



Original Research

A Study into the Reliability of the Data Flow from GPS Enabled Portable Fitness Devices to the Internet

PHILIP SHAMBROOK[†], PATRICK J. LANDER[‡], and OLIVIA MACLAREN[‡]

School of Health and Sport Science, Eastern Institute of Technology (EIT), Napier, Hawkes's Bay, NEW ZEALAND

[†]Denotes graduate student author, [‡]Denotes professional author

ABSTRACT

International Journal of Exercise Science 11(7): 1184-1193, 2018. The growth in availability and affordability of portable fitness devices (PFDs) has facilitated a concomitant growth in the collection and sharing of what are assumed to be reliable measures of exercise and physical activity. This data is increasingly used by fitness trainers to track performance progression, and plan training. Whilst the reliability and validity of these devices has been reported, investigation into the variance in the data at different access points is less well examined. The aim of this study was to investigate the reliability of the data flow from global positioning system enabled portable fitness devices, to the Internet, at multiple access points. Fifteen participants undertook four trials of two laps around a non-linear track (approximately 2350m per lap), at a self-determined pace, whilst wearing a PFD. Data was retrieved for comparison from three access points; a file recorded by the device, manually recorded data from the Internet, and a file retrieved from the Internet. There was no significant difference between the distance ($p=0.98$) and time ($p=0.99$) at any of the three points of access. However, recordings of elevation gain and loss were significantly different when compared across the three access points ($p<0.05$). It can be concluded from this study that the data flow from the PFDs used reliably reported the distance and time recorded at multiple access points, but the same was not true of the elevation gain and loss. Caution should be advised when comparing activity data from multiple access points to indicate performance progression or inform training plans.

KEY WORDS: Portable fitness devices, GPS monitoring, data flow, reliability

INTRODUCTION

Traditionally the most widely used instruments to record and compare an individual's physical activity have been self-reporting tools such as training diaries, questionnaires, and activity logs (15). The main benefit of these measures is their ability to collect data relatively easily and at low cost (15). However, these instruments have a number of limitations and have been shown to have limited validity and reliability (16). One US study reported that nearly 50% of adults met the recommended levels of activity of 150 minutes per week according to self-reports, but only five to seven per cent of the same population were found to meet the recommended levels when accelerometers were used to objectively record their activity (22, 23). This discrepancy between self-reported and objectively measured activity has also been

identified in other countries (20). These studies eloquently demonstrate the potential of PFD data to gain objective insight for fitness trainers into actual activity, as opposed to that which might be self-reported. Furthermore, it demonstrates the potential of publicly shared PFD data to investigate the physical activity habits of individuals and large population samples.

Data collection and sharing from Portable Fitness Devices (PFD) is expanding rapidly as the affordability and availability of devices increases. The market for devices that measure aspects of health and fitness (including smartphones and PFDs) is expected to reach 259 million units by 2020 (26). A recent review suggests that whilst the number of units is still increasing the number of brands entering the market peaked in 2014 (11). The collection and sharing of data is not new to any aspect of exercise and physical activity, but the combination of the volume of variables recorded, and the number of access points to such variables, has notably increased in recent years. Solutions for the aggregation of variables have been presented (6) however as the same authors acknowledge, the many disparate vendors of wearable devices and associated systems present challenges for post-activity analysis of the collected data (5).

Many PFDs enable users to collect accelerometer, GPS and associated physiological data and upload this to specific websites for post-activity analysis, storage or sharing with others (4, 13, 14). In addition, a number of third party companies such as MapMyFitness Inc., Zone Five Software and Strava Inc., allow users to upload data from PFDs from different manufacturers for analysis, sharing, and storage (12, 19, 21). As a result of the growth in the use of these devices there is potential for fitness trainers to gain objective data of actual activity as opposed to that which might be self-reported. This is however based upon assumptions of the reliability of this objective data which is perceived to be identical at all points of access. Evidence of the use of PFD's in scientific research has been reviewed (9, 11) however reliability of data at multiple access points has yet to be compared.

In the context of exercise and physical activity monitoring using data obtained from PFD, it should be noted that from the point of collection on a user's PFD to its display on the Internet, data may undergo a number of manipulations. The PFD's manufacturer, or other third party entities may manipulate the data at any stage in the data flow. Activity data collected on a PFD may be stored or displayed on the device. That data may then be transferred from the device for storage on a local computer before being transmitted to the Internet. The recorded data could then be displayed on the Internet and potentially made publicly available. Once publicly available anyone may then view the recorded activity and download a file of the data. At any point within this data flow, the data may be altered from that which was originally recorded, creating differences in the data dependent upon the point at which it was accessed. It is important that the data visible on the Internet or acquired via download is a reliable record of the activity undertaken, particularly if it is being used by fitness trainers to track performance progression or inform training plans. The flow of data from a wearable device to the internet and the integration of hardware and software has been described by other authors (9, 11).

While it may be assumed that device manufacturers would have designed the data flow to be reliable, in the interest of pursuing an evidence base to marketing claims (18) to-date there

appears to be no published research that has verified the reliability of this data flow from PFD to the Internet.

The principle aim of this study was to investigate the reliability flow of data from a PFD to the Internet. The displayed data was compared at multiple access points using a sample of Garmin GPS enabled PFDs.

METHODS

Participants

Fifteen participants (ten males, five females) took part in this study. The participants were required to own or have access to a Garmin PFD and be capable of running or walking approximately five kilometres. There was no requirement for any of the participants to provide any physiological data. Each participant provided informed consent after being fully briefed on the requirements and purpose of the study. The study was approved by the Eastern Institute of Technology (EIT) Research and Ethics Approvals Committee and meets the ethical standards described by Harriss and Atkinson (10) in the International Journal of Sports Medicine.

Protocol

Six Garmin Forerunner 910XTs, two Garmin Forerunner 310XTs, and one Garmin Forerunner FR10 devices were used. One or more participants shared the use of two of the 910XTs and one of the 310XTs. The features of these devices vary, notably the 910XT has an internal barometer whilst the 310XT and FR10 do not. However, all devices used the same GPS recording, retrieval and sharing mechanisms. The study focussed on comparing the distance, time, and elevation gain and loss reported at multiple data access points.

To investigate the flow of data, three points were identified where data could be accessed or retrieved; (1) the .fit file retrieved directly from the device (FIT); (2) manually recorded data from the Garmin Connect website where the activity information is displayed (GC); and (3) the related .tcx file retrieved from the Internet (TCX). The file formats of the FIT and TCX files have been developed by Garmin to enable the transport of activity data between devices and programs. These file formats were selected as they are common to the Garmin proprietary data flow.

A measuring wheel (C H Hanson, Speedmeter 13" electronic measuring wheel) was used to measure the distance around the two-lap circuit. The circumference of one revolution of the wheel was checked before use and measured at 1000 mm. Three measurements using the wheel (MW) were taken along a path as close to the centre of the track as possible, from which the mean distance was calculated.

Each participant was required to complete two-laps on four occasions around a limestone trail, running or walking at a self-selected pace wearing one portable fitness device. The track was

mostly flat with minimal elevation change and generally free of overhead obstructions that might impede a GPS signal.

A number of trials were undertaken before the data collection began to assess the viability of the chosen location. During the trials it was established that a GPS location accuracy of better than ± 5 m could be achieved, as determined by three Garmin 910XT devices. As a result, participants did not begin a trial until their device displayed 5 m accuracy or better.

Participants allowed a minimum of seven days between successive trials. The participants started and finished at the same point on the track for each trial moving around the circuit in a clockwise direction, as close to the centre of the track as possible. A bollard at the side of the track identified the start and finish point for all trials.

Participants recorded their activity data directly to their PFD and transferred the data to a personal computer (FIT file). This data was then uploaded to an account at Garmin Connect (4) where the researcher could manually record the data from the display (GC) and download the related TCX file. A shared folder was created for each participant using the free online storage service provided by Dropbox Inc. (7). Participants copied the FIT files from their device to the shared folder to allow the researcher access to the original source files.

All data was entered into a Microsoft® Excel® spreadsheet (Microsoft® Excel® for Mac 2011, version 14.4.4, Microsoft, Redmond, WA) for analysis. Distance, time, elevation gain and loss were retrieved from the FIT and TCX files and manually recorded from the Garmin Connect website (GC).

Statistical Analysis

Statistical analysis was carried out using MegaStat for Excel (version 10.2 release 3.1.5 Mac, McGraw-Hill, New York, NY, USA). Descriptive statistics were calculated for each access point in the data flow. One-Factor analysis of variance (ANOVA) was used to compare means. The magnitude of the treatment (size of the effect) was calculated from the ANOVA (24). Results were deemed significant at $p < 0.05$, and expressed with 95% confidence intervals (CI).

RESULTS

Analysis of 60 trials revealed no significant difference between the distance or time recorded at any of the three data access points (GC vs TCX vs. FIT; $p = 0.98$; GC vs TCX vs FIT; $p = 0.99$ respectively). The Cohen effect size was $d = 0.00$ for all comparisons. Descriptive statistics for the distance and time at each data access point are shown in Table 1 and Figure 1.

The elevation gain and loss data retrieved from the Internet (GC) was significantly different from the data retrieved from the FIT and downloaded TCX files ($p = 0.00$ for both). There was no significant difference in the gain and loss between the FIT and TCX files ($p = 0.77$ and $p = 0.86$ respectively). The Cohen effect size between FIT and TCX files was trivial $d = 0.12$ (3). The descriptive statistics for the elevation gain and loss data at all access points are shown in Table

2 and Figure 2. The elevation gain and loss data was inconsistent between and within device types, irrespective of whether the device had an internal barometer or not.

Table 1. Means with confidence intervals and standard deviations for GPS distance and time from three data access points.

Data source	Distance (m)			Time (s)		
	\bar{X}	95% CI	SD	\bar{X}	95% CI	SD
FIT	4725.83	[4715.22, 4736.45]	41.96	1728.49	[1624.35, 1832.64]	411.60
GC	4725.67	[4715.01, 4736.32]	42.12	1728.55	[1624.39, 1832.70]	411.63
TCX	4725.83	[4715.22, 4736.45]	41.96	1728.52	[1624.37, 1832.67]	411.62
MW (n = 3)	4525.3		42.00			

Note: \bar{X} = mean, SD = standard deviation, CI = confidence interval, FIT = .fit file from participant's computer, GC = data from Garmin Connect website, TCX = .tcx file downloaded from Garmin Connect, MW = measuring wheel.

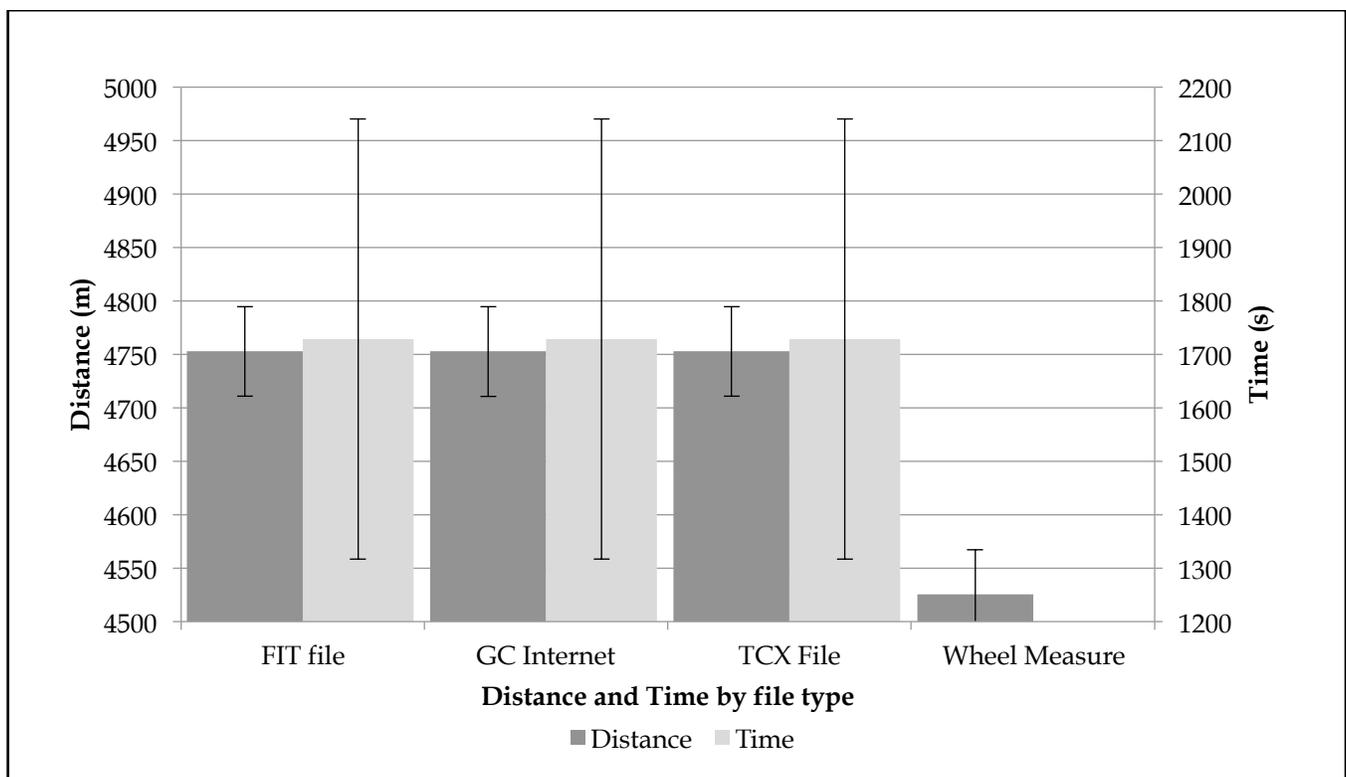


Figure 1 Recordings of distance and time by data access point. Note: FIT = .fit file from participant's computer. GC = data from Garmin Connect website. TCX = .tcx file downloaded from Garmin Connect.

Table 2. Means with confidence intervals and standard deviations for elevation gain and loss from three data access points.

Data source	Elevation Gain (m)			Elevation Loss (m)		
	\bar{X}	95% CI	SD	\bar{X}	95% CI	SD
FIT	40.20	[32.79, 47.61]	29.28	37.68	[30.53, 44.84]	411.60
GC	20.93	[15.69, 26.18]	20.72	18.37	[13.60, 23.13]	411.63
TCX	41.03	[34.10, 47.97]	27.41	39.07	[32.33, 45.80]	411.62

Note: \bar{X} = mean, SD = standard deviation, CI = confidence interval, FIT = .fit file from participant's computer, GC = data from Garmin Connect website, TCX = .tcx file downloaded from Garmin Connect.

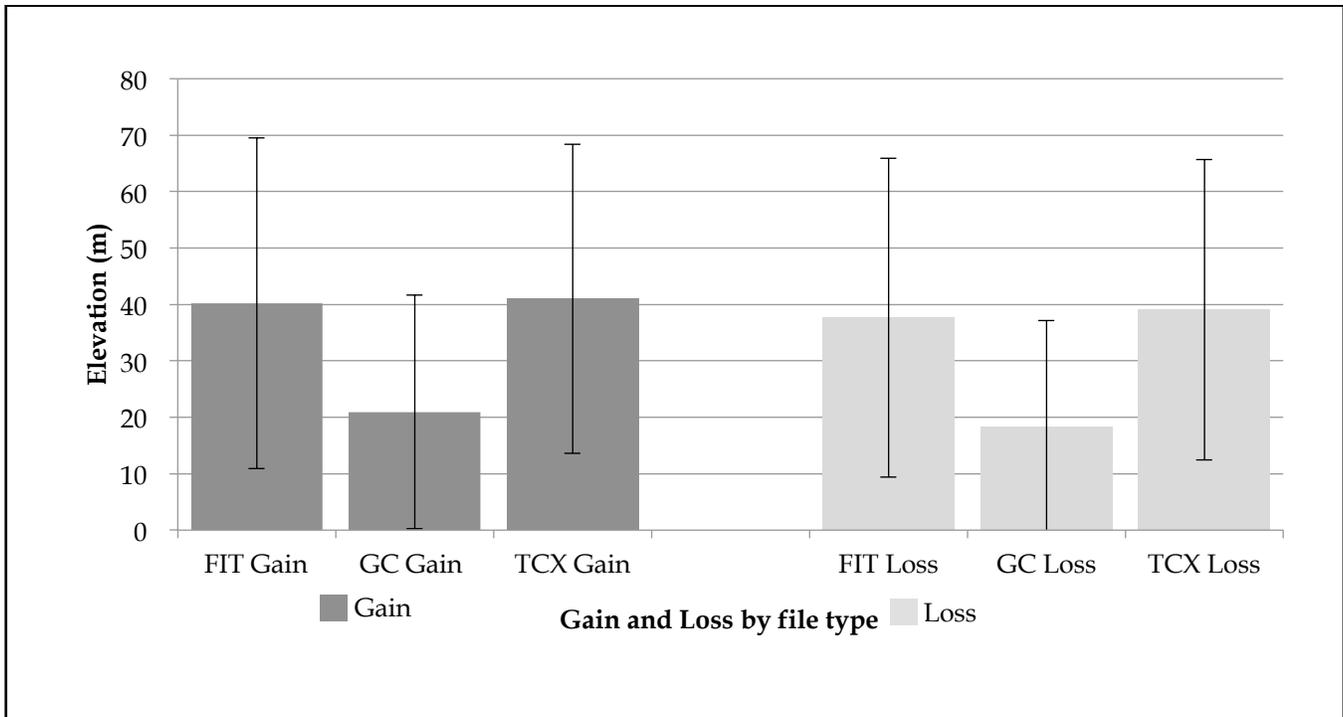


Figure 2. Recordings of elevation gain and loss by data access point. Note: FIT = .fit file from participant's computer, GC = data from Garmin Connect website, TCX = .tcx file downloaded from Garmin Connect.

Forty of the trials were carried out with devices recording data points at 1Hz intervals and the remaining 20 trials used Garmin's system of Smart Recording. The difference between these recording modes was non-significant ($p = 0.26$, and the Cohen effect size was trivial $d = 0.01$ (3)).

The mean distance using the measuring wheel for two laps around the track on three occasions was 4525 m (± 2 m SD). The mean distance for all trials from the PFDs was 4725 m (± 42 m SD).

DISCUSSION

The main finding from this study was that there were no significant differences in the distance and time recorded by Garmin PFDs at any point in the data flow between device, website, and downloadable file. Distance and time data displayed as publicly available records on the Garmin Connect website (4) might therefore be considered a reliable representation of the distance and time recorded on the PFDs. To our knowledge this is the first study to demonstrate the reliability of this data flow.

There can be less certainty about the elevation data. There were differences (both significant differences and non-significant trends) between the retrieved FIT, downloaded TCX data files and the GC data. The significant difference between the mean elevation gain and loss in the GC publicly available data versus the FIT and TCX data, in the absence of differences between the FIT (device) and TCX (download) data would indicate there is some inconsistent manipulation of the data within the data flow.

Traditionally data on physical activity has previously been collected using self-reported diaries and questionnaires that have consistently been shown to have limited reliability and validity (16). This study demonstrated that PFD data retrieved from the Internet, in relation to time and distance travelled, was consistent regardless of the point at which the data was accessed. Although data flow demonstrated reliability, it is interesting to note that the distance recorded on the devices was consistently higher than that measured with the calibrated measuring wheel. In this study, a difference of approximately 200 m between the measured distance and the distance recorded by the PFD represents approximately 4%. Without context, this variance between recorded and actual distances could result in inconsistencies in the interpretation of measures of performance by athletes and fitness trainers.

Caution is advised in the interpretation of the elevation data. As the start and finish of each trial was at the same point, and the route circuitous, it would be expected that the elevation gain and loss would be similar. Furthermore, it should be consistent at each data access point. A novel finding from this study is that whilst gain and loss were statistically similar within data files, the results could vary by approximately two metres, and were statistically different between data access points (GC vs FIT and TCX). Previous researchers have identified that the reliability of elevation measurement varied between 3 m and 16 m in a number of handheld GPS receivers, (25). In this context a variance of two metres in the current study is better than might have been expected. However, the finding of a two metre variation in elevation dependent upon the data access point, could also have practical implications for the reliable reporting of performance progression.

The findings of this study suggest that whatever manipulations were applied to the raw data to calculate elevation gain and loss, they did not appear to be consistently applied within the data flow. Devices with and without barometers were used in this study, yet the inconsistency was observed regardless of device, therefore, it cannot be assumed that the inconsistency was merely within the barometer of one device.

Two modes of data recording were used in this study. There was no significant difference in time and distance recorded between 1 Hz recording and Smart Recording both between and within the device type in this study. The Garmin Forerunner 910XT owner's manual noted that the only difference between 1 Hz and Smart Recording was the number of data points saved (8). Both modes record data at 1Hz intervals. Using 1Hz recording mode all data points are saved, whilst the Smart Recording mode smooths data, only saving points depending on changes to metrics such as position, speed or heart rate. Investigation into the effect of sampling rates used by PFDs is limited. Our study agreed with the results of Specht and Szot (17), which stated that sampling rate did not significantly affect the distance recorded. However, this was perhaps a consequence of the duration of the trials. In investigations such as those involving sprints (1), or on routes with changes in direction occurring at a rate of more than one change per second, the selection and identification of a sample rate high enough to overcome the lack of precision in GPS location recording should be considered. The

variability in recordings brought about by using an insufficient sampling rate should therefore be considered when interpreting data from PFDs, regardless of data access point.

A notable omission from this study is a comparison of the reporting of the physiological data at each access point of the data flow. The aim of this study was to investigate the reliability of the flow of location data from a PFD to the Internet. Future studies could consider the reliability of the reporting of physiological responses at each access point in the data flow or the manipulation of data between access points.

The results from this study showed that the data flow from the portable fitness device to the Internet was reliable for the distance and time data recorded, however this was consistently less than the distance measured with a calibrated measuring wheel. This study also demonstrated that the elevation change recorded at any data access point, whilst statistically similar, varied by approximately a two-metre difference in gain or loss. These findings indicate that manipulation of the data was occurring at one or more points in the data flow, and that this manipulation may not have always been consistent depending upon the type of data, and the point of data access. The practical application of this research is to advise caution when comparing PFD recorded activity data from multiple access points, as differences within the flow of data alone may impact on the data thereby altering training plans and indicators of performance progression.

ACKNOWLEDGEMENTS

The authors would like to thank the individuals who agreed to participate in this study, and their families who support them every day in the pursuit of science. This research was conducted for partial fulfilment of a Master of Health Science qualification.

REFERENCES

1. Barbero-Álvarez JC, Coutts A, Granda J, Barbero-Álvarez V, Castagna C. The validity and reliability of a global positioning satellite system device to assess speed and repeated sprint ability (RSA) in athletes. *J Sci Med Sport* 13(2): 232-235, 2010.
2. Butte NF, Ekelund U, Westerterp KR. Assessing physical activity using wearable monitors: measures of physical activity. *Med Sci Sports Exerc* 44(1S): S5-S12, 2012.
3. Cohen J. A power primer. *Psychol Bull* 112(1): 155, 1992.
4. Connect.[Internet].Garmin Ltd [cited 30 October 2014]. Available from: <http://connect.garmin.com>
5. de Arriba-Pérez F, Caeiro-Rodríguez M, Santos-Gago J. Collection and Processing of Data from Wrist Wearable Devices in Heterogeneous and Multiple-User Scenarios. *Sensors* 16(9): 1538, 2016.
6. de Arriba Pérez F, Santos Gago JM, Caeiro Rodríguez M. Analytics of biometric data from wearable devices to support teaching and learning activities. *J Information Systems Eng Management* 11(1): 1-14, 2016.

7. Dropbox.[Internet].[cited 30 October 2014]. Available from: <https://www.dropbox.com>
8. Garmin International.Garmin Forerunner 910XT, owner's manual.[Internet].[cited 30 October 2014]. Available from: http://static.garmincdn.com/pumac/Forerunner_910XT_OM_EN.pdf
9. Haghi M, Thurow K, Stoll R. Wearable Devices in Medical Internet of Things: Scientific Research and Commercially Available Devices. *Healthcare Informatics Res* 23(1): 4-15, 2017.
10. Harriss DJ, Atkinson G. Update - Ethical Standards in Sport and Exercise Science Research. *Int J Sports Med* 32(11): 819-821, 2011.
11. Henriksen A, Haugen Mikalsen M, Woldaregay AZ, Muzny M, Hartvigsen G, Hopstock LA, Grimsgaard S. Using Fitness Trackers and Smartwatches to Measure Physical Activity in Research: Analysis of Consumer Wrist-Worn Wearables. *J Med Internet Res* 20(3):e110, 2018.
12. MapMyFitness. [Internet]. MapMyFitness Inc [cited 30 October 2014]. Available from: <http://mapmyfitness.com>
13. Movescount.[Internet].[cited 30 October 2014]. Available from: <http://www.movescount.com>
14. Polar Personal Trainer.[Internet].[cited 30 October 2014]. Available from: <https://polarpersonaltrainer.com>
15. Sallis JF, Saelens BE. Assessment of physical activity by self-report: Status, limitations, and future directions. *Res Q Exerc Sport* 71(2): 1-14, 2000.
16. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med* 37(3): 197-206, 2003.
17. Specht M, Szot T. Accuracy analysis of GPS sport receivers in dynamic measurements. *Ann Navigation* 19(1): 165-176, 2012.
18. Sperlich B, Holmberg H-C. Wearable, yes, but able...?: it is time for evidence-based marketing claims! *Br J Sports Med* 51(16): 1240, 2017.
19. SportTracks.[Internet].[cited 30 October 2014]. Available from: <http://sporttracks.mobi>
20. Steene-Johannessen J, Anderssen SA, van der Ploeg HP, Hendriksen IJM, Donnelly AE, Brage S, Ekelund U. Are self-report measures able to define individuals as physically active or inactive? *Med Sci Sports Exerc* 48(2): 235-244, 2016.
21. Strava.[Internet].[cited 30 October 2014]. Available from: <http://www.strava.com>
22. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc* 40(1):181-188, 2008.
23. Tucker JM, Welk GJ, Beyler NK. Physical activity in US adults: Compliance with the physical activity guidelines for Americans. *Am J Prev Med* 40(4): 454-461, 2011.
24. Vincent WJ, Weir JP. *Statistics in Kinesiology*. 4th ed. Champaign, IL: Human Kinetics; 2012.
25. Wing MG, Eklund A. Elevation measurement capabilities of consumer-grade global positioning system (GPS) receivers. *J For* 105(2): 91-94, 2007.

26. Wireless health and fitness devices: Market report.[Internet].Electronis.ca Publications [cited 30 October 2014]. Available from: <http://www.electronics.ca/wireless-health-fitness-devices-market-report.html>

