closest to the treadmill (Median = 1.5; Mean = 1.52222) and the smallest Interquartile Range (IQR) of all the trackers (IQR=0.0). In contrast, the least reliable tracker was the iPhone Health Application (Median = 2.27; Mean=2.15356; IQR=0.76). This means that the Jawbone UP gave the more consistent distance compared to the other three trackers used in this experiment.

The Fitbit devices (One and Flex) were slightly different in their outputs compared to each other. By comparing Fitbit results to the treadmill output, a small difference was recorded based on the median of both devices and the median of the treadmill. Fitbit One was the second most accurate device in its output (Mean = 1.40844; Median = 1.41; IQR = 0.02) followed by Fitbit Flex (Mean = 1.37156; Median = 1.39; IQR = 0.025).

2. Validity

Based on data analysis, Jawbone UP and Fitbit devices are both valid in tracking the distance walked under controlled conditions. Our finding is similar to a previous study [24] in the validity of Fitbit tracking devices. Researchers of this study [24] stated that the Fitbit device provided the most accurate results with the least variability, which is in contrast to our findings that the Jawbone recorded the most accurate results. However, they did not include the Jawbone UP in their experiment and were only comparing their Fitbit devices to Nike+ Fuelband, Nike+ Sportband/Motion, iPhone Moves App and a Mechanical Pedometer [24]. Another study assessed the public satisfaction of three tracking devices, Jawbone UP, Fitbit One and Nike+ Fuelband in their performance of recording the distance walked [74]. Nike+ Fuel band gained the most positive satisfaction in recording distance walked, followed by Fitbit One and then Jawbone UP. They claim that a good estimation of distance recording is affected by a good performance in steps counting. The three devices do not have location sensors and the distance is estimated based on users' personal information [74]. However, their findings were based on public sentiment evaluation and not on experimental evaluation [74]. Furthermore, our results do not support the findings of a previous study in validating Fitbit One [23]. In this study it has been reported that the Fitbit One monitor was highly reliable but inaccurate in calculating the distance travelled as there was a significant difference between the criterion output of the treadmill and each Fitbit One monitor [23]. However, their explanation of inaccuracy was related to the step length and reported that it is also influenced by walking speed, particularly at slower speeds [23]. According to our data, there were no significant differences in Fitbit recording of distance travelled compared to the treadmill. However, we should keep in consideration our test conditions demanded a constant high walking speed.

Our findings demonstrate the variations of trackers' distance recordings and the output differences between each tracker and the treadmill while performing the same activity. Data that has been collected over 45 trials indicates that the Fitbit devices showed a slight underestimation of distance travelled while Health application showed overestimated distance. Jawbone UP showed the most accurate distance compared to the other devices. Consequently, based on our results and analysis, the Jawbone UP and Fitbit devices can be considered as useful tools in recording distance travelled while walking on a treadmill at constant higher speed. However, the validity of these devices may vary while performing different physical activities with different intensity and conditions.

3. Applicability

Based on our observations while performing the tests of this experiment, different points have been recorded for the ease of applicability for each device. We found that using either wrist-band trackers or waist-clip trackers are most suitable for walking activity. Holding a device in our hands while walking caused mild levels of discomfort and affected our ability. Even in our everyday activities, using a mobile device based physical activity tracking such as mobile applications would not be suitable because of users' inability to hold devices all the time. Waist-clip trackers may also be affected by the clothes style and material. We cannot guarantee that suitable clothes will also be worn where clip-based trackers can be attached on the waist area all the time. For wrist-band trackers, it was observed that they are a suitable method of placement except in home duties. Using a wrist-band tracker that is not waterproof while washing dishes or cleaning may cause device damage.

4. Limitations

This research has a number of limitations. Firstly, the research was undertaken by only one person. Furthermore, the time limitation is worth mentioning, as this experiment is part of a major research project, which aims to develop an active framework. Using a specific type of physical activity, walking on a treadmill, limits the demonstrated validity of trackers used in this research. A reliable tracker in distance walked recordings may not be valid for other types of physical activity, such as running. However, our findings would have a valuable contribution within the area of valid trackers in treadmill walking activity. Focusing on the distance walked measurement and excluding all other physical data recorded by a tracker would limit our research, especially when it has been reported that some physical activity monitors are accurate in steps recording and not accurate in distance recordings. Therefore, this study contributes to the field of distance estimation validation of physical activity monitors. The validity of distance walked shown by trackers was assessed during a session of treadmill walking using methods similar to previous activity monitor validation research. The distance of 1.5 km was determined as a standard distance value in all trials, which would give more validation for the results generated from the collected 45 observations of each tracker. Finally, as technology evolves so quickly, there should be a standard qualification of factors developed in a framework to assess the validation of every new type of technology that comes into the field of physical activity tracking technologies.

VI. Conclusion

The present study advances our knowledge about physical activity tracking technologies used for the objective assessment of physical activity in terms of distance walked. The concept behind assessing some of the popular physical activity tracking technologies is to find the most reliable physical activity trackers. Therefore, integrating such tracking technologies into our active living framework would have a positive impact on adults' levels of physical activity. Our primary aim in the field of active living technologies is to integrate the best available technology that can facilitate an individuals' physical workout while also motivating them and promoting higher physical activity levels.

Based on the data collected over 45 observations and statistical analysis presented in this paper, the answer to the research question, "What is the best reliable physical activity tracking technology that most accurately and reliably records the distance walked?' is the Jawbone UP tracker. The Jawbone UP most accurately recorded the distance walked compared to the other three trackers used in this research experiment, and had the smallest variation. While we do not intend to promote any individual physical activity monitory technology, we do hope that this research will assist other researchers in their choice of reliable equipment to use for their own research that involves reliable and accurate distance calculation. We can conclude that physical activity tracking technologies are varied in their recordings, even while performing the same activity.

Our findings after this research will help in the construction of a framework that integrates the best available physical activity tracking technologies to facilitate active living in adolescents and teens. Our future direction is the development of this active living framework and to run a pilot intervention test with real subjects to evaluate the effectiveness of reducing screen time while increasing physical activity time in youths. As information technology developers and researchers, we will consider the technical issues of the integration and work on the usability of the developed system.

APPENDIX

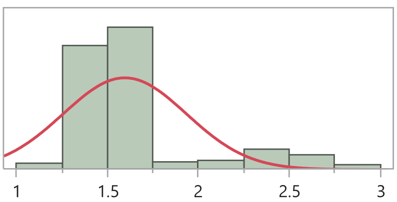

Fig. 2 Distribution of distance walked - Normal (1.59116,0.33981)

TABLE IV
QUANTILES

100.0%	maximum	2.86
99.5%		2.8522
97.5%		2.554
90.0%		2.278
75.0%	quartile	1.5
50.0%	median	1.5
25.0%	quartile	1.4
10.0%		1.38
2.5%		1.35
0.5%		1.0878
0.0%	minimum	1.08

TABLE V
SUMMARY STATISTICS

Mean	1.5911556
Std Dev	0.3398089
Std Err Mean	0.0226539
Upper 95% Mean	1.6357976
Lower 95% Mean	1.5465135
N	225
Variance	0.1154701
Skewness	2.0814387
Minimum	1.08
Maximum	2.86
Median	1.5
Mode	1.5
Interquartile Range	0.1

TABLE VI
FITTED NORMAL - PARAMETER ESTIMATES

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	1.5911556	1.5465135	1.6357976
Dispersion	σ	0.3398089	0.3110445	0.3744813

TABLE VII
GOODNESS-OF-FIT TEST, SHAPIRO-WILK W TEST

W	Prob<W
0.642627	<.0001*

-2log(Likelihood) = 151.804992375117
Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

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