4601 Six Forks Road
Suite 103
Raleigh, NC 27609
919.747.3668
www.valencell.com

Accuracy of step count from Valencell's Benchmark Ear 5.0

CTA standard for validating step count walking/running

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PURPOSE

This report examines the accuracy of Valencell's Benchmark Ear 5.0 biometric sensor (BE5.0) for measuring steps during walking and running. This report follows the guidelines of the CTA standard for step rate accuracy.

INTRODUCTION

Valencell's Benchmark™ sensor systems incorporate Valencell biometric sensor technology in a pre-packaged system. The Benchmark modules are complete biometric sensor systems that include all the hardware, optomechanical design, firmware and algorithms that allows for integration into a wide range of wearable devices.

Valencell has developed a wireless demonstration system (WDS) that allows for collection of biometric data over Bluetooth communication with a Benchmark sensor. For the purpose of evaluating validity, video was taken of the exercise sessions followed by manual step counting as a baseline device.

METHODS

Trials examining validity of step count output of BE5.0 compared to manual count obtained from video during walking and running were completed. For this dataset 20 participants total were utilized (characteristics in Table 1). Each participant completed separate walking and running protocols as outlined by the Consumer Technology Association standard 2056-2016 (ANSI) Physical Activity Monitoring for Fitness Wearables: Step Counting (protocol details in Table 2). Participants wore a WDS (BE5.0, Valencell, Raleigh, NC) in their ear fitted with small, medium, or large gel and tip sizes. Gel and tip size were chosen for the most secure fit (Figure 1). Participants were video recorded during the walking and running trials to allow for manual count of steps following the session.

Participants completed a five-minute walking trial and a five-minute running trial, separately. Video recordings included the participant's lower body from the sagittal plane. Participants walked at 1.34 m·s-1 (3 mph) and jogged at a self-selected pace within 2.24-5.36 m·s-1 (5-12 mph). The speed was held constant throughout each of their walking and running trials. All trials were conducted at a 1% grade. At the start of each trial, participants began standing on the treadmill with their hands at their sides. The treadmill was then started and set to the desired speed. Participants were reminded to walk normally, not to hold onto the handrails of the treadmill, and to refrain from any unnecessary movements with their hands. Anyone not following these instructions were asked to repeat the trial. After five minutes elapsed, the treadmill was stopped and the number of steps were recorded from each device.

Following data collection two separate researchers analyzed each video and manually counted the steps. Step counting began as soon as the treadmill began moving and stopped when the treadmill came to a complete stop. A step was defined as "a movement making forward progress" in order to standardize the manual step count via video. If the step counts did not match exactly, a third researcher also manually counted. Either the matching count of the two researchers or the average counts of the three researchers was used as the reference step count. The walking and running values obtained were compared to the baseline step count utilizing mean absolute percent error

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(MAPE) The acceptable MAPE was established to be less than 10% difference as outlined in the CTA Physical Activity Monitoring for Fitness Wearables: Step Counting standard.

Table 1. Participant Characteristics Summary

	Age	Height (m)	Weight (kg)	BMI (kg/m^2)	Calculated Max HR
Average	49	1.7	67.7	22.9	174
SD	16	0.1	13.2	2.5	11.2
Max	77	1.9	96.4	28.8	18
Min	21	1.5	45.5	18.6	150
Men	10				
Women	10				

Table 2. Walking and Running Protocols (all speeds at an 1% incline)

Time (min)	**Walking protocol (speed in km/hr)**
0:00 – 0:30	Standing
0:30 – 6:00	Walking between 4-6.5 (2.5 - 4 mph)
6:00 – 6:30	Standing

Time (min)	**Running protocol (speed in km/hr)**
0:00 – 0:30	Standing
0:30 – 6:00	Running between 8 -19.5 (5 - 12 mph)
6:00 – 6:30	Standing

Figure 1. Earbud Placement

RESULTS

Twenty trials resulted in a manually counted average step count of 569 ± 39 steps for walking and 832 ± 55 for running. The BE5.0 reported 569 ± 38 steps for walking and 838 ± 55 for running. The bias for BE5.0 was -0.02 steps walking and -6.06 steps running with a MAPE of 0.57% walking and 0.73% running.

Table 4. Statistical analysis for step count.

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Walking Protocol	Manual Count	Device (BE5.0) Count
Average count (mean ± SD)	569 ± 39	569 ± 38
Minimum count	480	479
Maximum count	628	626
MAPE	0.57%	
Bias (mean ± SD)	-0.02 ± 4.02	

Running Protocol	Manual Count	Device (BE5.0) Count
Average count (mean ± SD)	832 ± 55	838 ± 55
Minimum count	765	767
Maximum count	956	974
MAPE	0.73%	
Bias (mean ± SD)	-6.06 ± 5.66	

Conclusion

Valencell's BE5.0 device is accurate for monitoring steps during walking and running. The device greatly exceeds the 10% MAPE as outlined by the Consumer Technology Association. Additional analysis on cadence while walking, running and cycling, as well as distance and pace while walking and running can be found in Appendix A and Appendix B, respectively.

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APPENDIX A: Step Rate/Cadence while Walking, Running and Cycling

In addition to step count, cadence was also analyzed for walking, running and cycling protocols. For cadence, or step rate, while walking and running, the same tests and protocols were used as previously discussed for step count.

For the cycling trial, each participant completed a single, indoor cycling session on a stationary bike in accordance with the CTA-2065 dynamic indoor cycling protocol, shown in in Table 5. Cadence was recorded using a Bluetooth cadence sensor on the stationary bicycle's crank arm paired to the Wahoo mobile application. The cadence recorded on Wahoo was compared to the cadence recorded by the BE5.0 using 1-sec data on both.

Data from the devices was analyzed using Running mode for both the walking and running protocols and Cycling mode for the cycling protocol.

Table 5. Dynamic Indoor Cycling Protocol

Time (min)	Cycling Protocol
0:00 – 1:00	Sitting quietly on the bike
1:00 – 3:00	Easy to moderate cycling
3:00 – 5:00	Vigorous cycling utilizing a high cadence (>85 rpm, add resistance as necessary)
5:00 – 7:00	Easy to moderate cycling
7:00 – 9:00	Vigorous cycling utilizing a high resistance (add resistance as necessary)
9:00 – 11:00	Easy to moderate cycling
11:00 – 12:00	Sitting quietly on the bike

Table 6. Statistical analysis for cadence.

Walking Protocol	Manual Cadence	Device (BE5.0) Cadence
Average cadence (mean ± SD)	113 ± 8	113 ± 8
Minimum average cadence (mean ± SD)	96	96
Maximum average cadence (mean ± SD)	125	126
MAPE	0.56%	
Bias (cadence, mean ± SD)	0.00 ± 0.80	

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Running Protocol	Manual Cadence	Device (BE5.0) Cadence
Average cadence (mean ± SD)	162 ± 11	164 ± 11
Minimum average cadence	144	146
Maximum average cadence	187	191
MAPE	0.79%	
Bias (mean ± SD)	-1.18 ± 1.11	

Cycling Protocol	Cadence Sensor on Bike	Device (BE5.0) Cadence
Average cadence (mean ± SD)	75 ± 10	75 ± 10
Minimum average cadence	90	90
Maximum average cadence	52	52
MAPE	1.59%	
Bias (mean ± SD)	0.02 ± 0.34	

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