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Accuracy of a smartphone pedometer application according to different speeds and mobile phone locations in a laboratory context

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Introduction

It is well documented that a prolonged decrease of physical activity results in the rise of chronic diseases such as type 2 diabetes,¹ obesity,² hypertension,³ coronary diseases⁴ and therefore increases the healthcare costs.⁵ Considering that 44% of the European population does not exercise⁶ and that the WHO recommendations of 150 min of moderate physical activity per week are only fulfilled by 30% of the Swiss population,^{7,8} it is a priority for public health policies to encourage individuals to be more active.⁹

Being physically active by walking is free of charge, presents limited risks of injury and can be practiced in many places by those who can walk. That's the reason why Public health institutions are developing walking-based programs to encourage people to increase their level of physical activity.^{10,11} These programs are supported by large amounts of studies showing that walking 30 min/ day, 5 days/week diminishes risks of cardiovascular accident by 19%¹¹ and also has a positive impact on psychological well-being and diminishes the risks of depression.^{12,13} Ideally, it is recommended for adults between 26 and 65 years to reach at least 7000 steps per day.¹⁴ In an educational perspective, pedometers are often used in health promotion as they are easy to use, low-cost, motivational and self-monitoring tools for sedentary persons.¹⁵ In addition, a recent study showed that using a pedometer is likely to

be a more precise way to assess the level of physical activity as compared with subjective measure, especially in sedentary subpopulation.¹⁶ Pedometer-based programs are considered to be efficient to increase the volume of physical activity. In their systematic review, Bravata and collaborators¹⁰ showed that when the use of a pedometer is associated with daily step goal, walking performance can be increased by an average of 2187 steps/day. Interestingly, an extra 2000 steps/day in men with very low physical activity (i.e. 2000 steps/day) has been associated with reduced waist circumference¹⁷ supporting the assumption that increase of steps in sedentary population is likely to have major impact on health outcomes. The Yamax Digiwalker products range of pedometers (Yamasa Tokei Keiki Co. Ltd., Tokyo, Japan) are usually used as reference devices because they showed the best accuracy scores and reliability for step counting.^{18,19} However, it is also generally reported that at lower speed the error rate increases.²⁰ The work of Basset and colleagues (1996) already revealed that between walking speeds of 50 m/min and 70 m/min, the accuracy was less than 80% steps counted. Considering that preferred walking speed can be very low in general population,²¹ the accuracy of these devices at very low speeds (i.e. at 2 km/h) in real world setting may be lower.

The aim of this study is twofold: to evaluate the effect of different speeds on the accuracy of one pedometer application but also to test this accuracy when the smartphone is attached at different locations. First, the increased number of pedometer applications and the rapid evolution of technology allow smartphones to be used as step counters ²² Second, few studies have been conducted to validate the accuracy of Smartphone pedometer applications so far, while the location of the device seems to influence the accuracy of the step counts.^{23,24} Two studies have found applications to be inaccurate.^{25,26} In two other studies, the results are less straightforward. Åkerberg and colleagues found one application (Pedometer 24/7[©]) out of ten to be accurate²⁷ and Leong and Wong found one (Pedometer Tayutau[©]) application out of three to be accurate.²⁰ In this study, we tested the Runtastic Pedometer[©] application, which was one of the most popular pedometer application.²⁸ Because of its popularity among the Swiss population, the Iphone6[©] was selected among the multiple mobile phone models (Iphone6 is the best-selling mobile phone in Switzerland with 56%

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of the Swiss customers that possess this model at the time of the study versus 39% for its direct concurrent Android).²⁹ In addition, Åkerberg and collaborators concluded that the Iphone4[©] model was accurate with reasonable low standard deviation.²⁷ Probably, because it is equipped with a BMA280 accelerometer discriminating accelerations between 1/512 g and 1/4906 g, whereas walking from 2 to 8 km/h induces 0.1–0.61 g accelerations at hip level.³⁰

Our hypotheses were that 1) the smartphone application would be as accurate as the pedometer; 2) the sensibility of the smartphone accelerometers would be more accurate than the mechanical lever of the pedometer at slow speeds; and 3) the accuracy of the smartphone accelerometers would disrupt the measures in the loosest position ("jacket").

Methods

Participants

The sample size was calculated based on the Japanese standards for pedometer error that should not exceed 3%.¹⁹ The walking duration for the current study was 4 min and 50 s, which correspond to approximatively 500 steps.³¹ A sample size of 17 participants was deemed sufficient to detect a delta of 15 steps (with alpha = 0.05; power = 90%; standard deviation = 13 steps). We increased this number to 18 participants in case of drop-out.

The 18 participants (7 women, 11 men) involved in the study were aged between 30 and 60 years old. Participants with walking difficulties, chronic diseases, acute diseases, prosthesis and/or electronic medical devices were not included in the study. One subject was removed because of extreme outlier values at five different positions and back-pains after performing the task. The other outliers were excluded as individual data points and represent a total of 2.8% of the entire data set. Those outlier values were due to a technical malfunction of the Yamax Digiwalker. A total of 17 subjects (11 men, 6 women, age: 40 ± 10 yr) were considered for the statistical analysis of the data. The experimental protocol $(n^{\circ}31/$ 15) was approved by the local ethic committee of the Canton de Vaud and was in agreement with the declaration of Helsinki. All participants gave their written informed consent before participating to the experiment. They received 15 Swiss Francs for their participation.

Experimental design

During the protocol, the participant wore comfortable clothes and sport shoes. They were equipped with an iPhone 6[®] (Apple, United-States) on which the Runtastic Pedometer[®] (Runtastic, Austria) (RUN) application was installed. The sensitivity was set to "moderate", in line with the results of Boyce and collaborators²⁶ that pointed out good validity and reliability for two out of three mobile phone pedometers when set at the medium level of sensitivity. They were also equipped with a Yamax Digiwalker SW200[®] (Yamax, Japan) pedometer (YAM). The walking tests were performed on an instrumented Treadmill T150-FMT-MED[®] (Arsalis, Belgium), which measured the ground reaction forces in the vertical, forward and lateral axes at a sampling rate of 100 Hz, and it was used as reference during this study (see Dierick et collaborators for validation³²) (see below for details).

The experiment took place at the University of Lausanne, in the laboratory of the Institute of Sport Sciences. After having the opportunity to acquaint themselves with the treadmill during several minutes, the participant was then equipped with the pedometer and the smartphone. The pedometer was worn on a belt, over the middle of the right thigh, as described in its instruction manual. The smartphone was inserted in a phone case and worn at three different positions: « belt », the smartphone is attached to the belt, in vertical position; « arm », the smartphone is attached around the arm, over the biceps, in vertical position; and « jacket », the smartphone is attached to the jacket, in horizontal position. Two sizes (Small and Large) of the same model of jacket were used according to the anthropometry of the participants. The participants were asked to walk during 4 min and 50 s at three incremental walking speeds: 2, 4 and 6 km/h (respectively 0.56, 1.11 and 1.67 m/ s; zero gradient). For security reasons, the speeds were not randomized to avoid to start at the highest one. At each speed, the walking task was repeated three times in a randomized order with respect to mobile's position (i.e. « belt », « arm » and « jacket »). The number of steps was the primary outcome measured by the application, the pedometer and the treadmill. A custom MATLAB (MathWorks, Inc., Natick, MA, USA) script was used to extract the step counts from the lateral axis peak force of each foot contact on the treadmill.

Data analysis

The quantitative variable used in the statistical analysis was named DIFFSTEP. It was calculated as the difference between the numbers of steps counted by one of the tested devices (YAM or RUN) and the number of steps measured by the treadmill. DIFFSTEP was calculated using the following formula:

$$DIFFSTEP = steps_{YAM or RUN} - steps_{treadmill}$$
(1)

The closer DIFFSTEP is to zero, the more accurate the device is. Note that for YAM DIFFSTEP correspond to the mean score of the steps recorded at the three positions of the mobile phone.

The absolute percent error (APE) was also calculated³³ as follows:

$$APE (\%) = \frac{|steps_{YAM \text{ or }RUN} - steps_{treadmill}|}{steps_{treadmill}} \times 100$$
(2)

Statistical analysis

Because the DIFFSTEP measure was not normally distributed and did not show homoscedasticity, non-parametrical statistic tests were used. Wilcoxon rank signed tests were performed to compare the two devices at different speeds and Friedman tests to compare the different speeds for each device. To compare the effect of the positions, Friedman tests were used on the data for RUN only. Bland Altman plots and Spearman's correlations were computed to further describe the data. Bland Altman plots were used to determine congruency between each device and reference ³⁴. They display the variability in individual step counts around 0, the mean error score and the 95% confidence interval. Scores close to 0 indicate congruency between the two devices. Positive scores (over 0) indicate overestimation of device relative to treadmill, and negative scores (under 0) indicate underestimation. The significant threshold was set at p < 0.05.

Results

Descriptive analyses

Table 1 summarizes the data for DIFFSTEP and APE scores. The average number of steps made by all participants on all conditions were 353.2 ± 48 at 2 km/h, 494.2 ± 28.5 at 4 km/h and 577.2 ± 26.7 at 6 km/h.

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