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Can a mobile phone be used as a pedometer in an outpatient cardiac rehabilitation program?

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Abstract— **Our aim is to evaluate the use of a mobile phone as a step counter in cardiovascular disease patients, to measure daily walking activity through the course of an outpatient cardiac rehabilitation program. A conventional Omron pedometer (HJ-7201TE) and a mobile phone inbuilt step counter (Nokia StepCounter Beta V0.26) were used in the study. Firstly, we conducted a laboratory trial with 11 normal healthy subjects to investigate the performance of the two devices over different step rates during walking. Secondly, we collected and analysed 141 daily step count records from 18 patients wearing the two devices during a clinical trial. The laboratory study revealed that both devices maintain an accuracy of less than 2% error rate within step rates of between 85 and 125 steps/min but tend to degrade outside this step rate range. During the clinical trial, patients carried the mobile phone as well as the Omron pedometer in a free living environment. The results of this study showed that despite the underperformance of these devices during the slow walk, the reliability of the mobile phone ((error 10%+/-30%) was better than the Omron pedometer (20.5%+/30% error) and accounted reliable assessment of 84% of the patients. This demonstrates the feasibility of using the inbuilt step counter as an integral solution of the mobile phone for delivery an ICT-based home care CR program.**

I. INTRODUCTION

THIS study investigated whether a mobile phone step counter application can be used instead of a conventional pedometer in a home- based Cardiac Rehabilitation (CR) program, developed by the Care Assessment Platform (CAP) project of CSIRO [1]. The CAP aims to provide patients with an alternative CR program at home, so as to improve the uptake of the currently underutilised CR programs. In the CAP study, the number of total daily steps, reflecting the patient's activity level, is one of the major physiological measures to assess the patients' recovery status and health condition. The use of a pedometer in cardiac rehabilitation can improve the patient's self management as well as their awareness of their activity [2], and may result in an increase of their physical activity by 2000 steps per day in average [3].

During the CR a mobile phone, Nokia N96, was provided to each patient to record their health data such as sleep, blood pressure, stress and weight. The Nokia N96 has an inbuilt accelerometer which was used to automatically count the daily steps through the use of the StepCounter software by Nokia Research [4]. In comparison with conventional pedometers, the mobile phone based step counting applications may have many advantages. For example, the StepCounter software is free and available for a large range of mobile phone models. Mobile phone applications can have better user interfaces, provide more sophisticated analysis, and have connectivity to server applications for further data comparison and evaluation. However, the question of "Can a mobile phone be used as a pedometer in an outpatient cardiac rehabilitation program?" is yet to answer clearly.

In this study, we first investigated the step counting accuracy of the built-in pedometer in the Nokia N96 mobile phone with that of the Omron HJ-7201TE. Subsequently, we compared the consistency of the difference in accuracy between these devices from data collected from 18 subjects participating in the CAP clinical trial.

II. METHODS

A. Laboratory Trial

Initially, we tested the StepCounter performance for different walking speeds and test in eleven volunteers: 4 women and 7 men with median age of 32 years (minimum 21 and maximum 46 years). The protocol was to walk on a flat surface while wearing the Omron pedometer and the mobile phone on the waist on a belt simultaneously. Each participant was requested to walk 200 steps at three different speeds that they perceived to be slow, normal, and fast. The walking time for 200 steps (counted mentally) at each speed was measured with a stop watch and recorded by the participant. The data gathered was used to calculate step frequency in steps per minute (steps/min), to determine each subject's different walking speeds. The stride length was not measured to obtain actual walking speed but we choose to use step frequency to describe the speed variation during the test. Our aim was to obtain a range of different

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walking patterns from the study participants.

B. Clinical Trial

The CAP project is a randomised controlled clinical trial comparing the effectiveness of the alternative home-based care model using IT tools (IT Group) with the standard gym-based care model (No IT Group) [5]. As part of this trial, we are collecting physiological data such as weight and blood pressure as well as exercise behaviour by using a WellnessDiary, mobile phone application [5]. The results presented in this paper are based on the data gathered from patients enrolled in the IT group of the trial. Each patient from this group of the study was instructed to wear both the Omron pedometer and the mobile phone simultaneously for a minimum of five days, before and after six weeks of CR program. The data acquired by the mobile phone were then compared to the Omron pedometer data. The data recorded from the mobile phone were synchronised to a remote server by the patient and stored in the WellnessDiary database. The data from the pedometer were uploaded to a computer and stored in a comma separated value file when the device was returned to the research group. We used Matlab R2007a (Mathworks Inc, Natick) to retrieve the daily step count from these two sources and compare them for the days when mobile phone and pedometer data were simultaneously gathered. We used 141 daily step records coming from 18 patients. This permitted us to validate the use of the mobile phone in a non-controlled free-living environment. Neither the position of the mobile phone nor the gait or speed of the patients walking activity was controlled. The patients were simply asked to wear both devices simultaneously.

III. RESULTS

A. Laboratory Trial

The test results of the laboratory study are summarised in the Figure 1. The error percentage for both devices was calculated by comparing the step count from the device with the number of step counted by the participant. The slow, normal and fast intervals of perceived walking speeds are represented below in Figure 1. The range for slow was from 58 to 98 steps/min, for normal from 91.6 to 121.2 steps/min, and for fast from 110 to 141.2 steps/min.

The laboratory trial shows both devices to perform equally for step frequencies between 85 and 125 steps/min, or between 3.6 and 5.2 km/h if assuming an average stride length of 70cm, which corresponds to the normal walking speed of the participants.

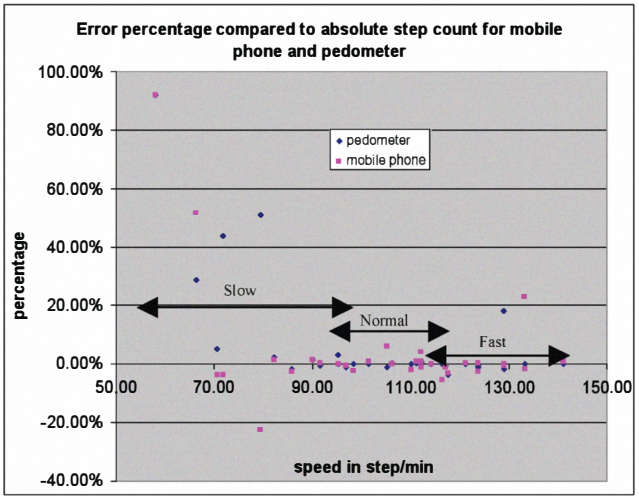

Fig.1: Error percentage of the mobile phone StepCounter and the Omron pedometer compared to the absolute step count (200 steps).

The mean ±SD error of the Omron pedometer step frequencies, between 85 and 125 steps/min, was 0.76%± 0.93%. The error of the mobile phone StepCounter for the same step frequency range was 1.62%±1.69%.This result from the Omron pedometer was slightly more accurate than the mobile phone. The next best accuracy was for fast walking speed with error of 1.00%±5.74% for the pedometer and 0.77%±7.59% for the mobile phone. Both devices, however, showed poor accuracy for slow walking with error of 20.5%+/30% for the Omron pedometer and 10%+/-30% for the mobile phone at step frequencies between 58 and 98 steps/min.

B. Clinical Trial

The clinical trial data analysis was done by comparing the mobile phone values with the Omron pedometer values. In this case the Omron pedometer was considered as the reference since it has been widely used in other similar applications.

Figure 2, represents the box plot of the error in percentage of the mobile phone's daily step count over the pedometer. As observed, some data points (red crosses) from the mobile phone differ significantly from that of the Omron pedometer data and can be considered as outliers. Using the box plot, outliers were defined as follows: *Upper limit = Q3 + 1.5 * IQR and Lower limit = Q1 - 1.5 * IQR*, where IQR =Q3-Q1 and Q1 and Q3 represent the first and the third quartile. The data points were then considered as outliers, when the mobile phone step count was more than 37.9% (Upper limit) or less than 48.0% (Lower limit) of the pedometer step count. There were 14.9% outlier points defined by this method. The big differences could be due to patients forgetting to use the one or the other device during walking exercise, forgetting to recharge the mobile phone battery or even walking slowly.

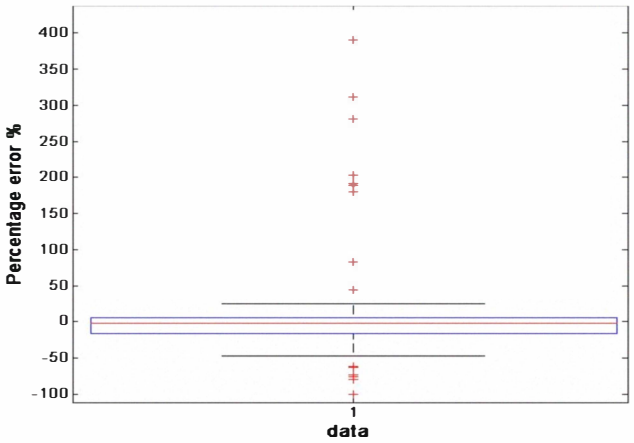

Fig 2: Boxplot of the error from the mobile phone compared to the pedometer.

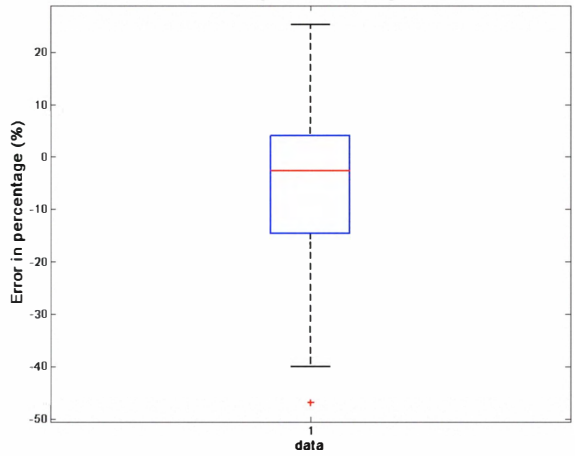

Fig. 3: Boxplot of the error from the mobile phone compared to the pedometer without the outliers.

The Figure 3 shows the box plot of the final error percentage of the StepCounter data when compared to the pedometer. In this analysis the outliers have been removed and do not contribute to the final error. The median of the difference between the StepCounter and the pedometer daily step count is -2.62% representing approximately 145 steps per day being 'missed' by the mobile phone. The first quartile is at -14% and the third quartile at 3.9%.

The outliers were removed and a linear regression analysis was performed to find the correlation between the number of steps counted by the mobile phone and the number of steps counted by the pedometer each day (see Figure 4).

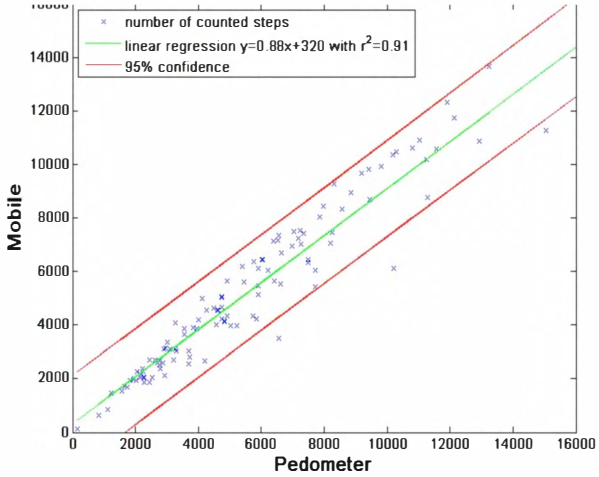

Fig. 4: Comparison of the StepCounter and pedometer data

The correlation between the mobile phone's StepCounter and the Omron pedometer was highly linear (r^2=0.91) with a slope of 0.88 and an offset of 320 steps.

IV. DISCUSSION

The widely recommended exercise goal for a healthy lifestyle is 10000 steps a day [6]. The patients attending a cardiac rehabilitation program set their individual exercise goals with the clinicians. The step goal may vary from a few thousands steps/day in the beginning of the program to over 10000 steps/day at the end of the program. The patients and clinicians use pedometer step counters to track the average weekly goal setting and aim to increase the daily step count significantly. Based on this clinical approach, an average discrepancy 10% or 500 steps/day for a goal of 10000 steps of walk on some days would be an acceptable target. This is provided that the patient is still able to achieve the set goals at least once towards the end of the program. Hence, a step count of within ±10% error due to missed or unaccounted steps or even steps not performed will not become an issue in the clinical assessment of a patient's progress.

In the results section we removed all the StepCounter data points that were considered as outliers from the pedometer count. This deviation can be assumed to be a result of the trial protocol design rather than device errors. It would have been too onerous to include within the trial design to expect patients to record a reference measurement (from mental count) and/or the frequency of their device's usage, for a period of 6 weeks in a free living environment, particularly in their post-cardiac condition. However, the outliers can be informative in showing the uptake and adherence on the daily usage and charging of the mobile phone to maintain the consistency of operation required of the CAP home care model for CR program.

The poor performance of both devices for slow speed walking in the laboratory study has been reported in previous medical research studies with pedometers degrading with decreased step rates [7]. Another study

related poor accuracy of pedometers to inappropriate placement [8]. This does pose a problem for patients with low functional capacity; patients who have slow walking speed during the 6 minute walk test (6MWT) assessment of the CR program. An example of this has been found in a previous study by Jehn et al [9], where a patient reduced 6MWT test of less than 400 meters translating to less than 80 steps/min has resulted in the inaccurate correspondence with the same Omron pedometer (as used in our laboratory study) applied to patients. Similar results were observed with 3 of the 18 patients, in our clinical trial, who walked under 400m at the 6MWT. The data from these patients accounted for 16% of the data analysed amounting to 25% of the resulting outlier points.

While the mobile phone performed equally good with the pedometer accuracy during normal walk (85 and 125 steps/min), the underperformance of the Omron pedometer (20.5%+/30% error) was worse than the mobile phone (error 10%+/-30%) during the slow speed. This is consistent with a previous study by Jehn et al, which demonstrated some accelerometers outperformed the Omron pedometer during 6MWT [9] and questioned on the reliability of applying the Omron pedometer on cardiac rehabilitation patients [10]. Hence, the mobile phone is reliable in our clinical trial, for at least 84% of the patients, and more reliable than the Omron pedometer for slow walking patients.

V. CONCLUSION

This study evaluated the performance of a conventional Omron pedometer and a mobile phone inbuilt step counter. The laboratory test evaluated the performance of both devices and was found to have a high accuracy of less than 2% error rate for normal step rate ranging from 85 to 125 (steps/minute). The results from the clinical trial showed a strong linear correlation between the two devices with r^2=0.91. Despite the underperformance of both devices for patients with low functional capacity, the mobile phone was found to be more reliable than the Omron pedometer. Hence, this study demonstrates that a mobile phone inbuilt step counter is a feasible solution on detecting patients' walking activities, particularly when it is an integral part of mobile phone's application to deliver the ICT-based CR program in home care setting.

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