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A Comparison of Two Commercial Activity Monitors for Measuring Step Counts During Different Everyday Life Walking Activities

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Abstract. The measurement of everyday physical activity by accelerometry has gained in recent years a large role in the medical, sports and psychology science research. The purpose of this study was to validate the accuracy of the Move II (movisens GmbH, Karlsruhe, Germany) activity sensor for measuring steps during different everyday life walking activities and compare it with GT3X (ActiGraph Manufacturing Technology Inc., FL, USA), a widely used activity monitor. Eight females (30.8 ± 8.6 yrs.) and 11 males (30.2 ± 9.0 yrs.) (Mean ± SD) ranging in BMI from 19.43 to 33.31 $kg \cdot m^{-2}$ were equipped with the Move II as well as the GT3X activity sensor and where asked to perform different everyday life walking activities. An ankle-mounted acceleration sensor which delivers raw data was used as reference for the manual annotation of steps during the free-living environment activities. Move II revealed a high accuracy in counting steps with a mean percent error of 0.6 ± 1.1 % for all the activities. GT3X displayed a mean percent error of 4.7 ± 3.7 %. The least accurate results for both devices were observed during stair walking; 1.8 ± 3.2 % and 13.7 ± 10.4 % for Move II and GT3X respectively. The greatest accuracy for both Move II and GT3X was found during walking fast; 0.0 ± 0.1 % and 0.0 ± 0.2 % of errors respectively. Our data suggest that both devices are appropriate for measuring step counts in everyday life.

Keywords: Accelerometers, Physical activity, Step counts

1. Introduction

Over the past years various studies have shown the positive effects of adequate exercise and physical activity on the health of people [1]. Recently there have been new recommendations regarding the amount of physical activity one should perform daily in order to remain active and lower the risk of developing various cardiovascular diseases or other chronic diseases such as diabetes mellitus type II and hypertension [2-5]. Therefore assessing physical activity provides opportunities for interventions for the prevention of various diseases.

Activity monitors are small accelerometry-based devices and have become a promising technique often used as means to objectively measure physical activity. Various studies have established the usefulness of these devices, providing accurate and reliable measures of ambulatory activity monitoring [6, 7]. To assess the physical activity and evaluate the interventions, measures that prove the validity and reliability of those devices for assessing free-living physical activity are needed [8, 9].

The activity sensor Move II (movisens GmbH, Karlsruhe, Germany) has already been validated for measuring energy expenditure over a time period of seven hours [10] and during daily walking activities with different intensities [11]. Walking is the most common everyday life activity and the number of steps is often used as dimension while assessing physical activity. Therefore the purpose of this study was to examine the accuracy of the Move II for measuring steps and compare it with GT3X (ActiGraph Manufacturing Technology Inc., FL., USA); the most verified and widely used activity monitor.

2. Methods

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2.1. Subjects

Eight females and 11 males, students and employees of the Karlsruhe Institute of Technology (KIT) volunteered to participate in the study. All participants completed an informed consent form prior to enrolling in the study. Height and weight was measured without shoes and in light clothing using a stadiometer and a calibrated physician's scale respectively. Descriptive data of the subjects is presented in Table 1.

Table 1: Physical characteristics of subjects (Mean ± SD)

Subject parameter	Males (N=11)	Females (N=8)	All subjects (N=19)
Age (yrs.)	30.2 ± 9.0	30.8 ± 8.6	30.4 ± 9.0
Height (cm)	179.8 ± 7.1	167.3 ± 4.3	175.0 ± 8.5
Weight (kg)	82.5 ± 12.2	64.9 ± 9.2	75.8 ± 13.8
BMI ($kg \cdot m^{-2}$)	25.5 ± 3.4	23.2 ± 3.2	24.6 ± 3.5

2.2. Devices and Protocol

All subjects wore the Move II and the GT3X activity sensor. Both devices were attached to the participant's waist above the right anterior axillary line based on the manufacturers' recommendations. Prior to beginning each trial, all devices were initialized and synchronized using their respective software. Both devices were set to record steps every second (epoch).

Karabulut et al. [15] showed that an ankle-mounted acceleration sensor provides the greatest accuracy for step counting. Therefore an additional ankle-mounted acceleration sensor which measures raw data was used as reference for the annotation of the steps during the free-living environment activities.

All subjects performed a series of different predefined activities. To assess the validity of the two devices to measure steps in free-living environments, we aimed to create situations similar to those found under free-living conditions. Therefore each subject was asked to perform each activity at his/her normal walking speed. In order to avoid influencing the subject's pace, the researcher walked always behind the subject and only gave instructions when to start and stop.

After the placement of the devices the recording was started and the subjects were asked to sit and stand for 5 min respectively inside a room. Then the subjects were asked to walk an outdoor predefined distance at three self-selected gait speeds (slow, normal and jogging). After this the subjects were instructed to cross an arched pedestrian bridge (walking up- and down-hill) four times and at the end to return inside the building and walk the stairs up and down three times. Each activity was followed by a 2-min break. Table 2 summarizes the activities performed by all subjects.

Table 2: Study procedure

Activity	Duration	Distance
sitting	5 min	-
standing	5 min	-
walking slow		415 meter
walking fast		415 meter
jogging		2x415 meter
walking up- /downhill (4 times)		4x130 meter
walking stairs up/ down (3 times)		3 floors

2.3. Statistical analysis

To validate the accuracy of the two devices for measuring steps, we calculated the mean and the standard deviation of the percent error between the actual and the predicted number of steps for each device and each activity. Thus a mean value of zero represents that no difference exists between actual and estimated steps, whereas a positive mean value shows underestimation and a negative one overestimation.

The agreement between the predicted values and the reference was calculated via a two-way mixed, single measure, intraclass correlation (ICC).

Additionally a Bland–Altman [12] analysis was performed. The Bland–Altman analysis is an often used statistical procedure to check the accuracy of two different measuring devices. We therefore constructed the Bland–Altman plots for each device and each activity. The measurement errors of both devices were plotted against their mean. The limits of agreement, which are defined as the mean difference (bias) plus and minus

1.96 times the standard deviation of the errors, are also shown. The smaller the range between these two limits the more accurate is the device.

All statistical analyses were performed in R 2.13.2 [13].

3. Results

Table 3 and Fig. 1 show the mean of the relative error and the standard deviation (in %) of the determined steps of each device in different activities over the complete measuring time. The mean errors for all the activities for Move II and GT3X are 0.6 ± 1.1 % and 4.7 ± 3.7 % respectively. The least accurate results for both devices are observed during stair walking; 1.7 ± 3.2 % and 15.1 ± 11.2 % while walking up stairs and 1.9 ± 3.1% and 12.2 ± 9.5 % while walking down stairs for Move II and GT3X respectively. Move II and GT3X show the greatest accuracy during walking fast (0.0 ± 0.1 % and 0.0 ± 0.2 % of error respectively). The positive mean values of the errors indicate an underestimation of determined steps for both devices for all the activities, whereas the Move II shows in all activities a smaller underestimation compared to the GT3X.

Table 3: Mean percent error (actual - predicted) ± SD during the different activities

Activity	Move II	GT3X
walking	0.1 ± 0.2	0.3 ± 0.4
walking fast	0.0 ± 0.1	0.0 ± 0.2
jogging	0.0 ± 0.1	0.2 ± 0.5
walking up- /downhill	0.1 ± 0.1	0.2 ± 0.2
walking stairs up	1.7 ± 3.2	15.1 ± 11.2
walking stairs down	1.9 ± 3.1	12.2 ± 9.5
all activities	0.6 ± 1.1	4.7 ± 3.7

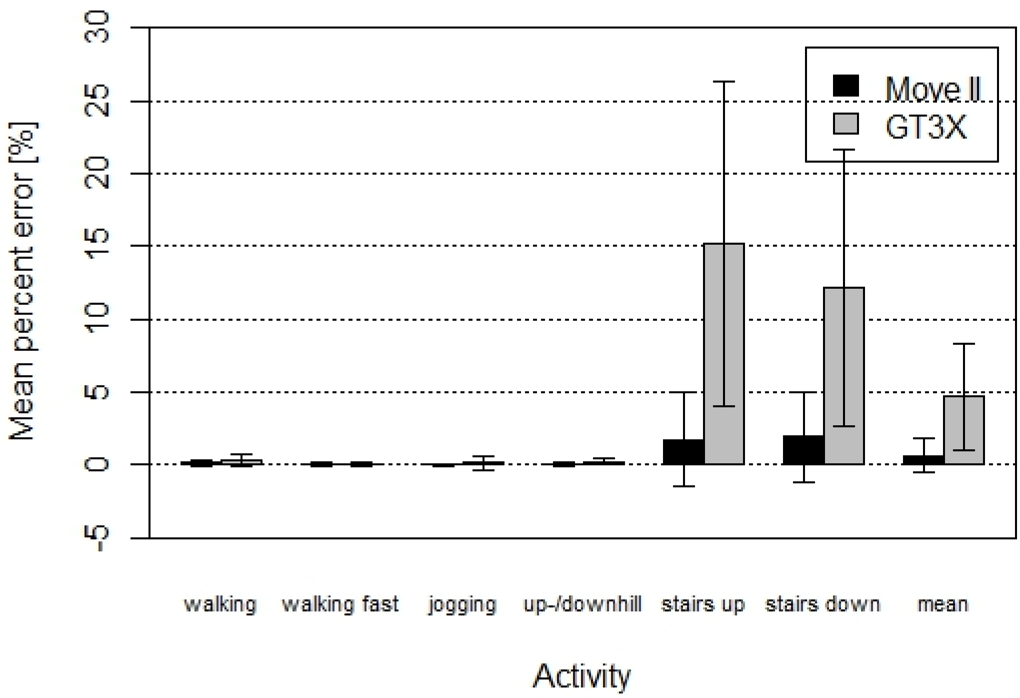

Fig. 1: Mean percent error (actual - predicted) ± SD during the different activities

Table 4 shows the ICCs for Move II and GT3X. The intraclass correlation analysis revealed a high correlation between the reference and the predicted values for walking, walking fast, jogging and walking up- and down-hill. During stair-walking the agreement between the predicted values and the reference for the Move II was smaller, but nevertheless significant. The results for the same activities for the GT3X were not significant.

Table 4: ICCs for Move II and GT3X

Activity	Move II ICC	Move II bounds	Move II p-value	GT3X ICC	GT3X bounds	GT3X p-value
walking	1.000	0.998-1.000	0.000	0.997	0.984-0.999	0.000
walking fast	1.000	1.000	0.000	1.000	0.999-1.000	0.000
jogging	1.000	1.000	0.000	0.999	0.997-1.000	0.000
walking up- /downhill	1.000	0.999-1.000	0.000	0.999	0.991-1.000	0.000
walking stairs up	0.789	0.486-0.917	0.000	0.060	-0.104-0.322	0.263
walking stairs down	0.529	0.102-0.790	0.003	0.061	-0.109-0.328	0.272

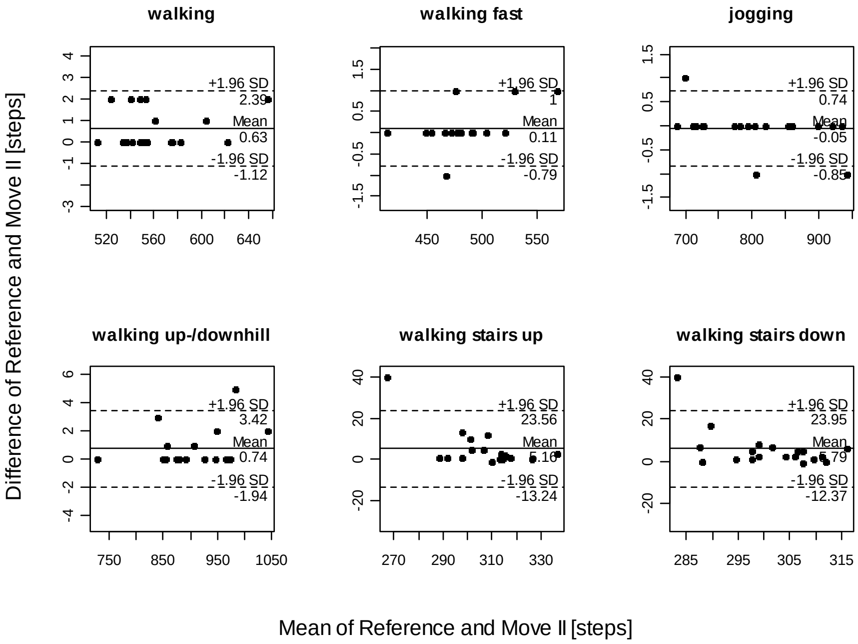

Fig. 2: Bland–Altman plots for Move II. The solid lines represent the mean bias between actual and calculated steps, and the dashed lines represent the limits of agreement (± 1.96 SDs)

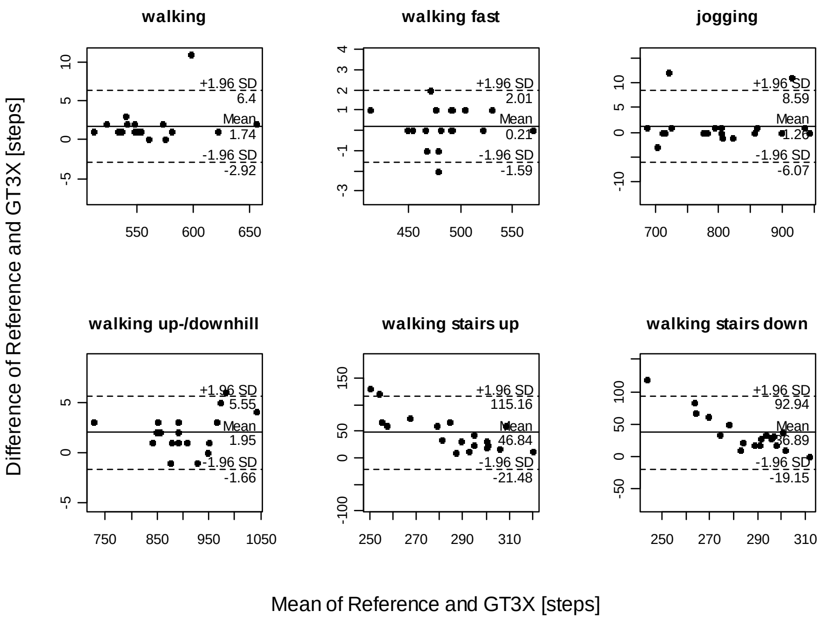

Fig. 3: Bland–Altman plots for GT3X. The solid lines represent the mean bias between actual and calculated steps, and the dashed lines represent the limits of agreement (± 1.96 SDs)

The Bland-Altman plots for the different everyday life walking activities for Move II and GT3X activity sensor are shown in Figs. 2 and 3 respectively. The Bland-Altman plots for the Move II (Fig. 2) reveal a bias of 0.63 (-1.12 to 2.39) while walking, 0.11 (-0.79 to 1.00) while walking fast, -0.05 (-0.85 to 0.74) while jogging, 5.16 (-13.24 to 23.56) while walking stairs up and 5.79 (-12.37 to 23.95) while walking stairs down.

The Bland-Altman plots for the GT3X (Fig. 3) reveal a bias of 1.74 (-2.92 to 6.4) while walking, 0.21 (-1.59 to 2.01) while walking fast, 1.26 (-6.07 to 8.59) while jogging, 16.84 (-21.48 to 115.16) while walking stairs up and 36.89 (-19.15 to 92.94) while walking stairs down.

Although the patterns do not exhibit any systematic form of bias for both devices, one can see that the relationships are tighter for the Move II estimations.

4. Discussion

In the current study two activity monitors were tested for their accuracy in measuring step counts during 6 different walking activities. Compared to other similar studies [14] we tried to examine the accuracy of the two devices not only for different gait speeds but also other walking activities such as stair walking or walking up- and down-hill. Both devices showed a very good accuracy for the different gait speeds. The biggest errors for both devices were observed during stair walking. This is probably due to the fact that the stair-walking gait differs from the normal walking gait, based on which most of the step detection algorithms have been developed.

The current study has limitations. All the test subjects had an average BMI of 24.6 ± 3.5 kg·m-2 which means that the effect of the obesity on the accuracy of the devices could not be investigated [8]. Additionally all the participants were between 22 and 46 years old and therefore these results can be not generalized for other groups of people (e.g. children, elderly people) without any further investigation.

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