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Brief Report

Examining the Accuracy of the Coros Vertix 2 and the Garmin Fenix 6 for Distance Assessment During Two Trail Running Conditions: A Pilot Study

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Abstract

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Purpose: The purpose of this investigation was to determine accuracy of the Coros® Vertix 2 and Garmin® Fēnix 6's integrated global navigation satellite system (GNSS) distance tracking during two trail running conditions in a group of recreational runners. Methods: Six participants (females n=4) completed four self-paced, 1.60 kilometers (km) trail runs, for a total of 24 unique trials. Device accuracy was assessed in two trail conditions, heavy (HT) and light tree coverage (LT). Both watches were worn simultaneously on opposite wrists and then switched for the next trial. Distance measured by the watches was recorded (to the nearest 0.001 km) every 0.402 km. The watches' distance data were compared to the criterion using repeated-measures analysis of variance, and LT versus HT and between left (LW) and right wrists (RW) were compared using paired-samples t-tests (alpha<0.05). Results: The Garmin reported 1.48±0.05 (mean ± standard deviation) km and the Coros reported 1.50±0.03 km for the trail, which was significantly less than the criterion distance (1.60 km) (p<0.01 for both watches) but was not different between watches (p=0.43). The distance measured by the watches was significantly greater in LT (1.53±0.03 km) than HT (1.47±0.05 km) (p<0.01). The distance was significantly greater for LW (1.52±0.06 km) than for RW (1.50±0.05 km) (p=0.04). Conclusion: Both watches were, on average, 6-7% below the measured distance and, in some trials, the watches underestimated nearly 11% from the criterion measure. Based on these findings, we urge caution when assessing distance in trail conditions especially under heavy tree cover.

Keywords: Wearable technology, activity tracking, GPS

Introduction

Wearable technology has been the number one fitness trend for five of the past seven years demonstrating their enduring popularity among both fitness professionals and the public.[1] Most of today's smartwatches employ global navigation satellite systems (GNSS) that allow users to track distance, speed, and location during an outdoor exercise bout. The world's satellite systems are GPS (United States), GLONASS (Russia), Galileo (European Union), QZSS (Japan), and BeiDou (China). Since May 2000, with the wide proliferation of personal GPS devices, civilians have had access to GPS devices with similar quality to military-grade GPS, with the main difference being the frequency the devices use. GNSS-enabled devices with single frequency

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capabilities connect to one global satellite system at a time while devices with dual-frequency connect to more than one satellite at once. When a GNSS-enabled device can connect with more than one satellite system around the globe simultaneously, the device's readings are typically more accurate.[2]

The first GPS-enabled watch marketed was the Casio PRT-1GP, released in 1999. In 2003, Garmin, an established GPS sport watch company, released the Garmin Forerunner; in 2006, Nike followed suit and released the Nike+. These early devices tracked user distance traveled and pace. Then, in 2008, the FitBit Classic became the first wireless activity tracker to send data to both the internet and a mobile phone app. Ever since, there has been a steady expansion in the number of companies manufacturing these devices. In 2015, there were 39.5 million adults in the U.S. using wearable technology which was over a 50% increase in usage from 2014 numbers.[3] According to a 2020 Pew Research study, one-in-five adults in the U.S. were regularly using wearable technology.[4] GNSS-enabled watches are used by many runners as an aid for their training, with a 2021 study of recreational runners showing that 87.6% of the participants reported using GPS-enabled watches to monitor their activity.[5] Moreover, GNSS watches are used in multiple different settings/ conditions (open road, track, and even heavily wooded trails). However, the accuracy of the GNSS technology is impacted by proximity to tall buildings and/or tree coverage.[6] For GNSS-enabled devices to function, they must connect with multiple satellites. The signals between watch and satellite reflect off tree canopies and tall buildings, therefore, reducing the signal quality.[7,8] Early GNSS watches were sensitive to even small increases in tree canopy coverage, which could result in large errors in distance tracking.[9]

More recently, Gilgen-Ammann et al.[8] investigated the accuracy of recorded distance in eight different sport watches including Apple, Coros, Garmin, Polar, and Suunto brands and in an urban setting, a forested area, and an open area 400m stadium track. These conditions were also performed at varying speeds by having subject walking, running, and cycling. The distance recorded was less accurate in urban and forest settings than in the track setting, and there were lower error rates in the walking and cycling conditions compared to the running condition. Furthermore, most of the measurements were significantly underestimated, other than in the track condition where measurements were overestimated.

Literature on more recent GNSS watches is lacking. Specifically, there are currently no studies examining the accuracy of the Garmin Fēnix 6 and the Coros Vertix 2 for assessing distance traveled during outdoor exercise. These watches are widely used in the trail running community.[10] Trail watch accuracy has been previously tested on the road; however, the performance of these watches is meant for the trails and their accuracy on the road may not transfer to their intended setting. Additionally, the Garmin Fēnix 5, the predecessor to the Fēnix 6, is cited as being one of the more accurate trail watches when compared to other trail watches.[11] The Garmin Fēnix 6 can communicate via one frequency with three major satellite systems—GPS, GLONASS, and Galileo. The Coros Vertix 2 is the first commercially available watch capable of communicating with all five of the satellite systems (GPS, GLONASS, Galileo, QZSS, and BeiDou) utilizing two frequencies simultaneously. Given the communication with multiple satellites by both watches, it is plausible that distance-tracking accuracy will be improved even under heavy tree cover. Determining the accuracy of these satellite systems in these two high performance watches is important for the running and research community because trail runners are using them and trusting that the device is accurately reporting their daily and weekly mileage. Wiesner et al. determined that the majority (76.8%) of wearable technology users reported that they fully trust the tracking capabilities of their device.[12] The accuracy, or lack thereof, of these watches could, therefore, influence training design for runners who use them. Thus, the purpose of this investigation was to determine the accuracy of the Coros® Vertix 2 and Garmin® Fēnix 6 in two trail running conditions among a group of recreational trail runners. We hypothesized that the Coros Vertix 2 would be more accurate than the Garmin Fēnix 6 because of the unique dual-frequency capabilities of the Coros watch. We also hypothesized that the watches would have greater agreement with the reference distance during the light tree coverage condition compared to the heavy condition.

Methods

Participants

Six participants (female n=4, male n=2, **reported otherwise n = 0**) were recruited by word of mouth. All participants were 18 years of age and older, healthy, experienced recreational trail runners.

The study was approved by the university's Institutional Review Board for Human Subject's Research and adhered to the ethical standards of the Helsinki Declaration. All participants provided written informed consent after details of the study and potential risks were communicated verbally and in written form before data collection.

This research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*.[13]

The total sample size was determined based on previous studies with similar designs but was ultimately constrained by the "pragmatics of recruitment and the necessities for examining feasibility" as noted by Leon et al[14] which are fundamental to pilot studies. Based on preliminary estimates, a future adequately powered study would require approximately 30 participants to detect a moderate effect size (power = 0.80, α = 0.05).

Protocol

Prior to GNSS data collection, participants reported to the lab to record height, weight, resting heart rate, and resting blood pressure.

Trail Courses.

Two courses were identified in Riley Trails Park in Holland, MI, USA (Figure 4). Trail 1 was identified to have little to no tree coverage with open areas along most of its length (LT). The course for Trail 1 was a loop. Trail 2 was identified to have moderate to heavy tree coverage and was almost entirely covered by overhead trees so that the sky was mostly obstructed (LT). The course for Trail 2 was point-to-point. The park was far from tall buildings, as the surrounding area was mostly forested or rural. The courses were measured twice using a TR Industrial FX Pro Series Measuring Wheel (TR Industrial, Pomona, CA) and marked to ensure runners stayed on course and completed exactly 1.60 km. The trails used in this study were hardpack dirt and well-worn from frequent mountain biking, creating a clear, <1 meter width that participants were able to comfortably remain within while allowing researchers good control of distance and direction.

Ground markings (spray painted vertical lines along the route) approximately every 18 to 36 meters were added to further demarcate the path. Most importantly, prior to data collection, participants were familiarized with both trails by walking their entire length with research staff and were instructed on exactly where to remain on the path. This investigation was performed in the summer months when the trees had full leaves and on two consecutive, mostly sunny days.

Data Collection.

The participants ran each trail twice, for a total of four trials. The four different conditions were: 1) LT with the Garmin on the right wrist, Coros on the left wrist, 2) LT with the Coros on the right wrist, Garmin on the left wrist, 3) HT with the Garmin on the right wrist, Coros on the left wrist, and 4) HT with the Coros on the right wrist, Garmin on the left wrist. Participants completed two distinct trail courses (HT and LT) across two testing days, with three participants tested per day. All participants completed either the heavy or light trail first, with trail order randomized and counterbalanced between participants. On each trail, participants performed two consecutive runs (back-to-back), alternating device placement (left vs. right wrist) between trials; wrist assignment order was also randomized and counterbalanced. After completing both runs on the first trail, participants rested while the remaining participants completed the same protocol, ensuring that all trials were conducted at approximately the same time of day. Participants then completed two consecutive runs on the second trail following the same procedures. This design minimized variability in environmental conditions (e.g., weather and cloud cover). Overall, there were 24 individual running trials, which is similar to Gilgen-Ammann et al.[8] who determined accuracy of eight different smartwatches using only one subject that wore the watches over multiple trials. Before beginning each trial, the wrist placement was indicated on each watch and device settings were updated with the participant's sex, body weight and height, per manufacturer instructions. Watches were calibrated by having participants hold their arm out, away from their body with the watch face pointing up. The participants held their arm in this position until the watches indicated that they were calibrated to the satellites and ready to begin tracking.

The participants completed each trial at a self-selected, submaximal pace, stopping every 0.40 km (quarter mile) so that distance for both watches was recorded manually from the device watch faces at 0.40, 0.80, 1.20, and 1.60 km. The data collection was done over a two-day period. The manually recorded GNSS data were compared against each other and against the criterion measure. The GNSS data were also downloaded off of each device for pace analysis (Table 1).

Table 1. Mean distance across all trials recorded at every 0.40km (quarter mile). **Data are presented as Mean (SD).**

Watch/Wrist	Light				Heavy			
Criterion distance (km)	**0.40**	**0.80**	**1.20**	**1.60**	**0.40**	**0.80**	**1.20**	**1.60**
Coros Vertix 2/ Left	0.40 (0.00)^	0.79 (0.01)^	1.18 (0.01)*^	1.56 (0.03)*^	0.38 (0.01)*	0.76 (0.01)*	1.15 (0.01)*	1.49 (0.02)*
Coros Vertix 2 /Right	0.39 (0.01)^	0.77 (0.01)*	1.14 (0.03)*	1.52 (0.03)*^	0.37 (0.02)*	0.76 (0.02)*	1.13 (0.02)*	1.48 (0.03)*
Garmin Fēnix 6/ Left	0.40 (0.01)^	0.80 (0.01)^	1.19 (0.02)^	1.56 (0.03)*^	0.37 (0.01)*	0.75 (0.02)*	1.12 (0.03)*	1.46 (0.06)*
Garmin Fēnix 6/ Right	0.40 (0.00)^	0.78 (0.01)*^	1.16 (0.02)*	1.53 (0.03)*	0.38 (0.02)*	0.75 (0.02)*	1.13 (0.02)*	1.46 (0.04)*

Light: condition with light tree coverage. Heavy: condition with heavy tree coverage. *Indicates significant difference from reference distance ($p<0.05$). ^Indicates significant difference from heavy tree coverage condition ($p<0.05$).

Statistical Analysis

Repeated-measures analysis of variance was used to compare the full trail distance reported by the Coros and Garmin compared to the flywheel, separately for Trail 1 (LT) and Trail 2 (HT). Paired-samples t-tests were then used to compare Coros versus Garmin for each distance covered and separately for LT versus HT within each watch brand at each distance, with a false discovery rate correction used to account for multiple comparisons.[15] The relationship between pace of the participants and the distance recorded on the watch was compared using a Pearson-r correlation. Bland-Altman tests were conducted to find the agreement between watch brands. Additionally, two one-sided tests of equivalence were used to determine how close the watches were to each other and to the criterion for the full running distance. Equivalence testing requires that an arbitrary, pre-defined equivalence zone to be determined, to avoid such an arbitrary decision, we started at 1% of the mean distance outputs for each watch and the criterion and increased by whole number percentages (e.g., 2%, 3%, 4%, …) until the measures were equivalent, and we report the minimum whole-number percentage at which the watches criterion were equivalent. The alpha value for all denoting statistical significance was $p<0.05$. Finally, Cohen's d effect sizes were calculated, with thresholds of 0.2, 0.5, and 0.8 used as thresholds to denote small, medium, and large effect size magnitudes.[16] Equivalence testing was conducted using the TOSTER package (version 0.4.1) in RStudio (R Core Development Team, Vienna, Austria). All other analyses were performed in SPSS version 28.0 (IBM Corp, Armonk, NY, USA) and Excel 365 (Microsoft Corp, Redmond, WA, USA).

Results

All participants were able to complete all trials, with average paces ranging from 7.7 to 12.1 km/hr, not including stop time, according to the watch data. Overall, both watches underestimated the total distance covered across every trial, with the average distance recorded on both watches being significantly different from the reference distance (reference: 1.60 km; Coros: 1.48-1.56 km, all $p<0.01$; Garmin: 1.45-1.56 km; all $p<0.01$) and with differences as small as 1% but as high as 13% when examining individual data points. The bias line on the Bland-Altman plot was 0.05 km and all but three data points fell within a 95% confidence interval (Figure 1) of ±~0.1 km when comparing the two devices. Equivalence testing revealed that the Coros was equivalent to within 7% (but not 6%) of the criterion, and the Garmin was equivalent to within 8% of the criterion (Figures 2a and 2b). Mean distances recorded for every 0.40 km in both conditions are reported in Table 1. Paired t-tests revealed that distances were significantly lower in the HT condition compared to the criterion for every combination of watch and side of body at each 0.40 km interval ($p<0.05$). For the LT condition, neither watch was significantly different from the reference distance at 0.40 km, both watches worn on the right wrist were significantly lower at 0.80 km, and all but the Garmin worn on the left wrist were lower than the reference distance at 1.20 km ($p<0.05$). The average total distance recorded by the watches in HT was 1.46-1.48 km depending on watch brand and placement, which was significantly shorter than the distance recorded in LT (1.52-1.56 km) ($p<0.05$). Additionally, distances were significantly shorter in HT compared to LT for the Coros and Garmin worn on the left wrist and for each 0.40 km increment, for the Coros worn on the right wrist at 0.40 and 1.60 km, and for the Garmin worn on the right wrist at 0.40 and 0.80 km ($p<0.05$). Effect sizes between the watch distance predictions and reference distance (Table 2) were smaller for LT than HT but were medium or large in magnitude for all conditions except for the Coros in the LT condition. In comparing watch brands, there was no significant difference for average distance recorded between the Coros Vertix 2 (1.50±0.05 km) and the Garmin Fēnix 6 (1.50±0.06 km) across both trail conditions ($p=0.43$) and were significantly equivalent to within

2% (Figure 2c). Additionally, effect sizes (Table 3) were mostly trivial or small, with no consistent trend based on level of tree coverage. When evaluating the relationship between jogging speed and watch-reported distance, the Pearson correlation revealed a significant positive, moderate relationship between average pace (km × hr^{-1}) and distance recorded (km) ($r=0.3$, $p=0.04$, Figure 3).

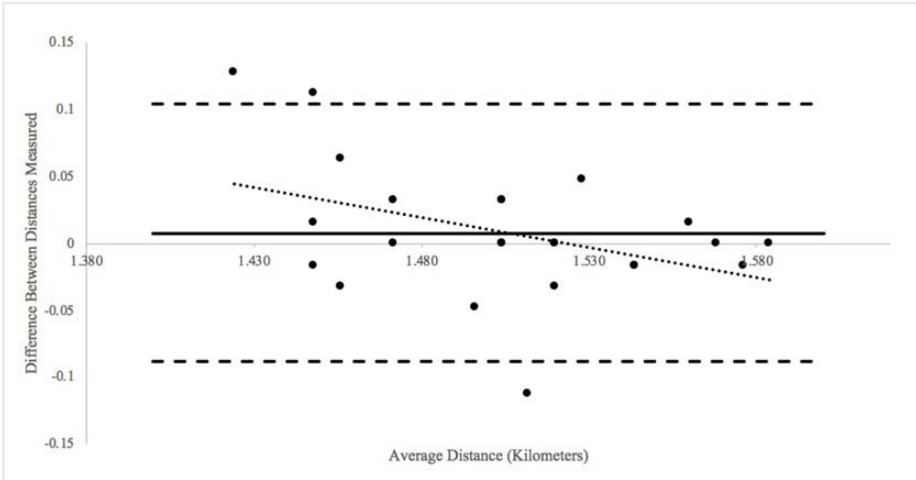

Figure 1. Bland-Altman Plot: agreement between Coros Vertix 2 and Garmin Fenix 6, bias line at 0.05. The solid black line is the mean difference, the black dashed lines with long dashes are the 95% limits of agreement, and the diagonal sloped line with short dashes is the trendline for the plotted points.

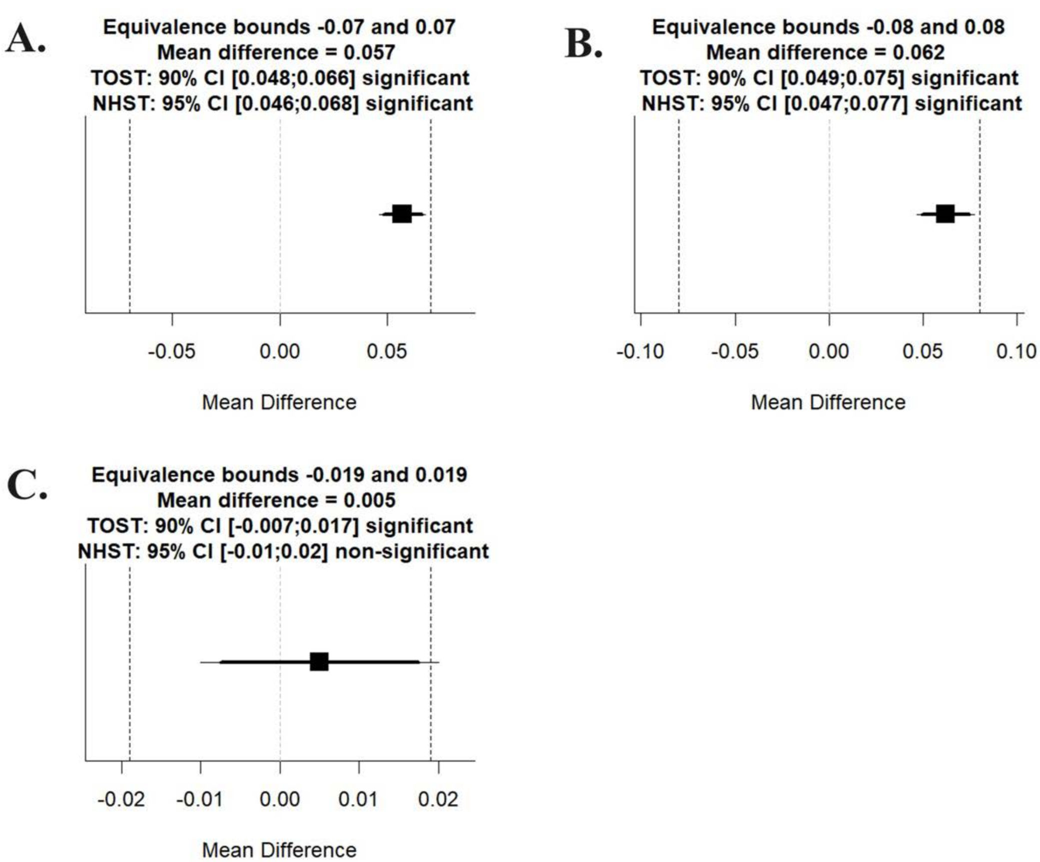

Figure 2a-2c. Equivalence Testing: (2a) Coros Vertix 2 was equivalent to within 7% of the criterion, (2b) Garmin Fenix 6 was equivalent to within 8% of the criterion, (2c) Coros and Garmin equivalent to each other within 2%.

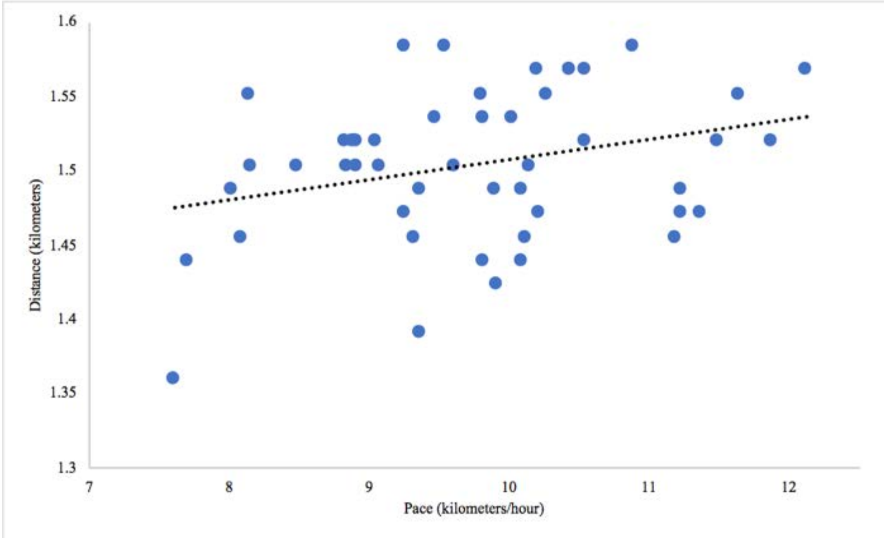

Figure 3. Pearson-r correlation, distance (km) versus pace (km × hr^{-1}) average from both watches.

Table 2. Effect sizes (Cohen's d)comparing Coros and Garmin watches to the reference distance recorded at every 0.40km (quarter mile).

	Coros light	Garmin light	Coros heavy	Garmin heavy
0.40 km	0.68	0.16	1.69	2.00
0.80 km	1.20	0.65	2.59	2.65
1.20 km	1.40	0.98	3.09	2.94
1.60 km	1.81	1.78	4.57	2.74

Light: condition with light tree coverage. Heavy: condition with heavy tree coverage.

Table 3. Effect sizes (Cohen's d) comparing Coros and Garmin watches to each other for distance assessments at every 0.40km (quarter mile).

	Light	Heavy
0.40 km	0.49	0.10
0.80 km	0.55	0.46
1.20 km	0.49	0.71
1.60 km	0.15	0.52

Light: condition with light tree coverage. Heavy: condition with heavy tree coverage.

(a) (b)

Figure 4a&b. Images from heavy tree coverage (HT) trail (a) and light tree coverage (LT) trail (b).

Discussion

This investigation determined the accuracy of two premium commercially available smartwatches, the Coros® Vertix 2 and Garmin® Fēnix 6, across trails with heavy and light tree coverage in a group of recreational runners. Both watches underestimated distance across all trials, but there was a greater underestimation of distance in HT compared to LT. Distance was underestimated by 6-7% on average and between 1 to 13% for individual trials. These findings are consistent with previous findings of a 3.5% to 8.9% underestimation in similar devices across brands in forest and urban settings [8]. Gilgen-Ammann[8] used a reference distance of 2.08 km (1.3 miles); though this distance is slightly longer than the present study's reference distance, this difference is negligible. In longer distances, such as the marathon, a previous study[2] found significant overestimation in both road and trail watches, although the percent error was small (mean difference of ~0.10 km at half-marathon and ~0.16 km at full marathon lengths). It is unclear why the watches tested underestimated distances on the trail in our investigation and overestimated on the road as reported by Lluch et al.[2] Because our study measured 1.60 km, it is not yet known the effect of longer distances on accuracy in trail conditions. However, the overestimation on the road in the marathon suggests that the discrepancy may not be cumulative, or that conditions inherent with road running (e.g., closer proximity to buildings) may affect GPS in different ways than tree coverage.

The magnitude of the underestimation in distance was affected by the amount of tree coverage. Specifically, both watches recorded less distance in HT, with mostly large effect sizes. GPS technology was designed to work in open-sky scenarios; therefore, GPS positioning can be significantly altered by just small increases in tree canopy coverage.[9] Trail runners will run on trails with tree coverage that varies frequently with the landscape. These athletes must understand the GPS discrepancies that arise with such varying coverage above them. Unfortunately, even using multiple satellites and/or multiple frequencies did not seem to improve distance accuracy, as both watches underestimated distance and to a similar degree (Figures 1 and 2a-c).

While GPS-enabled watches from Garmin and Coros are mainly marketed to and used by consumers, it is notable that these devices are also sometimes utilized by investigators in research settings. Consumers use GPS-enabled watches to monitor activity levels and most users trust what their device is telling them.[12] Researchers used GPS-enabled watches to track participants' weekly mileage.[17,18] and even as a method of subject recruitment.[18] Therefore, the accuracy of these devices has implications across multiple domains, and both consumers and researchers should consider the potential that these devices will underestimate distance covered during trail running when determining how to interpret collected data.

It is important to consider both the strengths and the limitations of this study. The sample size of the present study (n=6) is both smaller and larger than other, similar studies. Gilgen-Ammann's investigation was done with only one subject who completed all the trials.[8] Other studies that used GPS watches, such as Neilson[17] and Mayne[5] had far more participants because the nature of their investigation was focused on how the watch affected the user. In contrast, this investigation, along with Gilgen-Ammann's, was focused on the watch itself, necessitating many trials rather than more participants. In the present study we tried to balance the detrimental effects of varying weather patterns with that of multiple participants. Understanding that a larger number of participants increases the likelihood of different movement patterns affecting the watch's accuracy, we also wanted to obtain as many trials as possible with similar weather/cloud cover conditions. Therefore, we utilized a sample size that provided the largest number of trials in the shortest amount of time in an attempt to negate the impact of varying weather conditions. Even with the small sample size, the large effect sizes allowed us to identify many significant differences between the watches and reference distance, and some of the more modest effects can inform future research on sample sizes needed for identifying potential small differences in how devices measure distance under different conditions. Another limitation is that the present study did not compare the watches' accuracy on trails versus the on the road. However, the relationship between trail and road has been investigated previously and established that overhead obstructions (i.e., tall buildings, tree canopies) interfere with GNSS signals reaching the satellites, causing reductions in accuracy.

In conclusion, our findings suggest that commonly used GNSS-enabled watches may underestimate running distance in trail environments, particularly under HT conditions. Coaches and runners should account for this potential error when monitoring training load or performance in such settings. Future research should explore device accuracy across more diverse terrains and environmental conditions to better inform their validity for outdoor exercise activities.

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