



Validation of the PiezoRx® Step Count and Moderate to Vigorous Physical Activity Times in Free Living Conditions in Adults: A Pilot Study

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ABSTRACT

International Journal of Exercise Science 11(7): 541-551, 2018. The purpose of the study was to: 1) Validate the PiezoRx® for steps and intensity related physical activity in free-living conditions compared to the criterion measure. 2) Compare PiezoRx®'s steps and intensity related physical activity to physiological assessments. 3) To assess the utility of the PiezoRx® in a subsample of participants. Thirty-nine participants consisting of 28 females aged 54.9±10.6 (33-74) years and 11 males aged 63.9±10.9 (44-80) years wore the PiezoRx® physical activity monitor and the ActiGraph® accelerometer for one full week and completed a physical assessment. A subsample (n=24) wore the PiezoRx® for an additional two weeks and completed a questionnaire regarding usability. The PiezoRx® had strong correlations to the ActiGraph® for step count ($r=0.88$; $p<0.001$), moderate-vigorous physical activity (MVPA) ($r=0.70$; $p<0.001$), and sedentary activity ($r=0.93$; $p<0.001$) in the 1-week monitoring period. The PiezoRx®'s steps/day and MVPA/week were negatively correlated ($p<0.001$) to body mass index and waist circumference, and positively correlated ($p<0.05$) to aerobic fitness, pushups, and 30 second sit-to-stand. Within the subsample who completed the additional two-week monitoring, 75% of participants reported that the PiezoRx® increased their physical activity. In conclusion, The PiezoRx® appears to be a valid measure of free-living PA compared to accelerometry. Because of the correlations of the PiezoRx®'s steps/day and MVPA/week to anthropometric, musculoskeletal and aerobic fitness these PA measures may be valuable objective surrogates to use in clinical or professional practice for physical health.

KEY WORDS: Physical activity, objective measure, steps, moderate-vigorous physical activity, validation, free-living

INTRODUCTION

Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure (6). The Canadian Society for Exercise Physiology (CSEP) recommends 150 minutes of moderate-vigorous aerobic physical activity (MVPA) per week with high levels of fitness associated with additional benefits (30). The evaluation of physical activity is an important measurement for researchers and practitioners as means of assessing current physical activity behavior and to initiate health related behavior change. Physical activity questionnaires such as the CSEP-Physical Activity and Sedentary Behaviour Questionnaire

(PASB-Q) offer a simple cost-effective way for clinicians and exercise professionals to measure patient activity levels. Due to the errors and challenges associated with self-reporting of PA (28), there is a need to identify tools that can reliably and objectively measure PA in free living conditions. Accelerometers are prevalent in physical activity research due to their objectivity, reliability and ability to distinguish intensity-related activity (16); however, research grade accelerometers tend to be higher cost and requires specific software to analyze data; negatively influencing their practicality among the general public and in clinical settings.

The PiezoRx® is a class one medical grade piezo-electric, uniaxial accelerometer-based physical activity monitor developed for researchers and physicians that uses step rate thresholds to measure intensity related physical activity (29). Step rate thresholds may be tailored to accommodate the fitness needs and anthropometrics of the individual, with factory settings set at moderate=100 steps per minute (spm) and vigorous at 120 steps per minute (spm). Piezoelectric technology uses a horizontal cantilevered beam with a weight on the end that compresses a piezoelectric crystal when subjected to acceleration. This acceleration induced compression generates a proportional voltage; these voltage oscillations equate to step counts. The device also record time spent in 'total physical activity' (TPA), which is time spent in >60 steps per minute. Previous research suggests that this device is an accurate measure of steps and intensity related activity (7, 26). A challenge with interpretation of these findings is that validation studies are restricted to a laboratory setting using specific treadmill speeds, suggesting the need for an evaluation of the PiezoRx® in a real-world setting.

The primary purpose of this study was to assess the accuracy of the PiezoRx® to measure steps and intensity related physical activity compared to ActiGraph® accelerometer in free-living conditions in adults. High levels of physical activity typically confers a higher physical fitness, therefore, construct validity was also assessed by comparing individuals' steps per day and MVPA per week to measures of anthropometric, musculoskeletal and aerobic fitness. Lastly, the usability of the PiezoRx® to support regular PA behavior, was assessed in a subsample of participants.

METHODS

Participants

Twenty-eight females aged 54.9±10.6 [33-74 years] and 11 males aged 63.9±10.9 [44-80 years] ranging in body mass index from 21 to 42 (\bar{x} =30) kg/m² and waist circumference from 65 to 118 (\bar{x} =96) cm volunteered for the study. Participants were recruited via word of mouth, posters around the local community (Wolfville, NS, Canada) and a community-wide email in order to increase the diversity of the sample. Females and males had a predicted aerobic fitness of 29.9±6.6 ml/kg/min (8.5 METs) and 32.9±7.6 ml/kg/min (9.4 METs) respectively. The majority (59%) of participants engaged in resistance training 1-2 times per week while 66% perceive their aerobic fitness as "Good" or higher. Conversely, 41% of the sample do not engage in any form of resistance training and 34% perceive their aerobic fitness as "Fair" or "Poor". The majority of participants were <65 years old (F=22, M=6). The procedures were reviewed and approved by the Acadia University Research Ethics Board (REB# 12-29). Each

subject completed a Physical Activity Readiness Questionnaire Plus (PARQ+) (32) and signed a written informed consent form before participating in the study.

Protocol

All participants completed the CSEP-PASB-Q prior to physical testing (12). Physical fitness was evaluated using measures of anthropometric, musculoskeletal and aerobic fitness by CSEP-Certified Exercise Physiologist candidates. Testing protocols were completed according to published guidelines (5, 15). Anthropometric measures collected included height (cm), weight (kg), and waist circumference (cm) taken using a standard anthropometric protocol (5) to calculate body mass index (BMI). Aerobic fitness was assessed through 6-minute walk test or modified Bruce maximal or submaximal treadmill protocol; depending on existing health conditions. Muscular fitness was assessed through grip strength, pushups, vertical jump without countermovement but with arm-swing, and 30 second sit-to-stand. Grip strength was calculated by adding the right and left hand scores for a total score. Relative vertical jump power was calculated using the Sayers equation and dividing by weight. Sayers equation: Power (W) = [60.7 × vertical jump displacement (cm)] + [45.3 × weight (kg)] - 2055.



Figure 1. Activity monitor placement with the PiezoRx and the ActiGraph accelerometer positioned on the participants left and right hip respectively.

All participants wore an initialized ActiGraph® GT3X accelerometer on their right hip (ActiGraph, Pensacola, Florida, US) and the PiezoRx® pedometer (StepsCount, Ontario, Canada) on their left hip (see Figure 1). Previous studies have shown no statistical differences between pedometers worn on the left versus right side of the body (9). Placement of the blinded devices was standardized by placing it on the belt or waistband, in line with the mid-thigh, as per manufactures recommendations. The ActiGraph® data was computed using Actilife Software (Version 5, Pensicola Florida, US) according to published guidelines (13). In brief, the following PA thresholds were used: sedentary activity (0-99 counts/min), light activity (100-1951 counts/min), moderate activity (1952-5723 counts/min), and vigorous

activity (≥ 5724 counts/min). The ActiGraph® has been shown to be a valid and reliable measure of physical activity (1, 18, 21), and has previously been used as a criterion measure in a field-based validation study (11). The PiezoRx®'s settings were tailored for height based on unpublished observations from our laboratory; typically, the standard setting was 100 steps per minute (spm) for MPA and 120 spm for VPA. Adjustments for height were in 5 spm for each 10 centimeters (cm) taller (-5 spm) or shorter (+5 spm) than 170 cm (5'7") which has been shown to increase the accuracy of intensity related PA compared to direct calorimetry. Participants were instructed to wear blinded devices (taped shut to not get any feedback) during all waking hours for 7 days. The PiezoRx stores PA data for up to 33 days. Data collected by the devices included: steps and time spent in moderate physical activity (MPA; $3 \leq 6$ METs), vigorous physical activity (VPA; ≥ 6 METs), moderate to vigorous physical activity (MVPA; ≥ 3 METs), total physical activity (TPA; ≥ 1.5 METs), sedentary activity (SedA; < 1.5 METs) and total number segments of 10 minutes or more of MVPA activity (Bouts).

Following the one-week blinded data collection period, a subsample ($n=24$) of adult ($n=17$) and older adult ($n=7$) participants were instructed on the PiezoRx® functions and wore the device for an additional two weeks, receiving feedback from the device (i.e. daily monitoring of steps, MVPA etc.). Following the two week usability period, participants completed a questionnaire regarding the utility of the device. One participant from the subsample was removed from weekly comparison of physical activity levels due to insufficient wear time.

Statistical Analysis

All analyses were performed using SPSS 23.0 for Mac (IBM, NY). For all analyses, a p-value of 0.05 was used to denote statistical significance. Valid data was defined as at least 4 days with at least 1 weekend day for a minimum of 10 hours of wear time per day. If the participant wore the device for 4-6 days, their data was averaged and multiplied by the corresponding factor to represent one full week. Of the 39 participants, 7 were removed from step count analysis due to insufficient data files, an additional 2 were removed from sedentary behavior analysis due to insufficient data files. Five participants did not complete pushups or vertical jump as a precaution to their existing health conditions. Descriptive statistics (mean, standard deviation, range) were calculated for participant characteristics. Frequency statistics were calculated for PASB-Qs resistance training frequency and perceived aerobic fitness. Self-reported MVPA was calculated by multiplying the number of days engaging in MVPA by the time spent doing such activity. Self-reported sedentary time was calculated by time occupational and leisure sedentary time. Pearson Correlations were calculated between the devices steps per day, MVPA-7, MPA-7, VPA-7, TPA-7, Bout (min)-7, and SedA per day. Sedentary activity was calculated by subtracting TPA of each device from the ActiGraph®'s recorded wear time. Wear time was calculated by subtracting non-wear time from 24 hours. Non-wear time was defined as at least 60 consecutive minutes of zero counts, with allowance for 1 to 2 minutes of counts between 0 and 100. Correlations compared PiezoRx®'s steps/day, MVPA-7, and SedA/day to physiological measurements. Sensitivity (ability of the PiezoRx® and ActiGraph® to identify subjects not meeting guidelines) and specificity (ability of the PiezoRx® and ActiGraph® to identify subjects meeting guidelines) was measured by comparing participants' who do not meet physical activity guidelines (< 150 minutes of MVPA

per week) and who meet physical activity guidelines (>150 minutes of MVPA per week) between the PiezoRx® to the ActiGraph®. Percent agreement between the devices was calculated to determine if the PiezoRx® distinguished those meeting guidelines compared to the ActiGraph®. Bland-Altman plots were generated for steps/day, MVPA-7, and SedA/day using the ActiGraph® as the criterion measure. This analysis evaluates the agreement among two measurement techniques, and is the standard method to show accuracy of biomedical devices (3). Limits of agreement were set at $\pm 1.96SD$ of the difference (ActiGraph® - Piezo®) scores.

RESULTS

As shown in Table 1 all of the correlations between the ActiGraph® and PiezoRx® functions were statistically significant ($p < 0.05$) with the the strongest correlation being sedentary activity per day with $r = 0.93$ ($p < 0.001$). Other strong correlations ($r \geq 0.7$) include: steps, MVPA-7, MPA-7, TPA-7 and Bout (time)-7. There was a moderate correlation between the ActiGraph® and PiezoRx® to detect VPA ($r = 0.39$; $p = 0.014$). Despite measuring similar amounts of mean step counts per day (7601 vs 7700), the mean amount of MVPA, MPA, and VPA were higher in the PiezoRx® compared to the ActiGraph®. Self-reported MVPA tended to be lower than values determined by the ActiGraph® (146 ± 105 vs 185 ± 129 mins). Self-reported sedentary time was much lower than the ActiGraph®'s objectively measured sedentary time (382 ± 212 vs 746 ± 66 mins).

Table 1. Comparison of the PiezoRx and ActiGraph step count and intensity related physical activity.

	PiezoRx	ActiGraph	r
Steps/day ^a	7700 \pm 2831	7601 \pm 2767	0.88 †
MVPA-7 ^b	266 \pm 139	185 \pm 129	0.70 †
MPA-7 ^b	225 \pm 123	165 \pm 112	0.74 †
VPA-7 ^b	39 \pm 54	19 \pm 30	0.39*
TPA-7 ^b	472 \pm 166	349 \pm 200	0.80 †
Bout (min)-7 ^b	10 \pm 11	13 \pm 13	0.75 †
SedA/day ^c	725 \pm 70	746 \pm 66	0.93 †

Presented as mean \pm SD; an=32, bn=39, cn=30; * $p < 0.05$, † $p < 0.001$. MVPA-7, weekly moderate-vigorous physical activity; MPA-7, weekly moderate physical activity; VPA-7, weekly vigorous physical activity; SedA, sedentary activity

The sensitivity and specificity values of the PiezoRx® to the ActiGraph® were 90.5% and 44.4% respectively, while the percent agreement between the devices was 69.2%.

As shown in the Figure 2A, 95% of participants were within the mean difference of the ActiGraph®-PiezoRx® which was -81 minutes per week with upper and lower limits of agreement of 121 and -284 respectively. As shown in Figure 2B and 2C the mean difference for steps/day and SedA/day was -99 steps/day and 22 minutes/day respectively.

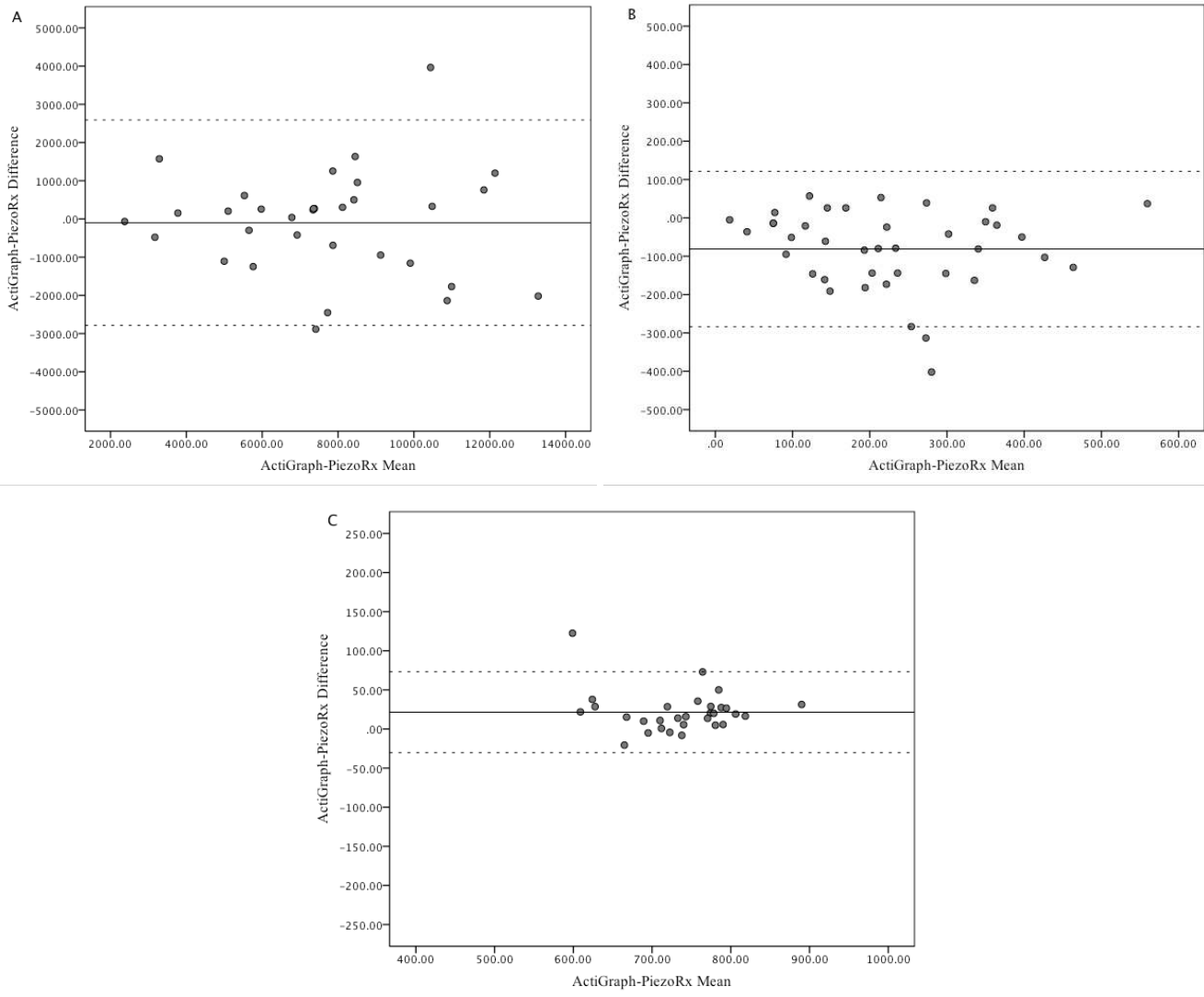


Figure 2. ActiGraph versus Piezo Bland-Altman plots for: A) steps per day (n=32), B) MVPA (minutes/week) (n=39), C) sedentary activity (minutes/day) (n=30).

As shown in Table 2, Steps per day and BMI had a strong negative correlation ($r=-0.75$, $p<0.001$). Steps per day had moderate ($r= -0.62$ - -0.75) negative correlations to both BMI and waist circumference, and had moderate positive correlations with predicted VO_{2max} , pushups and sit-to-stand ($r=0.37$ - 0.58). MVPA-7 had moderate negative correlations to BMI and waist circumference and had moderate positive correlations to predicted VO_{2max} , pushups and sit-to-stand. Sedentary activity was not correlated to any physical fitness measures. Both grip strength and vertical jump were not correlated to physical activity functions. The majority of subsample that wore the PiezoRx® for an additional two weeks said the device increased their physical activity (75% of participants) and helped them achieve physical activity guidelines (75%). Most participants reported that they planned on using the device in the future (87%) and would recommend the device (90%) to a friend. The subsamples steps/day for week 1, 2 and 3 was 7818 ± 2877 , 7132 ± 3142 , and 7308 ± 2146 respectively. The subsamples MVPA/week for 1, 2 and 3 was 297 ± 130 , 241 ± 137 and 257 ± 130 minutes per week. There were no significant

differences between week to week steps and intensity related physical activity within the subsample.

Table 2. Correlations between physical measures and PiezoRx measurements

	Steps/day (n=32)	MVPA-7 (n=39)	SedA/day (n=30)
Predicted VO ₂ max (ml/kg/min)	0.58†	0.37*	0.18
Body Mass Index (kg/m ²)	-0.75†	-0.53†	-0.06
Waist Circumference (cm)	-0.62†	-0.53†	-0.01
Grip Strength (kg)	0.27	0.23	0.20
Pushups	0.55†	0.50† ^a	0.06
Relative Vertical Power (W/kg)	0.10	0.27 ^a	0.25
Sit-to-Stand	0.37*	0.48†	0.01

Presented as correlations (r); ^an=34; *p<0.05, †p<0.001.

DISCUSSION

The purpose of this pilot study is to determine whether the PiezoRx® can accurately measure steps and intensity related physical activity measures in free-living adults. In this environment, the PiezoRx® pedometer had high correlations to the criterion measurement for both steps ($r = 0.88$) and intensity related PA measurements ($r > 0.70$). These findings are consistent with other lab based validations studies comparing the ability of the PiezoRx® and ActiGraph® to measure intensity related physical activity in children and youth (26). Findings are also consistent with Colley and colleagues (2013) evaluation of the PiezoRx® step count function during treadmill walking and running ($r^2=0.97$) (7). The PiezoRx® was also strongly correlated to the ActiGraph® for sedentary time per day ($r = 0.93$), MVPA-7 ($r = 0.70$), MPA-7 ($r = 0.74$), TPA-7 ($r = 0.80$) and bout (time)-7 ($r = 0.75$). However, the PiezoRx® consistently reported greater time spent in MVPA, MPA and VPA than the ActiGraph®. Other studies have shown that the ActiGraph® may over- or under predict intensity related physical activity (8, 22). Likewise, this study also shows that the step thresholds used to set intensity related physical activity are important to get accurate measurements of MVPA in free-living conditions using a Piezo pedometer.

The similar step rates between the devices but large difference in weekly MVPA is likely due to the intensity related step settings of the PiezoRx®. Although the spm thresholds employed in this study were individualized, they were likely still too low causing an overestimation of MVPA. This is consistent with unpublished data from our laboratory that suggests that the factory settings of 100 spm for moderate and 120 spm for vigorous are too conservative, and that step rates should even be higher for moderate (3 MET) and vigorous (6 METS) physical activity for many adults. The conservative settings used in this study explain the high sensitivity, low specificity but reasonable percent agreement values to those meeting Canadian physical activity guidelines. Further research should evaluate the most optimal moderate and vigorous step thresholds for free-living conditions in adults and older adults.

High levels of steps/day and MVPA/week were correlated to a lower BMI and waist circumference which is consistent with the American College of Sports Medicine (ACSM) position stands outlining that physical activity helps improve body composition and is a primary component of weight management (10, 20). Performing high levels of regular physical activity improves aerobic fitness which was exemplified with the significant correlation between aerobic fitness and both steps/day and MVPA/week. There was a moderate relationship between physical activity and both upper body (pushups) and lower body (sit-to-stand) measures of muscular fitness. The positive association between physical activity and muscular fitness has been observed previously (19, 25). Given the strong relationship between aerobic fitness and mortality (2) and between muscular fitness and mortality (23) and risk of falls (14), and the complexities and resources required to measure physical fitness, the use of objectively measured PA may be important in clinical settings to indicate overall physical health of patients. There is a strong movement to support the use of an 'exercise vital sign' (i.e. physical activity behavior) as an indicator of overall health in clinical care (24) and using a reliable, valid and practical objective measure of PA would make this type of assessment more accessible to clinicians.

The tertiary purpose of the study was to assess the utility of the PiezoRx® in a subsample of participants. It was revealed that the PiezoRx® increased participants' *perceived* level of physical activity, helped them meet physical activity guidelines, and they would recommend the device and plan on using it in the future. Despite the increase in perceived physical activity levels, there was not a significant increase across the three weeks of wear time. Participants had the highest PA in week 1 of no feedback (i.e. blinded), then a drop down in physical activity in week 2 and a small return back up in week 3 (with the ability to see their daily PA). This small increase from week 2 to 3, although statistically not significant, likely attributed to the participants' 'perception' of increased PA because they could see their data at this point and observe changes. These small changes observed are typical behavior changes associated with participating in a physical activity study but were not on the magnitude of those seen in other pedometer studies (4, 31), likely because of the relatively high fitness (8-9 METS) and good PA level (+185 min MVPA) of our participants. Although our sample averaged ~7600 steps per day, the ~13 '10 min bouts' per week indicates more structured effort for physical activity at a given level and duration, indicative of 'exercise'. Given the participants reported perceptions, and the fact that PA was at least maintained at an active level indicates that the use of a validated research grade pedometer can help adults achieve a physically active lifestyle.

The findings from this study have significant implications for both future research and clinical purposes. The PiezoRx® is ten times cheaper than the ActiGraph®, therefore making the PiezoRx® more accessible for future research studies and among the general public. The PiezoRx® can help adults achieve or maintain a more physically active lifestyle which could have significant health implications within societal and clinical settings as walking 30 to 60 minutes per day at moderate intensity decreases risk of mortality by 44% (27). A systematic review by Bravata and colleagues stated that participants who received pedometers took 2491 more steps per day compared to control groups (4), as pedometers can address physical activity barriers such as lack of time, self-motivation, self-efficacy, lack of knowledge/skill and

lack of self-management. Furthermore, individuals' knowing the duration and intensity of their activity have a starting point to help them increase their physical activity related to attaining the guideline recommendations, as all PA guidelines specify at least 'moderate' level of intensity to count toward guidelines.

Healthcare professionals can benefit from objective measurements to monitor and prescribe physical activity to patients. Providers may use the steps/day and intensity related physical activity levels as indicators of patient's aerobic muscular fitness, which otherwise requires some degree of training and may be cumbersome to evaluate. Incorporating objective measurements of physical activity within health care would be a major step forward in utilizing exercise as an effective form of preventative medicine to address disease burden and relieve the economic stress on the health care system (17).

A strength of this study was measuring physical activity for a full week including 5 weekdays and 2 weekend days (≥ 10 hours of data per day) allowed for more data to compare devices; some free-living validation studies using different devices only use 24 or 48 hours of data collection. The primary purpose of the study was to assess the ability of the PiezoRx® to measure physical activity in free living conditions compared to the criterion measure; and data from this sample and conclusions are strong in this regard. A limitation is that physical activity studies primarily appeal to physically active populations, potentially biasing the tested cohort to have a higher fitness compared to the general public, which limits generalizability of this study. Future research should increase the sample size to increase the generalizability of the conclusion made and further define specific step rate thresholds for absolute and relative intensity physical activity prescriptions in laboratory and field-based settings.

This study revealed that the PiezoRx® is a valid measure of both steps and intensity related physical activity compared to accelerometry in free-living conditions. The PiezoRx® also exhibited correlations to measures of physical health, warranting the promotion of medical grade physical activity monitors in healthcare as a means of supporting the physical activity levels of the general population.

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