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Activity trackers are not valid for step count registration when walking with crutches

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ABSTRACT

Background: The use of activity trackers has been proposed in rehabilitation where resuming physical activity is deemed crucial, e.g. after total knee arthroplasty (TKA). As patients initially often walk with crutches, it is of importance that clinicians can rely on the information provided by activity trackers.

Research question: To determine concurrent validity of 2 activity trackers for step count, positioned on different locations on the body during gait with crutches.

Methods: Thirty healthy participants performed normal gait and gait with one crutch and two crutches over a distance of 400 m while wearing a Garmin Vivofit 3 and Nokia Go on both wrists and both sides at the waist (only Nokia Go). The gold standard was manual step count. Inter-device reliability (within brand) was assessed by calculating Intraclass Correlation Coëfficients (ICC) and concurrent validity was determined by performing paired sample t-tests, ICC and Bland-Altman Plots with % bias and 95% CI Limits of Agreement (LoA).

Results: During normal gait, both the Nokia and Garmin showed good to excellent inter-device reliability (ICC > 0.75). Both devices showed concurrent validity compared to manual step count, with slightly better results for the Garmin compared to the Nokia at the wrist (% bias = respectively 0.0% and -1.4% with 95% CI LoA: respectively -1.7%;1.7% and -8.6%;5.8%; ICC: respectively 0.995 and 0.859). During gait with crutches, however, overall 95% CI of LoA were beyond clinically acceptable differences and ICC values with the gold standard were poor. Therefore, notwithstanding a sometimes reported small average % bias, validity of the activity trackers for step count during gait with crutches was not established, independent of tracker position.

Significance: Activity trackers showed no concurrent validity when monitoring step count during gait with crutches. This should be taken into account when implementing this technology in e.g. post-operative goal setting in patients with TKA.

1. Introduction

As clinicians are often dependent on patient information in a home rehabilitation setting, reporting bias could hamper best possible care. Wearables, such as activity trackers with integrated accelerometers, might bypass this bias by objectifying patient specific information such as step count [1,2]. Several activity trackers have been proven reliable and valid, both in healthy [3,4] and patient populations [5,6].

The use of activity trackers has been proposed in the rehabilitation e.g. after total knee arthroplasty (TKA) [7]. It is crucial for these patients to resume physical activity in the early stages of rehabilitation [8]. Recently, a progressive loading scheme has been proposed based on daily step count [7]. To optimize compliance and objectify actual activity, patients should be monitored and receive feedback on whether or not they attained their activity goal (step count). However, during the first weeks of rehabilitation after orthopedic surgery to the lower limbs, patients usually walk with crutches. It is of importance that clinicians can rely on the information provided by activity trackers, as calculation algorithms might be inaccurate during impaired gait. Currently, validity of activity trackers when walking with one or two crutches has not been established.

The goal of this study was to determine concurrent validity of two consumer-based activity trackers on different locations during gait with one or two crutches. Inaccurate measurements during gait with crutches were hypothesized.

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2. Methods

2.1. Subjects

Thirty healthy participants (15♀/15♂, 24.9 ± 5.33yrs, 171.7 ± 0.79 m, 68.4 ± 8.62 kg) in this controlled repeated measures study were recruited from a convenience sample via direct personal contact. The XXX University Hospital's ethics committee approved the study protocol and all participants signed informed consent.

2.2. Instruments

The Nokia Go Activity & Sleep tracker (NoGo) (Nokia Europe, Issy-les-Moulineaux, France) and Garmin Vivofit 3 (GaVi3) (Garmin International Inc., Olathe, KS, USA) were used. As gold standard, steps were counted with a manual step counter by two independent observers.

2.3. Procedure

First, participants walked at own comfortable speed without crutches. Subsequently, participants walked with one elbow crutch and the randomly chosen 'affected' leg was moved forward simultaneously with the crutch in the opposite hand ('non-affected' side). Finally, the gait pattern was performed analogues to the second modality, however, with two elbow crutches. For both crutch modalities the participant was instructed to unburden 50% of the body weight. Practice trials were performed with feedback of both a scale and the researchers to assure consistent performance during the actual test trials. For each modality, the subjects had to walk a fixed distance of 400 m on a rectangular circuit in a sports hall.

Two NoGo trackers and one GaVi3 were fastened on one wrist and vice versa on the other wrist. In addition, a Nokia Go tracker was attached on each side of the belt. Positioning of the activity trackers in relation to wrist side and the 'affected' leg in relation to crutch side were randomized for each subject, but the same for every within subject condition.

2.4. Statistical analysis

All statistical analyses were performed using SPSS 25 (SPSS Inc., Chicago, IL, USA). Normality of all data was checked with the Shapiro-Wilk test. To identify differences in speed between conditions, a repeated measures ANOVA with post hoc pairwise comparisons with Bonferroni correction was performed. Inter-device reliability, between two sensors of the same brand at different locations was assessed by calculating intraclass correlation coefficients (ICC (2,1): two-way random, absolute agreement, single measures) with 95% confidence intervals (CI) and interpreted according to Cicchetti and Sparrow (ICC ≥ 0.75 = excellent; ≥0.60 = good; ≥0.40 = fair; < 0.4 = poor) [9]

For establishing validity, ICC's (2,1) between the two methods were calculated. A paired sample *t*-test was performed to determine systematic differences between each tracker/position and the manual step counter (gold standard). Subsequently, Bland-Altman plots with 95% limits of agreement (LoA) (mean difference ± 1.96 SD) were generated to visualize the degree of agreement between the each tracker and the gold standard (Fig. 1). Percentage bias with the manual step counter was calculated (((activity tracker–manual step count)/ manual step count)*100). Alpha error level was set at 5%.

3. Results

Self-selected walking speed was significantly higher during normal gait (= 1.36 m/s) compared to both gait with one and two crutches (respectively 0.93 m/s and 0.93 m/s, $p < 0.001$). The number of included trials per modality differed between trackers due to data acquisition error (Table 1).

3.1. Inter-device reliability

Reliability of both the NoGo and the GaVi3 worn at the same wrist during normal gait was excellent with ICC (95%CI) values of 0.801 (0.613-0.904) and 0.993 (0.986-0.997) respectively. Reliability for the NoGo and the GaVi3 worn at different wrists and for the Nokia Go worn at both sides of the belt, was also good to excellent with ICC (95%CI) values of 0.606 (0.308-0.797), 0.988 (0.975-0.994) and 0.777 (0.586-0.887) respectively.

3.2. Concurrent validity

Table 1 displays comparative data for both activity tracker systems and the manual step count during different gait modalities.

For normal gait, concurrent validity was established for both activity trackers in particular for the GaVi3 showing a 0% bias with the manual step count and low LoA only ranging from -1.7% to 1.7%. The NoGo did show a significant difference in the paired sample *t*-test with the manual step count for both the location at the wrist and the belt, however, the %bias remained < 2% with acceptable 95% LoA (Bland-Altman plot, Fig. 1). Strong correlations were observed between the activity trackers and the manual step count.

During gait with one crutch, wearing the NoGo on the belt at the 'non – affected' side, and both activity trackers at the wrist at the 'affected' side (= wrist not holding the crutch) showed no significant difference ($p > 0.05$) with the manual step count with small %bias (< 5% [10]). Other tracker positions did show a significant difference ($p < 0.05$) with a %bias > 5%. For both trackers and positions, however, broad LoA were observed and poor correlations with the gold standard.

During gait with two crutches, only the NoGo on the belt at the 'non – affected' side showed no significant difference with a %bias of 0.3%. However, as for the other positions of the NoGo and the GaVi3 at the wrist, broad LoA and poor correlation with the gold standard were noted.

4. Discussion

During normal gait, both the NoGo and GaVi3 showed good to excellent inter-device reliability and concurrent validity. However, during gait with crutches, both activity trackers proved to be not valid, independent of sensor positioning. Despite a small average %bias, overall 95% CI of the LoA where beyond clinically acceptable differences (up to 100%). In general, the NoGo overestimated the amount of steps and the GaVi3 underestimated the true amount of steps, although not consistently.

A possible explanation for lower validity in gait with crutches is lower walking speed [11,12]. Crutches might also affect the walking pattern by limiting arm swing, resulting in smaller displacement and accelerations of the center of mass, probably affecting validity. Therefore, implementing different calculation algorithms based on normal or restricted gait should be focus of further development. Future research should also consider controlling for speed between conditions as this was a limitation of the current study.

In conclusion, these two activity trackers are not valid when used to monitor step count during gait with crutches. This should be taken into account when implementing this technology in e.g. post-operative goal setting in patients with TKA.

Declarations of interest

None.

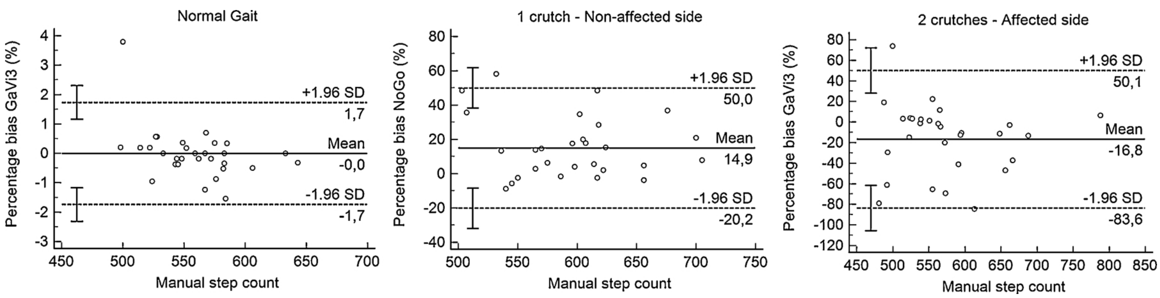

Fig. 1. Representative selection of Bland-Altman plots per gait condition: Normal gait comparing the Garmin Vivofit 3 (GaVi3) to manual step count; Gait with 1 crutch comparing the Nokia Go (NoGo) worn at the wrist (side of the crutch) to manual step count; Gait with 2 crutches comparing the Garmin Vivofit 3 (side of the 'affected' leg) to manual step count. In every plot, the percentage bias ((activity tracker - manual step count)/ manual step count) is plotted against the manual step count as gold standard.

Table 1
Concurrent validity outcome measures for Nokia Go (NoGo) and Garmin Vivofit 3 (GaVi3).

Walking modality	n	Mean (SD)	Manual count Mean (SD)	Paired sample *t*-test		Bias %	95%CI of Limits of Agreement	ICC (95%CI)
				Mean diff (95%CI)	P-value			
Normal gait (speed: 1.36 (0.16) m/s)								
NoGo Belt	30	553.5 (30.96)	559.1 (34.28)	−5.53 (−10.40; −0.67)	0.027	−0.9	−5.1; 3.3	0.910 (0.803;0.958)*
NoGo	30	550.6 (31.75)	559.1 (34.28)	−8.43 (−16.77; −0.97)	0.048	−1.4	−8.6; 5.8	0.753 (0.535;0.876)*
GaVi3	30	558.9 (32.64)	559.1 (34.28)	−0.16 (0.85; −1.91)	0.846	0.0	−1.7; 1.7	0.991 (0.980;0.996)*
One crutch (speed: 0.93 (0.17) m/s)								
NoGo Belt NA	26	599.8 (123.17)	591.2 (50.23)	8.73 (−49.04; 66.50)	0.758	2.6	−45.1; 50.3	−0.163 (−0.535;0.246)
NoGo Belt A	28	651.1 (122.73)	595.9 (52.69)	55.18 (2.90; 107.45)	0.039	10.2	−37.2; 57.7	−0.017 (−0.325;0.324)
NoGo NA	29	685.3 (111.5)	598.0 (52.92)	87.31 (48.39; 126.22)	< 0.001	14.9	−20.2; 50.0	0.212 (−0.087;0.505)*
NoGo A	29	565.8 (148.5)	598.0 (52.92)	−32.27 (−94.50; 29.95)	0.297	−4.3	−57.3; 48.6	−0.077 (−0.425;0.292)
GaVi3 NA	29	514.5 (167.23)	598.0 (52.92)	−83.52 (−155.95; −11.09)	0.025	−12.6	−72.8; 47.7	−0.150 (−0.431;0.189)
GaVi3 A	27	583.1 (116.1)	597.1 (54.77)	−14.00 (−62.26;34.26)	0.556	−1.8	−44.2; 40.7	0.099 (−0.296;0.460)
Two crutches (speed: 0.93 (0.20) m/s)								
NoGo Belt NA	27	558.3 (159.18)	566.6 (68.76)	−8.29 (−81.50; 64.90)	0.818	0.3	−63.1; 63.7	−0.145 (−0.514;0.255)
NoGo Belt A	28	630.5 (129.40)	570.1 (70.05)	60.39 (1.20; 119.58)	0.046	12.2	−39.7; 64.2	−0.067 (−0.373;0.279)
NoGo NA	30	668.4 (155.21)	575.9 (71.01)	92.53 (38.82; 146.25)	0.001	16.6	−36.2; 69.5	0.228 (−0.076;0.516)
NoGo A	30	662.2 (135.20)	575.9 (71.01)	86.37 (37.55; 135.18)	0.001	15.7	−28.3; 59.7	0.206 (−0.089;0.494)
GaVi3 NA	30	430.1 (208.69)	575.9 (71.01)	−145.80 (−236.27; −55.33)	0.003	−23.0	−102.3; 56.3	−0.149 (−0.394;0.164)
GaVi3 A	30	476.8 (191.68)	575.9 (71.01)	−99.10 (−169.72; −28.48)	0.008	−16.8	−83.6; 50.1	0.119 (−0.170;0.421)

SD = standard deviation; CI = confidence interval; ICC = intraclass correlation coefficient; GC = gait cycle; NA = non-affected side; A = affected side; * = $p < 0.05$.

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