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Accuracy of the "S Health" pedometer application during walking and stair climbing

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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abstract

Background: The S Health application provides an estimate of the amount of physical activity by measuring the number of steps during activities. The purpose was to assess the accuracy of step-counting with different smartphones using the S Health step counting application at long and short walking distances, and stair climbing.

Material and methods: 26 participants (aged 28.85 ± 4.85 years) conducted three tests: 20-step test, 60-step stair test, and 6-minute walk test. Three smartphone models of the latest generation and two models of an earlier one were assessed. The StepWatch pedometer was used as a criterion.

Results: Only one phone of the latest generation produced the most consistent and accurate results as compared to the pedometer in the 60-step stair test and 6-minute walk test (r=0.840), while the correlation of the other four smartphones was weak, from r=0.257 to r=0.482. Generally, the accuracy increased with the increasing amount of steps in all devices and the mean absolute percentage error decreased. Errors ranged between 5.8 and 56.9% for the 20-step test, 1.9-22.4% for the 60-step stair test, and 1.1-17.8% for the 6-minute walk test.

Conclusions: The results suggest that accuracy of smart-phones increase with increased number of steps and correspond to newer model.

Key words: measurement, agreement, walking, wearable technology, step-counting.

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INTRODUCTION

Physical inactivity and sedentary lifestyle have been associated with numerous health conditions and their influence on people's well-being and health indices. It is also responsible for a substantial economic burden; therefore, the promotion of regular physical activity (PA) is essential [1]. The guidelines for the amount of physical activity of the American College of Sports Medicine recommend a minimum of 150 to 300 minutes of moderate-intensity physical activity, or 75 to 150 minutes of vigorous activity weekly, for the maintenance of the musculoskeletal and cardiovascular systems [2, 3]. To estimate the degree of PA, counting daily steps is a readily accessible method to monitor and set PA goals. Recent evidence supports an inverse dose-response relationship of daily steps with health outcomes [4]. Since the use of smartphones is increasingly widespread among younger as well as older populations, their use for PA self-monitoring is continuously increasing. Subjective evaluation of PA levels [5] could thus be upgraded with the monitoring of PA with smartphones.

However, it is not evident whether accuracy of the smart-phone technology is already sufficient also for the purposes of research that requires precise collection of real-time PA for longer periods of time [6] and in different occupational and environmental conditions.

Several mobile phone application techniques were identified that have the potential to foster physical activity [7]. Their advantage is the complete hardware and software for creating an independent PA tracking system [8]. If accurate enough, the applications might be used also for research data collection when longer time periods are required. The practical advantage of the smartphones is also that the data are collected and processed simultaneously, which enables easier data collection as compared to the more specific measurement systems like pedometers or accelerometers.

Several features influence the accuracy of the estimate of PA via counting steps with smartphones and their applications. The most important being the walking speed or the type of physical activity, and secondly the way the smartphone is being carried. Major and Alford [9] reported very high consistency of step counts with an iPhone and a hand-held counter and StepWatch pedometer during self-selected or fast walking speed. However, it decreased when participants walked at low speed. The absolute percentage error of the phone was 8%, 4%, and 21%, at self-selected, fast and slow walking speeds, respectively. The effect of walking speed on the accuracy of counting steps with smartphones was also studied using treadmills [10–14]. All findings showed that the accuracy of phones and step counting devices decrease at fast and very slow walking speeds [10–14].

The way the phone is carried during self-selected walking speed does not affect the results. They were comparable when the phone was carried in a backpack or a handbag [15] or in the chest or pants pocket [16], indicating that the phone need not be carried in a back trouser pocket, as previously suggested [15]; therefore, people can carry them in whichever way they are accustomed to [8].

The accuracy of step counts by smartphones was reported in a series of research reports in which Apple phones were assessed [10–12]. The results have shown that the iPhone application for counting steps was inaccurate when compared to the results of a hand-held counter and StepWatch pedometer. The correlations were weak and insignificant, except for one model (iPhone 3G carried in the pocket at a pace of 107 m/min [11]. There are numerous other applications with pedometer characteristics (some of the most popular applications in Google Play are Step Tracker – Pedometer Free & Calorie Tracker, Pedometer-Step Counter & Daily Health Tracker, Pedometer – Step Counter Free & Calorie Burner). Reports indicate that their measuring results are invalid and unreliable

[13, 17]. There have been few published reports that included the S Health application. Johnson et al. [14] described the influence of different ways of carrying a phone with an Android operating system on the results of the number of steps and compared them to the results obtained with a pedometer. The results were more accurate at a self-selected walking speed than at the speed of 2.24 m/s, as tested on the treadmill. At the time of the research, the phone was within a higher price range [14]. Recently Beltran-Carrillo et al. [18] tested the validity of two Samsung smartphones with the S Health application during walking and running and placed phones in three different locations (waist, arm, hand). The results depend on the smartphone model, body location, and the type of gait. Acceptable validity was found only when the phone was placed on the waist when walking and when placed on the arm during the running trial [18].

For successful estimates of PA, several consecutive daily measurements are required. Kocherginsky et al. [19] reported that reliable estimate of a persons' PA is the average of three to seven consecutive days for older adults when accelerometers are used. For this reason, the smartphone is a very practical platform. However, everyday activities also include short or very short bursts of activity such as office work, and they also include travelling by bus, and driving a car. In an earlier study, Ebara et al. [20] assessed different models of phones with the same Android operating system during office work, travelling on a bus, and driving a car. The results were diverse and inaccurate, with weak correlations between phones and the pedometer, ranging from r = 0.443 to 0.504. False-positive results were also reported during non-walking activities [21].

Due to the technological progress and applications updates, the data collecting methods are continually changing. Therefore, the purpose of the present report was to determine the accuracy of the step counts using S Health application version 6.1.0.047 with five smartphones, four Samsung phones, and one Huawei phone with reference to the criterion measurements obtained with pedometers. Three different walking conditions were assessed: self-selected walking speed at short and long walking distances and climbing and descending stairs. This study upgrades the data obtained by two previous studies [14,18] and differs in several features. First: five phone models were evaluated (Johnson et al. [14] one phone and Beltran-Carrillo et al. [18] two phones). Second: a newer version (6.1.0.047) of S Health application was used (Johnson et al. [14] used 2.0.0.009 version and Beltran-Carrillo et al. [18] version 5.7.1.0003). Third: different functional walking tasks were performed (short and long distances and stair climbing). Fourth: the number of participants was larger (twenty-six) as compared to the previous report (Beltran-Carrillo et al. [18] sixteen). We hypothesised that the updated S Health pedometer application is accurate on different Samsung smartphones models in different walking tasks.

MATERIAL AND METHODS

Participants

A convenient sample of 26 adults participated in the research, 15 women and 11 men, with the mean age of 28.9 ± 4.9 years. Their average height was 167.5 ± 5.6 cm; their average weight was 64.5 ± 11.7 kg. The average body mass index was 22.9 kg/m^2± 3.05 kg/m^2. The inclusion criteria were young adults, capable of PA, with no walking aids, not pregnant, without any musculoskeletal or cardiovascular problems, and not taking any type of medication that could influence walking [9, 10]. The health status was assessed with the Physical Activity Readiness Questionnaire (PAR-Q) [22], which is a specific and sensitive measuring tool used for medical purposes [23]. In the case of just one positive answer, that person was excluded [14].They were dressed in light, comfortable clothing and footwear with no high heels that could influence the walking pattern. Prior to testing, the participants were familiarised with the purpose and procedures of the testing, and they signed informed consent. The research was approved by the Slovenian National Medical Ethics Committee (number: 0120-592/2018/5).

Instrumentation

For counting steps, we used a StepWatch™ (Cyma, Mountlake Terrace, WA, USA) pedometer located on the right ankle as a criterion measure and a hand-held counter Voltcraft (USA) as a validity test for StepWatch™. The validity of the StepWatch was determined with a 20-step test and a 60-stair climbing tests with a hand-held counter. The results of the 20-step test showed that the absolute percentage error of the pedometer in relation to the hand-held counter was 2.1% and 2.3% for the 60-stair climbing test. A value below five per cent meant an acceptable error [9, 13, 15].

We used five smartphones: at the time, the latest model Samsung Galaxy S9 (hereinafter phone “A”), two relatively recent models: Samsung Galaxy A7 (2018 DUAL SIM) (phone “B”), Samsung Galaxy J4+ (2018 DUAL SIM) (phone “C”), and two smartphones of a somewhat older generation: Samsung Galaxy A5 (2016) (phone “D”) and Huawei P9 lite (2016) (phone “E”). The S Health application, version 6.1.0.047, was installed on all smartphones. All further application updates were declined to keep the same version of the application on all phones during the time of testing. The icon of the application was installed on the home screen of the smartphone, as previously described by Johnson et al. [14].

Procedure

The pedometer was placed on an ankle, and its sensitivity was set up to normal [11]. The S Health application was restarted for all the smartphones before the beginning of testing, and all the settings in the devices were set to zero [15]. For every participant before each test all five phones were, in no particular order, placed into a sports belt bag fixed at the hip-height and in the midline of the right thigh. They were placed with their long axes horizontal and their short axes vertical. Recording of steps began one minute after the belt bag was gently attached to the participant’s hip, and when StepWatch was activated [9]. After the completion of each testing session, the phones were carefully taken out of the bag, and the step-counting was stopped, followed by data transfer from the pedometer to the computer.

The participants completed all the tests on one occasion [9]. Before the beginning, they performed a five-minute warm-up that included five repetitions of stretching exercises for the eight main muscle groups of the lower limbs and body, and three minutes of slow running on a running track. After a ten-minute rest, the bag with the phones and the pedometer were attached, and the data-recording began. During testing, they walked with a self-selected walking speed [9] with none of the artificial speed limitations that are common in walking on the running track or when walking with the help of another person [24]. Between tests, the participants had a two-minute rest.

Assessment protocol

The 20-step test and 60-stair climbing test were used to establish the validity of the pedometer for the two different walking conditions. The recordings of the pedometer were then used as a criterion for the calculation of accuracy of the smartphones data. This procedure was previously validated by Orr et al. [13]. An error exceeding five per cent (one step) was regarded as unacceptable [13].

The 60-stair climbing test included 120 steps (60 going up and 60 going down) without skipping stairs or stepping on one stair with both feet at the same time, as previously described by Orr et al. [13]. The researcher counted them simultaneously with a hand-held counter. An error exceeding five per cent (six steps) was regarded as unacceptable.

The 6-minute walk test is designed to measures the distance the individual can make in six minutes and is mostly used in rehabilitation for the assessment of mobility-impaired patients [25]. The test is valid, reliable, and can be used to track changes after treatment [26]. However, we used it as a time frame for measuring the number of steps with the described devices. The test was executed on a 400 m running track. For all three tests, the number of steps was measured and recorded.

Statistical analysis

For statistical analyses, SPSS 26.0 (Statistical Package for the Social Sciences, Inc., Chicago, Illinois, USA) was used. A series of analytic methods for accuracy and agreement were used [27]. A Shapiro-Wilk test was used to determine the normality of data distribution, while Spearman's rank correlation coefficient was used to calculate the correlation □ between the results. To establish accuracy, a Mean Absolute Percentage Error (MAPE) was calculated; to determine the direction of error, Mean Percentage Error (MPE) was calculated. To assess the agreement, a one-sample Wilcoxon Signed Rank Test followed by the graphical presentation of the results with the Bland-Altman plots was used [28]. For easier comparison between the pedometer stride counts and phones step counts, the results recorded with a pedometer were multiplied by two. The limit of the alpha error was set to $p \leq 0.05$.

RESULTS

The Shapiro-Wilk calculations showed that the distribution of data was not normal; therefore, we used Spearman's rank correlation coefficient for further analysis.

20-step test

The number of steps during the 20-step test were also recorded by the five smart-phones. The detailed results are presented in Table 1. The most accurate value was recorded by phone A, with MAPE 5.79%. The MPE indicated that all devices underestimated the number of steps (Table 1). At the 20-step test, some smartphones even recorded a zero value. On average, 26.2% of the recordings were zero. The exception was Phone A, which did not once record a zero value in all 26 trials.

Table 1. The descriptive statistics for the results of the 20-step test for the pedometer and five smartphones, together with the mean absolute percentage error and mean percentage error

Instrument	Average no. of steps (SD)	Min-max	MAPE (%)	MPE (%)
P*	19.6 (0.8)	18-20	/	/
A	18.5 (0.9)	15-20	5.8	5.4
B	12.3 (8.7)	0-22	39.6	37.1
C	11.6 (9.2)	0-25	32.1	30.8
D	13.5 (7.8)	0-21	44.5	40.6
E	9 (9.4)	0-25	56.9	54.2

IP* = StepWatch pedometer multiplied by 2, A = Samsung Galaxy S9, B = Samsung Galaxy A7, C = Samsung Galaxy J4+, D = Samsung Galaxy A5, E = Huawei P9 lite, MAPE = mean absolute percentage error, MPE = mean percentage error.

60-stair climbing test

The descriptive statistics of the 60-stair climbing test for all five smartphones are given in Table 2. The table includes the average values, and the minimum and the maximum number of steps, recorded with the smartphones. The accuracy of the results obtained with the phones as compared with the results of a pedometer showed that only Phone A exhibited the mean absolute percentage error of less than five per cent (MAPE = 1.9%). The MPE indicated that, except Phone A, all other devices underestimated the number of steps (Table 2). A zero value was recorded during the stair-climbing test in 3.8% of the cases, twice by Phone D and three times by Phone E, both of the earlier (2016) generation.

Table 2: The descriptive statistics for the results of the stair climbing test for a hand-held counter, a pedometer and five smartphones together with the mean absolute percentage error and mean percentage error

Instrument	Average no. of steps (SD)	Min-max	MAPE (%)	MPE (%)
P*	141.4 (4.7)	132-154	/	/
A	140.4 (7.2)	132-167	1.9	0.8
B	127.5 (12.5)	110-160	11.1	9.9
C	126.4 (12.3)	108-149	21.1	18.9
D	115.1 (37.9)	0-168	11.3	10.6
E	111.2 (42.8)	0-156	22.4	21.5

P* = StepWatch pedometer multiplied by 2, A = Samsung Galaxy S9, B = Samsung Galaxy A7, C = Samsung Galaxy J4+, D = Samsung Galaxy A5, E = Huawei P9 lite, MAPE = mean average absolute percentage error, MPE = mean percentage error.

The mean differences between smartphones and the pedometer during the stair climbing test ranged from 1.1 (Phone A) to 30.2 steps (Phone E). The differences as assessed by Wilcoxon Signed Rank Test were significant ($p < 0.001$).

6-minute walk test

The descriptive statistics of the 6-minute walk test results are presented in Table 3. It includes the average values of the recorded steps and their minimum and the maximum values, as recorded with the smartphones and pedometer. The correlation coefficients between the pedometer and the smartphones varied from the minimum of 0.418 to the maximum of 0.980. The accuracy of results gathered by the phones, compared with the results of the pedometer as expressed with the MAPE, showed that Phone A was the most accurate one, with the error being 1.1%. The MPE indicated that three devices slightly overestimated the number of steps and one device underestimated the number of steps (Table 3). The value zero was never recorded during the 6-minute walk test by any of the phones.

Table 3: The descriptive statistics of the 6-minute walking test results for a pedometer and all five smartphones, along with their correlation with the values of the pedometer and the mean absolute percentage error and mean percentage error

Instrument	Average no. of steps (SD)	Min-max	Spearman's r	p	MAPE (%)	MPE (%)
P*	567.9 (55.7)	422-652	/	/	/	/
A	566.1 (55.7)	415-649	0.980	0.001*	1.1	0.3
B	571.5 (82.8)	310-704	0.448	0.022*	8.5	- 1.5
C	583.5 (68.9)	439-738	0.482	0.013*	7.6	- 4.3
D	587.1 (67.6)	436-750	0.469	0.016*	7.6	- 3.6
E	499.4 (141.0)	180-698	0.418	0.013*	17.8	11.5

P* = StepWatch pedometer multiplied by 2, A = Samsung Galaxy S9, B = Samsung Galaxy A7, C = Samsung Galaxy J4+, D = Samsung Galaxy A5, E = Huawei P9 lite, MAPE = mean absolute percentage error, MPE = mean percentage error, *statistically significant values $p \leq 0.05$.

The mean differences between smartphones and pedometer during 6-minutes walk test ranged from 1.8 of phone A to 68.4 steps for phone E. Also the 95% limits of agreement largely varied between the smartphones and were between 19.1 and -15.6 steps for phone A and 345.1 and -208.3 steps for phone E (Figure 1).

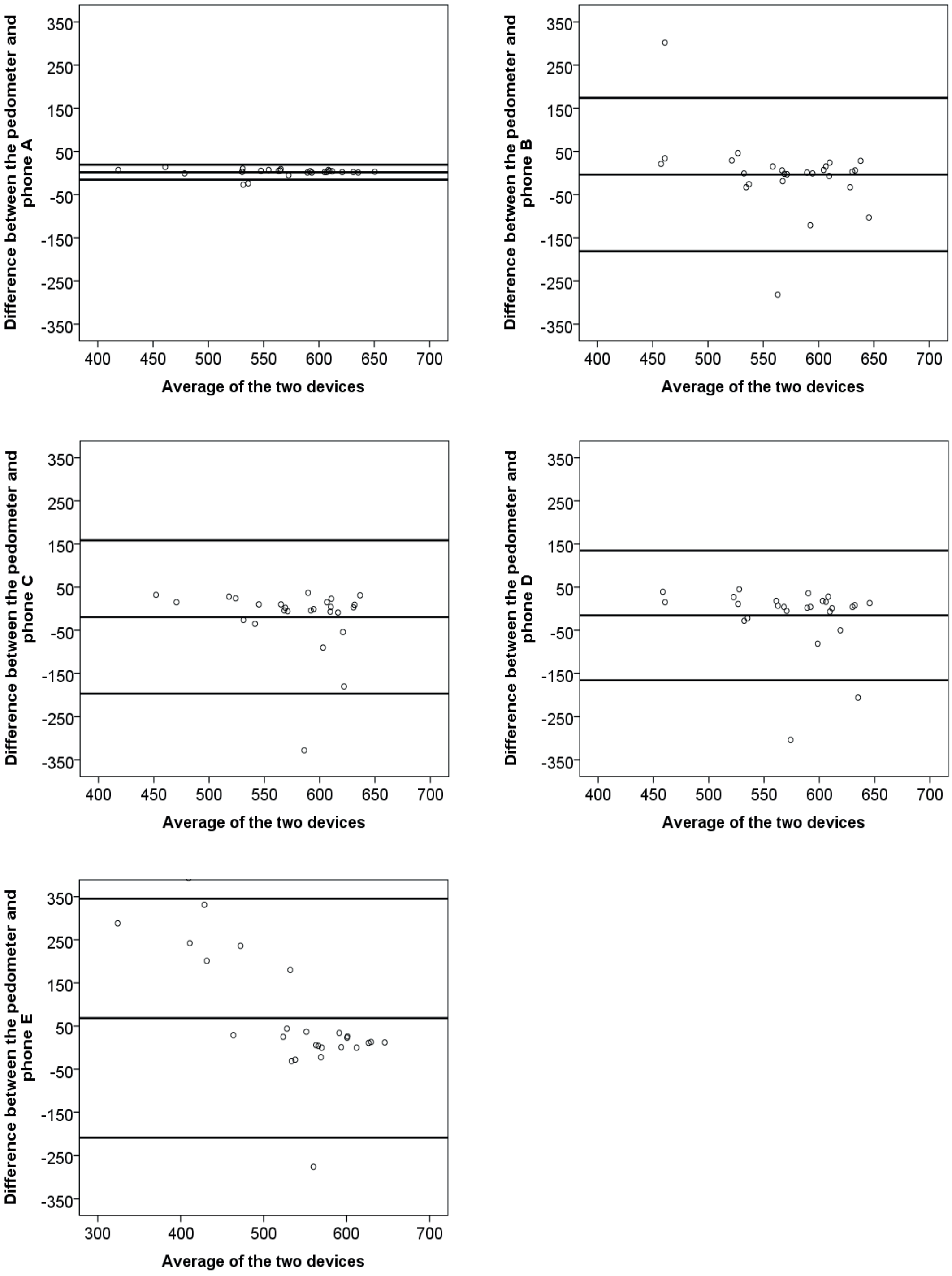

Fig. 1. Bland-Altman plots of step counts during 6-minute walk test comparing five smartphones and the pedometer as criterion (gold standard). The lines represent the mean difference and its 95% limits of agreement

DISCUSSION

The purpose of this study was to compare the results of five smartphones with the installed S Health application to the results recorded with a StepWatch pedometer during short and long-distance walking and climbing and descending stairs. This is the first study comparing the step-counting results using the updated S Health application in five different smartphones. The S Health application was pre-installed on three recent Samsung models, whereas it had to be installed manually in the two phones of the 2016 generation (one Samsung and one Huawei). The results showed that Smartphone A was the most accurate, with excellent correlation to the pedometer, the lowest MAPE and the narrowest limits of agreement, while correlations of other phones were weak in all three testing conditions, and the MAPE was higher than 5%. The error rate of Phone A was close to acceptable 5% [13] even at a short distance, while all the other phones exhibited errors exceeding this value in all three test conditions.

In our study, manual step counting was used to determine the criterion validity of step watch for walking on level ground and on stairs. The measurement error was 1.9% and 2.28%, respectively and was well below the acceptable predetermined 5% error [13]. Our results are in agreement with previous validity reports. Leong and Wong [17] determined the accuracy of the Yamax Digiwalker CW-700 (Yamasa Tokei Keik Co., Ltd Japan, Tokyo) pedometer to be 2.2% as compared to manual counting of steps during five different walking speeds on a treadmill. In contrast, Orr et al. [13] reported an even lower error (0.7%) in comparison to manual step-counting.

The 20-step test was, in addition to validation of the StepWatch pedometer, also used to evaluate the accuracy of smartphone pedometers at very short distances. In free living conditions, this is similar to walking indoors from room to room, for which the regularity of steps could be lesser. In the 20-step test, the most accurate smartphone was device A with 5.8% of MAPE. The results support the previously obtained results by Orr et al. [13] which reported errors (MAPE) higher than five per cent for all step-counting applications in comparison to manual step-counting during the 20-step test. During the 20-step test, some devices even recorded zero step counts; these were recorded 34 times (i.e., in 26.2% of all measurements). The exception was Phone A, which did not display a zero value in any of the 26 measurements. Orr et al. [13] also reported measurements in which the devices did not detect any steps, although the settings and data acquisition methods never changed. This could decrease the accuracy of the free-living measurements when the number of steps is recorded throughout the day, as daily life mainly consists of numerous outbursts of short activities either at home or in the office.

In contrast to the 20-step test, during the 6-minute walk test, a zero-step value was not recorded. The results indicate that, for most smartphones, a higher number of steps is needed for the application to start counting. Generally, our results showed that the accuracy of smartphones increase with the increasing number of steps and thus with longer measuring times. In the 6-minute walk test, all of the assessed smartphones displayed significant correlations to the pedometer (r = 0.981–0.418), and their errors decreased as well as the limits of agreement. Of the five assessed phones, Phone A had the highest correlation to the pedometer counts (r = 0.981), the smallest error (MAPE 1.9%), and the narrowest limits of agreement. All other phones showed higher errors ranging from 8.5 to 17.8%. As stated earlier, Orr et al. [13] accepted the five per cent error as a cut-off value in their research although some researchers reported the acceptable level of error up to ten per cent [29, 30]. A low acceptable error is especially important when recording in free-living conditions, and it relates to the 2018 guidelines for PA of American College of Sports Medicine [2, 3] that states that every minute of physical activity counts [31].

Therefore, sufficiently high accuracy of the recording devices is required to be able to monitor short bursts of activity, since in real life measurements the situations occur in which a person is engaged in numerous short walking distances (walking indoors, going from room to room). These results may assist in decision making for future free-living designed monitoring of daily steps in which a cumulative result may be a sum of several short and very short bursts of activity. This could be especially the case in frail elderly persons or persons with chronic neurological conditions.

In addition to level walking, real-life situations also require stair climbing. The results of our study indicate a systematically low accuracy with large errors for all tested smartphones. Furthermore, during the stair-climbing test, zero values were recorded five times, twice with Phone D and three times with Phone E, which were both the phones of the 2016 generation. Phone A was the only one in which the error of the 60-stair climbing test was very low (MAPE = 1.9 %). There are few research reports assessing smartphone accuracy during stair climbing. Previous reports consistently showed increased error, specifically decreased accuracy of pedometers [13] as well as smartphone pedometers [13, 16].

Phone A was also the only phone in which the error of the 6-minute walk test was smaller than five per cent (MAPE = 1.1%) and had the smallest error in the 20-step test (MAPE = 5.8%). Leong and Wong [17] calculated the measurement errors to range between 16% and 18% for phone applications, in comparison to the measurements of a pedometer. That is in agreement with the present results for the remaining four (B–E) smartphones assessed in our study.

Accuracy can be evaluated with different statistical methods that provide complementary information [27]. In our study, four methods were used (Spearman’s rank correlation coefficient, MAPE, MPE and Bland-Altman plots). The results of all three statistical methods consistently showed that Phone A (Samsung Galaxy S9) was the most reliable smartphone assessed, followed by B (Samsung Galaxy A7), C (Samsung Galaxy J4+), D (Samsung Galaxy A5), and E (Huawei P9 lite). According to our data, the accuracy of the S Health pedometer application together with the smartphone differed depending on the date of release of the model; the price range as well might influence the accuracy of the obtained measurements. Phone A (higher price range) exhibited significantly smaller errors in all tests and had a higher correlation to the pedometer as compared to the phones of a lower price range, while the results of Phone C (lower price range) were quite comparable with Phone B (middle price range).

The other studies that assessed the reliability and validity of the S Health pedometer application differ in various features. The first research that studied the validity of the step counting application S Health was carried out using a treadmill [14]. Their results showed that the application was the most accurate during self-selected walking speeds, and the position of carrying the phones did not affect the results. More recent research [18] reported that the validity of the results depends on the position of the smartphone. During running, higher validity was obtained when the phones were placed on the arm or in the hand and during walking when the smartphone was placed on the waist. Our study additionally revealed that the application obtained different results when coupled with different devices. The MPE results indicated that during short distances, the results of smartphone step counting was consistently underestimated, while during longer walks only one phone (E) underestimated the number of steps. We can conclude that phones A–D are suitable for monitoring longer distances. While monitoring during free-living conditions during which persons are engaged in indoors activities for the majority of the time, only Phone A had a clinically acceptable percentage error. For research purposes, the agreement to the gold standard, either pedometers or video, the errors of applications and devices should decrease, and further evaluations of newer devices are warranted.

The estimation of PA by means of pedometers could be clinically used for screening, tracking, and clinical decision making. However, persons with chronic conditions are likely to have situations with several short bursts of walking in real life. Therefore, the accuracy of pedometer application during short walks needs to be increased in order to be able to monitor whole day PA with smartphones in free-living conditions.

The differences between the results of the phones and a pedometer could be attributed to the phone sensors (type, model, or producer of the accelerometer sensor) that are different in different phone types and years of manufacture [17]. The second reason for the differences in the test results can be the consequence of different sensitivities for detecting steps, which is related to the detection of a vertical movement created while stepping [17]. The third reason could be in software settings of the accelerometer sensor and the settings of the operating system. It could also be assumed that the applications for counting steps are backed by different algorithms and hardware [32]. Regardless of the reason, the settings of the devices are mostly unaccusable by the user or researcher. Therefore, the accuracy of the devices need to be individually established against a gold standard before research use. Present results offer accuracy results for three recent and two older smartphones.

The limitations of our study are the relatively small number of involved participants, their narrow age group, and the limitation to only healthy adults. Additionally, in our study, the position of the phone during data acquisition was also different from the most common one. Carrying a phone in a belt bag probably does not represent the most common position of the phone that people most commonly use [13]. Therefore, to test the accuracy of measurements with smartphones and their applications should, in future, also include the other ways of carrying the phone. The accuracy of smartphones as a step-counting device needs to be tested across a range of everyday activities, with the inclusion of elderly persons with chronic conditions for whom slow walking with short distances could be expected, as well as for monitoring the intensity, volume, and progression of balance-specific exercises [33]. Additionally, it is of great importance to test different age groups, especially elderly ones, for whom PA monitoring in daily life can contribute to healthier lifestyles.

CONCLUSIONS

Samsung smartphones, with their step-counting application S Health, had different levels of accuracy of counting steps during self-selected walking speed and stair-climbing. Only the phone of the latest generation performed with acceptable accuracy in all three tested conditions. The accuracy compared to the pedometer increased as the number of steps or the duration of measurement increased for all phones. Accuracy was lower for all smart-phones in stair climbing compared to level walking.

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