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Comparison of two ActiGraph accelerometers in laboratory and free-living conditions

Eveleen Sng[1], Ovuokerie Addoh[1], Paul D. Loprinzi[1]
[1]Department of Health, Exercise Science and Recreation Management, Physical Activity Epidemiology Laboratory, The University of Mississippi, University, MS

ABSTRACT

Objective: Evaluate the agreement between the GT3X+ and GT9X link with respect to the vertical axis under laboratory and free-living conditions using the normal filter and low frequency extension (LFE) filter, respectively and to evaluate the agreement between the minutes spent in different activity intensities between the devices under free-living conditions using both the normal and LFE filter, respectively.
Methods: Eight participants (mean age = 28.3 ± 3.8) were enrolled. Participants completed four walking trials of two different speeds [2 and 3 miles per hour (mph), 3-minute stages] while wearing two GT3X+ and two GT9X link accelerometers on an elastic belt on the right sides of the hip. They continued wearing them for another 6–10 hours in the free-living setting.
Results: There were no significant differences between the mean counts per minute between the devices for the walking trials and free-living assessment when both filters were applied. There were also no significant differences in the different physical activity intensity categories. There was strong evidence of agreement between the GT3X+ and GT9X link.
Conclusion: Data collected with the GT3X+ and GT9X link should be comparable across past and future studies.

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KEYWORDS

Accelerometry; objective monitoring; physical activiy; GT3X+; GT9X link

Introduction

The use of accelerometers in physical activity research has gained popularity since the 1980s and has been used by researchers to quantify physical activity [1]. Accelerometers are defined as "physical activity monitors that sense body accelerations" by John et al. [2]. ActiGraph is the most widely used brand of accelerometers that is commercially available. There are many generations of the ActiGraph (Pensacola, FL) accelerometers such as the AM 7164, GT1M, GT3X, GT3X+ and the GT9X link.

The AM 7164 is a uniaxial accelerometer that uses a piezoelectric sensor. It has been used extensively in the mid 1990s and early 2000s in population-based studies such as the National Health and Nutrition Examination Survey [1–4]. The successor of the AM 7164, the GT1M, is also a uniaxial accelerometer that uses a more advanced technology, the micro electric mechanical system (MEMS) capacitive accelerometer that can detect both static and dynamic accelerations. The GT1M was launched in 2005 with three different versions [3]. After ActiGraph released the GT1M, the newer generations such as the GT3X, GT3X+, and the GT9X link all used the MEMS. The GT3X is a triaxial accelerometer, was released in 2009, while the improved version, the GT3X+, was released in 2010 with advancements in technology [5].

The latest version of the physical activity accelerometer released by ActiGraph in 2014 is the GT9X link, and has an integrated inertial measurement unit (IMU) that contains an additional secondary accelerometer, gyroscope, and magnetometer to analyze body movements and gait patterns. Furthermore, ActiGraph introduced the normal filter and low frequency extension (LFE)

Contact Paul D. Loprinzi pdloprin@olemiss.edu Department of Health, Exercise Science and Recreation Management, Physical Activity Epidemiology Laboratory, The University of Mississippi, University, MS.

filter, which can be applied to data collected from the newer accelerometer models. The normal filter is designed to eliminate any acceleration noise outside of the human activity bandwidth, while the LFE extends the lower end of the bandwidth of the normal filter and allows data to be captured more accurately during slower and lighter intensity types of movements [6].

Physical activity accelerometers are extensively used because they are a valid and reliable measure of physical activity, measures physical activity objectively, and are more feasible than indirect calorimetry or direct observations [7,8]. Since there are several models of ActiGraph accelerometers since the 1990s, it is important to conduct comparison studies of the different generations of ActiGraph accelerometers so that the comparability of the data collected from the different models can be established. Most of the related studies on this topic have compared the older generation models with the newer models (AM 7164, GT1M, GT3X, and GT3X+) with respect to the vertical axis and have established that there were no significant differences with the output and are generally comparable [2–4,6,9,10]. However, there are no studies that have compared the GT9X link to an older model of the ActiGraph accelerometers. Thus, the purpose of this study was to evaluate the agreement between the older GT3X+ to the newer GT9X link with respect to the vertical axis under laboratory and free-living conditions using the normal filter and LFE filter respectively. The secondary aim of this study was to evaluate the agreement between the time spent in different activity intensities from the output of the older GT3X+ to the newer GT9X link under free-living conditions using both the normal and LFE filter respectively. As stated, the main difference between the GT3X+ and GT9X link is the inclusion of the IMU for the GT9X link. Thus, based on the mechanical similarities of both devices, we hypothesize that there will be evidence of good agreement between these devices. However, such an empirical investigation is necessary to confirm this hypothesis.

Methods

This study was approved by the Institutional Review Board at the author's institution. Eight healthy individuals (mean age = 28.3 ± 3.8) were recruited via a convenience sampling approach for the study. They were eligible for the study if they answered "no" to all questions on the physical activity readiness questionnaire, had no perceived or actual difficulties walking 2 or 3 mph, and were willing to wear the accelerometers during the free-living assessment. All eight of the participants' data were included in the final analyses as there were no accelerometer malfunction or non-compliance issues during the free-living assessment. They also provided informed consent to be part of the study.

The ActiGraph GT9X link (14 g, 3.5 × 3.5 × 1 cm) is lighter and smaller than the GT3X+ (19 g, 4.6 × 3.3 × 1.5 cm) and has a high-resolution liquid crystal display. As these accelerometer models are newer and use the MEMS, they do not require any prior calibration before use. Before testing in the laboratory, participants' height, weight, waist circumference, and suprailliac crest skinfold were measured using a stadiometer (SECA 213, Germany), weighing scale (SECA 803, Germany), measuring tape and skinfold calipers (Lange, Santa Cruz, CA), respectively. Participants' were fitted with four (two GT3X+, two GT9X link) accelerometers (ActiGraph, Pensacola, FL) on the elastic belt that came with the GT3X+ with the placements randomized and counterbalanced to avoid any potential placement and confounding effects. The accelerometers on the belt were arranged in a way that the GT3X+ would be next to the GT9X link [See Table 1 for configurations (P1–P4) of accelerometers]. They wore it on the right side of their hip (at the level of the iliac crest) with the accelerometers placed 2 cm apart from each other with the mid axillary line as the gap that separates the four accelerometers. Once participants' were fitted with the accelerometers, they were taped to the belt to ensure similar degrees of monitor stability (i.e., GT3X+ was not "looser" than the GT9X link and vice versa). They also had placement dots dotted on their bodies right above the accelerometers; this was done to ensure the accelerometers did not move from their designated position during the activity trials. Accelerometers were initialized and synced to a digital stopwatch.

Table 1. Configurations of accelerometers on belt.

P1	P2	P3	P4
$GT3X_1$+	$GT3X_1$+	$GT9X_1$ link	$GT9X_1$ link
$GT9X_1$ link	$GT9X_1$ link	$GT3X_1$+	$GT3X_1$+
$GT3X_2$+	$GT9X_2$ link	$GT9X_2$ link	$GT3X_2$+
$GT9X_2$ link	$GT3X_2$+	$GT3X_2$+	$GT9X_2$ link

P = Position; from top to bottom, the monitors were placed most anteriorly to most posteriorly. For example, for P1, the $GT3X_1$+ was placed most anteriorly and the $GT9X_2$ link was placed most posteriorly.

Table 2. Paired *t*-test, Spearman correlation, and ICC results for average CPM from the vertical axis of the GT3X+ and GT9X link with normal filter (N) and LFE filter applied.

Setting	GT3X+		GT9X link		*n*	*p*	S_p	ICC
	M	SD	*M*	SD				
2 mph (N)	1,680	422	1,635	299	8	0.50	0.95*	0.941*
3 mph (N)	3,939	631	3,848	508	8	0.14	0.93*	0.978*
Free living (N)	597	295	581	286	8	0.24	1.0*	0.996*
2 mph (LFE)	1,863	362	1,821	262	8	0.43	0.95*	0.951*
3 mph (LFE)	4,042	620	3,956	504	8	0.14	0.93*	0.979*
Free living (LFE)	628	303	617	102	8	0.34	0.99*	0.998*

* denotes $p < 0.05$.

The exercise protocol consisted of four 3-minutes walking trials on the treadmill (Woodway, Waukesha, WI), with the first two walking trials at a speed of 2 mph, and the other two walking trials at a speed of 3 mph. Each trial started with them walking on the treadmill for 30 seconds before data is recorded. At the end of the full third minute, participants would continue to walk for another 30 seconds before the treadmill came to a complete stop. The extra 30 seconds of walking before the first minute and after the third minute was employed to ensure that the full 3 minutes of data was recorded and not capturing the data during the transition. Participants had a brief break in between for the researcher to check the placements of the accelerometers and to check if the participant could continue on to the next trial. This protocol was repeated four times until all four trials were completed. Having four trials in our protocol would allow us to compare the validity and reliability of the devices. Once the laboratory trials were concluded, participants were told to keep their accelerometers on for another 6–10 hours for the free-living setting. They were instructed to wear the accelerometers during all waking hours (except swimming or bathing). Participants were asked to engage in their normal daily routine.

When accelerometers were returned, data was processed using two different epochs (1 second for the walking trials and 60 seconds for free-living settings) as well as applying the normal filter and LFE using the ActiLife Version 6.13.2. Data were analyzed in Stata version 14 (College Station, TX) after data cleaning (in Excel). Paired *t*-tests were performed to determine if there were significant differences between the mean counts per minute (CPM) from the vertical axis of the accelerometers (GT3X+ *vs.* GT9X) in both laboratory and free-living settings. In addition, Bland-Altman plots were used to evaluate the agreement between the mean CPM from the vertical axis of the GT3X+ and the GT9X link in both settings. However, these Bland-Altman plots did demonstrate some evidence of fixed and proportional bias. Spearman correlation and intraclass correlation (ICC) coefficient (absolute agreement) were also computed to examine the relationship between the CPM across the two accelerometer models.

For the free-living assessment, physical activity intensity cut points were defined as: sedentary; 0–99 CPM [11], light; 100–2,019 CPM [12], moderate; 2,020–5,998 CPM [8], and vigorous: more than 5,999 CPM [8]. Non-wear time in the free-living assessment was calculated based on at least 60 minutes of consecutive zero activity counts in the vertical axis, with allowance for 1–2 minute of counts between 0 and 100 [8]. Significance was established as $P < 0.05$.

Results

The final sample included all data from eight participants who completed the walking trials in the laboratory and had an average wear time of 10.7 hours [standard deviation (SD) = 1.9] in the free-living settings. Paired t-test showed no significant differences between the mean CPM from the vertical axis of the GT3X+ and the GT9X link during the 2 mph walking trials ($P = 0.50$), 3 mph walking trials ($P = 0.14$), and the free-living settings ($P = 0.24$) with the normal filter applied (See Table 2). When the LFE filter was applied, paired t-test showed no significant differences between the mean CPM from the vertical axis of the GT3X+ and the GT9X link during the 2 mph walking trials ($P = 0.43$), 3 mph walking trials ($P = 0.14$), and the free-living settings ($P = 0.34$) (See Table 2). In addition, Spearman correlation and ICC (with absolute agreement) analyses showed that mean CPM from the vertical axis of the GT3X+ and the GT9X link to be significantly highly correlated in the different settings, regardless of normal or LFE filter applied (see Table 2). Bland-Altman plots displayed in Figures 1 and 2

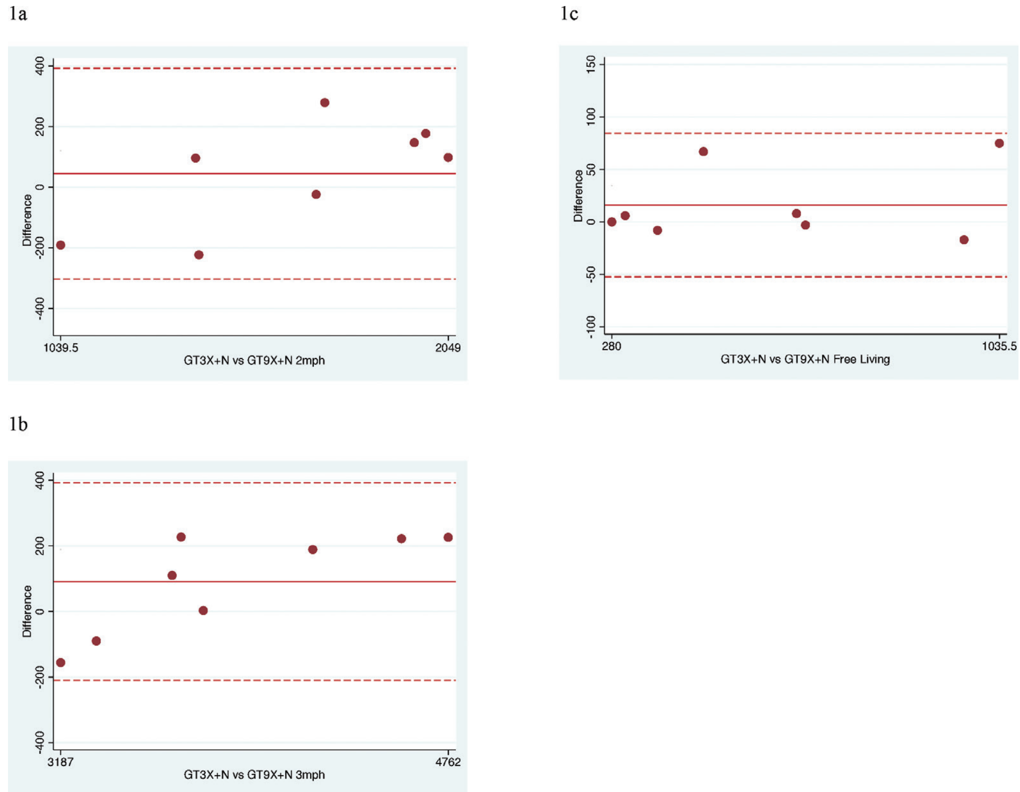

Figure 1. Bland-Altman plots assessing agreement of vertical axis mean CPM between GT3X+ and GT9X link using the normal filter for the 2 mph (a), 3 mph (b) walking trials and free living (c) setting. *Solid line* depicts mean CPM difference between accelerometers, and *dashed lines* depicts upper and lower limits of 95% agreement.

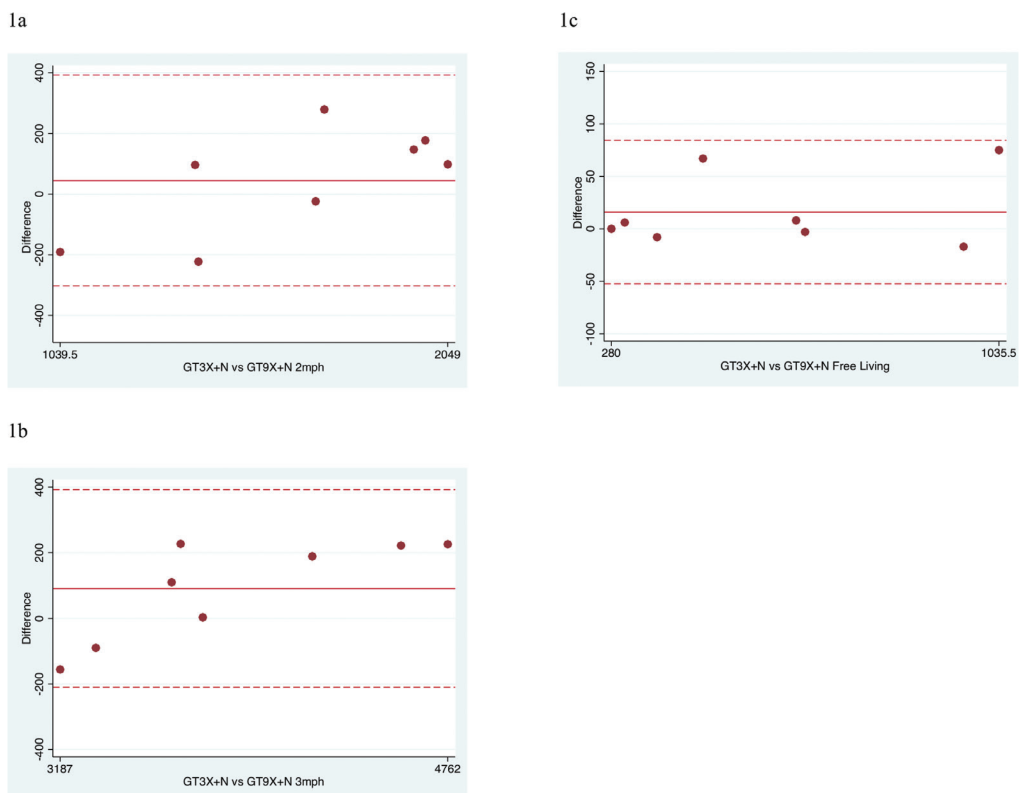

Figure 2. Bland-Altman plots assessing agreement of vertical axis mean CPM between GT3X+ and GT9X link using the LFE filter for the 2 mph (a), 3 mph (b) walking trials and free living (c) setting. *Solid line* depicts mean CPM difference between accelerometers, and *dashed lines* depicts upper and lower limits of 95% agreement.

Table 3. GT3X+ *vs*. GT9X link time engaged in different intensities (minutes) with normal (N) filter and LFE filter.

Participant	$3X_{SED}$ (N)	$9X_{SED}$ (N)	$3X_{LIGHT}$ (N)	$9X_{LIGHT}$ (N)	$3X_{MVPA}$ (N)	$9X_{MVPA}$ (N)	$3X_{SED}$ (LFE)	$9X_{SED}$ (LFE)	$3X_{LIGHT}$ (LFE)	$9X_{LIGHT}$ (LFE)	$3X_{MVPA}$ (LFE)	$9X_{MVPA}$ (LFE)
1	261	266	419	418	34	30	254	265	414	411	52	44
2	441	437	160	163	65	66	418	416	181	181	67	69
3	349	393	198	166	110	98	332	374	212	180	113	100
4	298	300	204	202	72	72	278	283	220	214	76	77
5	473	477	225	221	35	35	452	451	245	245	36	37
6	462	498	241	219	33	20	441	480	263	235	33	22
7	270	338	252	254	34	30	387	391	260	263	40	33
8	223	223	163	165	10	10	205	200	182	187	11	11
Average	347.1	366.5	232.8	226	49.1	45.1	345.9	357.5	247.1	239.5	53.5	49.1

For normal filter, $P = 0.08$, $Sp = 0.95$, ICC = 0.975 (Sedentary); $P = 0.18$, $Sp = 0.98$, ICC = 0.993 (Light); and $P = 0.18$, $Sp = 0.98$, ICC = 0.969 (Moderate-vigorous). For LFE filter, $P = 0.12$, $Sp = 0.98$, ICC = 0.988 (Sedentary); $P = 0.17$, $Sp = 0.86$, ICC = 0.990 (Light); and $P = .08$, $Sp = 0.98$, ICC = 0.986 (Moderate-vigorous).

Table 4. Paired *t*-test, Spearman correlation, and ICC results for average CPM from the vertical axis of the $GT3X_1$+ and $GT3X_2$+ with normal (N) filter and LFE filter applied.

Setting	$GT3X_1$+		$GT3X_2$+		*n*	*p*	S_p	ICC	$GT9X_1$		$GT9X_2$		*n*	*p*	S_p	ICC
	M	SD	*M*	SD					*M*	SD	*M*	SD				
2 mph (N)	1,680	422	1,343	495	8	0.0015*	0.90*	0.843*	1,635	299	1,397	491	8	0.028*	0.93*	.833*
3 mph (N)	3,939	631	3,591	792	8	0.005*	0.98*	0.918*	3,848	508	3,615	780	8	0.137	0.76*	0.883*
Free living (N)	597	295	632	260	8	0.24	0.90*	0.980*	581	101	583	263	8	0.87	0.98*	0.996*
2 mph (LFE)	1,863	362	1,569	434	8	0.002*	0.90*	0.837*	1,821	262	1,611	439	8	0.037*	0.93*	0.821*
3 mph (LFE)	4,042	620	3,700	774	8	0.005*	0.98*	0.918*	3,955	504	3,725	762	8	0.125	0.78*	0.887*
Free living (LFE)	628	303	674	262	8	0.15	0.93*	0.975*	617	288	625	264	8	0.55	0.97*	0.996*

* denotes $p < 0.05$.

showed the agreement between the GT3X+ and GT9X link. This analysis provides additional evidence to support the results of the paired *t*-test that there were no significant differences between the mean CPM from the vertical axis obtained from the two devices.

Table 3 displays the results of the comparison for the time (minutes) engaged in different physical activity intensities for the eight individuals during free-living setting. Paired *t*-test showed no significant differences between all activity intensity categories ($P > 0.05$); Spearman correlation and ICC (with absolute agreement) showed that the time engaged in each intensity category of the GT3X+ and GT9X link (regardless of normal or LFE filter applied) to be significantly highly correlated (*S*p and ICCs were all >0.8). Bland-Altman plots evaluated acceptable limits of agreement for all categories of intensities between the GT3X+ and GT9X link (not shown).

Although this was not part of the main aims of our study, we also compared the data for inter-monitor reliability. Table 4 displays the results of the comparability of the two GT3X+ and two GT9X link devices respectively. There were some significant differences between the devices for the laboratory trials ($P < 0.05$) but Spearman correlation and ICC still showed that they were significantly highly correlated.

Discussion

Comparing the CPM of the vertical axis between the GT3X+ and GT9X link for both laboratory and free-living settings, the average CPM for all participants were in close range. Furthermore, there were no significant differences detected between the devices in both laboratory and free-living conditions when the normal or LFE filters were applied. Bland-Altman plots also showed reasonable agreement between the monitors and free-living conditions using the normal and LFE filters. From our findings, it can be inferred that there is strong evidence of agreement between the GT3X+ and GT9X link in both settings and, thus, these models can be used interchangeably in a single study.

When we compared the different intensity categories (sedentary, light, moderate-vigorous) engaged between the GT3X+ and GT9X link in the free-living setting based on the participants wear time, there were no significant differences detected between the monitors for the time engaged in sedentary, light, and moderate vigorous physical activity. Although no study has looked at the comparison of time spent in various physical activity intensities between the GT9X link to the older models, there is one study [6] that looked at the comparison of physical activity intensity between the different filters (normal and LFE) applied to the GT3X+ in comparison to the AM7164. When the normal filter was applied to the GT3X+ in that study, less sedentary minutes were computed when compared to the LFE filter applied. When LFE filter was applied, more light and moderate-vigorous minutes were computed when compared to the normal filter applied to the GT3X+. Our present findings of the different physical activity intensity categories of the GT3X+ were consistent with the findings from Cain et al. [6] when both filters were applied respectively. Bland-Altman plots (not shown) also demonstrated acceptable limits of agreement for sedentary, light, moderate-vigorous activity between the devices, hence we can conclude that we can use these devices fairly interchangeable in physical activity research and should be comparable across past and future studies.

In our present study, we also looked at the inter-monitor reliability of the devices and the results underscored the importance of considering multiple analytic tests when evaluating accelerometer monitor reliability. Comparing the CPM of the vertical axis between the two GT3X+ and two GT9X link devices for the laboratory setting, even though there were significant differences from the results of the paired *t*-tests, Spearman correlation and ICC (with absolute agreement) showed that there were still highly significant correlations between the devices. Significant differences (for this reliability assessment) could be due to the placement effect of the devices as the GT3X1+/GT9X1 link and GT3X2+/GT9X2 link could be placed too far apart from each other based on the randomization of the devices worn on the belt (see Table 1); i.e., for the validity aspect of this study, we ensure that GT3X1+ and GT9X1 were side-by-side. To our knowledge, there is no study that has had participants wear four accelerometers on a belt at one time; a previous study utilized three monitors and found some evidence of a placement effect for the ActiGraph 7164 monitor [13]. Thus, future research evaluating reliability and validity of accelerometers using multiple monitors should consider the effect of placement. That could have accounted for the significant differences in the paired *t*-test analysis for our reliability analyses. However, based on the other analytical tests that showed a significant correlation and agreement between the devices, we can conclude that there is evidence of monitor reliability in both settings.

This study had several strengths. To our knowledge, no study has compared the GT9X link to any older ActiGraph models, making our study novel. We collected data for both laboratory and free-living conditions, which are settings that physical activity takes place. We also employed both the normal filter and LFE filter to our data collected and looked at the comparability of the devices in both situations. Limitations of this study include a small sample size and the convenience sample may limit the generalizability of results. However, we feel confident that our sample size was reasonable because, for example, nearly all eight participants were with in the limits of agreement for the Bland-Altman analyses and we observed high levels of ICC (a larger sample would likely increase ICC). We also did not collect data for high intensities in the laboratory setting, which should be investigated in future research.

In conclusion, based on results from our present study, we conclude that the GT3X+ and GT9X link are comparable and can be used interchangeably in future studies. The findings of this study also suggest that it would be acceptable to compare findings of studies that used these two different devices. Future research would benefit by employing a large sample size, including older adults to further evaluate the sensitivity of the LFE and include a free-living assessment that expands beyond a single day. Evaluating placement effects for accelerometer CPM and the agreement of step counts of GT3X+ and GT9X link would give a more comprehensive assessment of the comparability of the aforementioned devices.

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