STEP COUNTS USING A TRI-AXIAL ACCELEROMETER DURING ACTIVITY

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INTRODUCTION

Physical activity has been associated with health improvements in a number of populations. Step counting is one of the most commonly used measures of physical activity [1]. Due to their small size and light weight, the use of wearable sensors for step counts has been investigated in many studies [2, 3] as they are suitable for home deployment. One of the main issues with step counts as a physical activity measure is that a high level of accuracy is needed. The aim of this study was to validate step detection using a tri-axial accelerometer in healthy adults.

METHODS

Accelerometer and video data were acquired from 10 (2 M, 8 F) healthy adults using custom built activity monitors strapped bilaterally on the ankles, waist and thigh as they performed a 5 minute protocol in the laboratory. The protocol consisted of static and dynamic activities involving standing, sitting, shuffling feet while standing and sitting, lying, walking, stair climbing and jogging. At the time of evaluation, the mean age and BMI of the subjects were 33.4±10.49 yrs, and 23.6±2.7 kg/m², respectively. The study protocol was approved by the Mayo Clinic IRB and written informed consent was obtained before participation. Each activity monitor incorporated a tri-axial accelerometer (±16g) and sampled each axis at 100 Hz. Video data were simultaneously acquired at 60 Hz using a handheld camera and were synchronized to the accelerometer data by three vertical jumps performed by the subjects prior to the protocol.

Steps were manually counted in the video data using Windows Movie Maker. Accelerometer data were analyzed offline using MATLAB. The calibrated acceleration signals were filtered using a median filter (with n=3) and separated into its gravitational component by using a third-order zero phase lag elliptical low pass filter, with a cutoff frequency of 0.25 Hz, 0.01 dB passband ripple and -100 dB stopband ripple. Subtracting the gravitational component from the original signal provided the bodily motion component [4].

Waist and thigh angles were used to identify upright standing postures. Activity was characterized as jogging when the signal magnitude area of the bodily motion component of the waist exceeded 0.8 g and as walking (including stair climbing) when it was between 0.135 g and 0.8 g for epochs of 1 s. During identified walking and jogging segments, the anteroposterior accelerations of the right and left ankles were analyzed using a peak detection method with adaptive thresholds to calculate the number of steps taken [5]. Step counts were validated against the steps counted manually from the video data (gold standard). The sensitivity, positive predictive value (PPV) and agreement were calculated for the group.

RESULTS AND DISCUSSION

The average sensitivity (Fig. 1), positive predictive value (Fig. 2) and agreement (Fig. 3) of step counts in this study were 96, 97 and 98%. The 2% average difference in agreement from the manual step count was due mostly to segments of activity with shuffling of the feet while standing and segments with less than 5 steps. The results of this study suggest that this method would be suitable for counting steps using tri-axial accelerometers placed bilaterally on the ankles and waist in a free living environment.

With some subjects, step counts were less accurate, mostly due to small inaccuracies of the detection of the walking and jogging segments at the beginnings.
and ends (walking activity detection had a sensitivity of 98.0% (1.3%) and a PPV of 95.5% (3.5%), while jogging activity detection had a sensitivity of 94.5% (6.8%) and a PPV of 98.8% (2%), resulting in one or more missing steps at the beginning and end of the activity. The number of steps taken for each segment ranged from 2 to 115. The accuracy of the step detection would be expected to increase for longer segments of walking and jogging activity as the inaccuracies occur at the beginning and end of the segments. Previous studies have shown that the most accurate pedometers can give step counts within ±3% of the manual step count, with step counts being classed as ‘acceptable’ when within ±10% [3].

The higher average sensitivity (Fig. 1) and positive predictive values (Fig. 2) obtained with step detection during jogging (95 and 100%) in comparison to walking (94 and 94%) were due to the consistent and higher accelerations. An even higher level of accuracy of step detection would be expected in free living as the confined space of a laboratory sometimes resulted in the subjects moving unnaturally by turning often and taking smaller steps. The advantage of using an accelerometer for step counting is that it can also provide data such as gait event timings, amplitudes, and other temporal parameters derived from these.

CONCLUSIONS

The results suggest that the analysis methods are suitable for step counting in free living using tri-axial accelerometers on the ankles, waist and thigh, which remains to be tested in future work.

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