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Occupational physical activity in brewery and office workers

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ABSTRACT

Active lifestyles are beneficial to health and well-being but our workplaces may not be inherently supportive of physical activity at work. With the increasing use of technology in the workplace, many jobs are becoming more sedentary. The purpose of this study was to characterize levels of occupational physical activity (OPA) among active and sedentary workers. Two types of activity trackers (Fitbit Charge HR and Hexoskin) were used to assess activity measures (steps, heart rate, and energy expenditure) among workers during one full work shift. The first objective of the study was to assess the agreement between two types of accelerometer-based activity trackers as measures of occupational physical activity. The second objective of this study was to assess differences in measures of OPA among workers in generally physically active (brewery) and sedentary (office) work environments. Occupational physical activity data were collected from 50 workers in beer-brewing tasks and 51 workers in office work tasks. The 101 subjects were from the brewing service sector, a call center, and an engineering office within a manufacturing facility. A two-factor repeated measures analysis of variance (ANOVA) was used to assess the two activity tracking devices while two-sample t-tests were used to compare the two worker groups. There were statistically significant differences in total steps and mean heart rate between the two devices. When comparing the two groups of workers there were statistically significant differences in measures of steps, mean heart rate, and energy expenditure. The results of the present study provide quantitative evidence that levels of OPA should be identified for different work groups.

KEYWORDS

Activity tracking; Fitbit; Hexoskin; monitoring; occupational physical activity

Introduction

"Sitting is more dangerous than smoking, kills more people than HIV and is more treacherous than parachuting. We are sitting ourselves to death."[1] Reduced physical activity is the fourth leading risk factor for worldwide mortality.[2] As technology like smartphones and tablets enable an efficient lifestyle, humans are becoming increasingly sedentary. Inactive lifestyles result in fewer calories burned and have been attributed to increased mean body weights for both men and women in the last 50 years.[3] Additionally, reduced physical activity is strongly associated with obesity, cancer, cardiovascular disease, diabetes, and depression.[4–7] Compromised physical health also has adverse societal effects. A U.S. study comparing health care expenses of physically active and inactive adults reported that over 11% of health care expenditures were attributable to inactive lifestyles.[8]

Maintaining an active lifestyle is important to health. Studies have shown that highly active adults have lower rates of all-cause mortality, coronary heart disease, depression, and several other adverse health outcomes.[2,4–6,9,10] Yet, many modern jobs may not be designed to support physical activity due to a heavy reliance on technology.[11] In the U.S., Americans occupy an average of 45 hr working every week, which equates to one-third of the average lifespan.[10,12] Studies have suggested that Americans who sit for long periods of time are at an increased risk of developing adverse health effects,[9] or even early mortality when sitting longer than 6 hr per day.[6] Consequently, studies have evaluated the benefits of physical activity in sedentary environments.[13–15] Sedentary workers who participated in physical activity during their workday have reported decreased mental fatigue and food cravings.[16] Some organizations have acknowledged the potentially dangerous health effects of a sedentary work-life by encouraging

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occupational physical activity (OPA) among office employees.[17] A popular example of OPA promotion at work is the encouragement of activity tracking using wearable devices. In fact, it is projected that corporate wellness programs will foster over 13 million wearable devices into workplaces within the next 5 years.[18]

OPA may continue to decline for many workers as a result of increasing computer-based and desk-time work. However, lifestyles with excessive physical activity (e.g., construction, logging, fire-fighting) can also be harmful. Studies have reported that physical overexertion attributable to work demands has been associated with cardiovascular overload, fatigue[19,20] and an increased risk of musculoskeletal disorders.[21,22] The "Goldilocks model" proposed that optimal levels of work (based on economic realities) are somewhere between too much and too little.[23] It is likely that the same principle of "not too much but not too little" also applies to OPA. Both high and low OPA are potentially harmful to the health and well-being of workers, although formal guidelines for OPA have not yet been established.

Objective measures of OPA across occupational groups have not traditionally been measured.[7] This is partly attributable to wearables only becoming popular among the general public in the early 2000s. Self-report is still considered to be the most common measure of physical activity.[24] Self-report instruments, like the Occupational Physical Activity Questionnaire (OPAQ) and the Occupational Sitting and Physical Activity Questionnaire (OSPAQ), are validated methods to measure physical activity in the free-living environment.[25–28] However, self-report methods are not designed to collect physiological measures that are indicative of physical intensity.[26] Barrero et al.[29] reported that workers who use self-report methods have a tendency to overestimate their physical activity exertion level when a job task is perceived as challenging. Another study evaluating activity in white and blue collar workers also reported disparities in objective and subjective measures of OPA among university staff.[30] Disparities between self-report and objective methods have prompted many validation studies of self-reported measures, like the OPAQ as compared to accelerometers[27,28,31] and activity trackers.[32–37] According to the mentioned studies, self-report is a valid method, as compared to accelerometers. Though these studies were primarily focused on workers in sedentary environments and physically active workers were not evaluated.

Some studies have assessed OPA among construction, nursing and other patient care industries using objective tracking methods.[38–40] Objective measures have also been used in non-work settings to measure physical activity in patient care, epidemiology, pediatric, and clinical research.[41–43] In summary, OPA was examined in a context of whether workers were getting "enough" activity and meeting physical activity guidelines, rather than defining levels of OPA across occupations. Therefore, it is still unclear how much OPA workers in varying occupations should receive. Typically, studies that have used activity tracking devices employ equipment that is either expensive (e.g., electrocardiograms, etc.) or mundane (pedometer, accelerometer). For these reasons, the mentioned devices may be unappealing to the average worker and make them less likely to be worn, especially in the workplace.

However, the recent trend in physical activity trackers like the Fitbit, have made daily activity tracking "user friendly" and appealing to a broad sector of the U.S. population. This is in part because many wearables, like the Fitbit Charge HR can now measure variables beyond steps such as heart rate, sleep and energy expenditure. In a meta-analysis conducted by Evenson, et al.[35] it was reported that Fitbit devices produced greater step validity and reliability than other devices, but low validity and high reliability for energy expenditure.[35] Accuracy and reliability findings of the Fitbit Charge HR are mixed, but if the Fitbit Charge HR or another similar device can be deemed an appropriate measure of OPA, tracking of activity at work would become accessible to many workers and organizations. For these reasons, the Fitbit Charge HR was chosen as a device for this study to measure OPA across different occupations.

In addition to wrist-worn wearables, athletes and health enthusiasts are also adopting wearable smart clothing to track activity. Smart clothing can be designed with sensors built into the material to measure heart rate, steps, and breathing rate. Hexoskin is a type of smart shirt designed to measure physiological activity. Although studies evaluating the validity and reliability of smart clothing are very limited, a few studies have recently reported the established validity of the Hexoskin in laboratory settings.[44–46] The Hexoskin's built-in electrocardiogram potentially makes this device a good comparison measure of OPA. Therefore, the Hexoskin was selected as a second method for evaluating OPA.

Having baseline measures of OPA may assist in the evaluation of interventions aimed at modifying OPA

in the workplace. The first objective of this study was to determine the level of agreement between two types of accelerometer-based activity trackers for assessing OPA. The second objective of this study was to assess differences in OPA among workers in physically active and relatively sedentary work environments.

Methods

Subjects

Fifty participants in the physically active (brewery) work group were recruited after brewery management expressed interest in evaluating OPA among workers in to determine whether job rotation, etc. should be implemented. Fifty-one office participants were recruited from a service call center and an engineering department at a manufacturing company. The brewery work group included subjects who packaged bottled beer, distributed packaged beer to liquor stores, loaded delivery trucks with pallets of beer, poured beverages for customers in taprooms, and provided brewery tours. The call center was an office that accepted large capacity customer service phone calls, while the manufacturing company designed and produced control systems. Management at each company recruited participants for the study internally during employee meetings and e-mail announcements. Once management obtained names of interested participants, a list with potential subject names was given to the study investigators. The study investigators entered participant information into an Excel spreadsheet in which each participant received a unique identifying code to replace their name. Brewery and office subjects were categorized as either "brewery" or "office" by management based on the nature of work. After observation and informal conversations with participants, the investigators agreed with management on their brewery and office job classifications. Work shifts ranged from 5–12 hr.

Data were collected in Fort Collins, Colorado from December 2016 to February 2017. Subjects 18 years of age or older of both genders were invited to participate. Participants were offered monetary compensation for their participation. All subjects signed an informed consent document and demonstrated an understanding that participation in this study was voluntary. If subjects decided to participate in the study, they understood that they could withdraw their consent and stop participating at any time without penalty or loss of benefits to which they were otherwise entitled. Colorado State University human subjects Institutional Review Board approval was obtained prior to data collection.

Activity tracking devices

Fitbit

The Fitbit Charge HR is one of the most popular wearable activity trackers and was chosen for this study based on validation results from other studies.[36,47–49] The Fitbit Charge HR is wrist-worn and designed with a tri-axial accelerometer and photoplethysmography to track activity. Photoplethysmography measures heart rate by shining a light through skin to detect blood flow.

Hexoskin

The Hexoskin smart shirt is designed for activity tracking. It is equipped with a hip-worn triaxial accelerometer and electrocardiogram. The Hexoskin was used to evaluate OPA by reason of being a smart shirt with a built-in electrocardiogram. The Hexoskin is a fairly new activity tracking device, but studies have reported it to be a valid measure of physical activity.[44–46]

Accelerometers and Electrocardiograms as Measures of OPA

Electrocardiograms (e.g., Hexoskin) and photoplethysmography (e.g., Fitbit Charge HR) are the most widely used measures of heart rate in wearable activity tracking devices. Studies conducted in laboratory settings have found high correlations between electrocardiogram measures and photoplethysmography.[50,51] Although one study recently evaluated the Fitbit Charge HR in free-living conditions compared to an electrocardiogram and reported that the Fitbit consistently underestimated heart rate.[52] There are many variables (e.g., stress, work/family conflict, individual differences, etc.) that can affect heart rate, and thus compromise the accuracy of electrocardiograms and photoplethysmography.[53] Therefore, it has been suggested that heart rate measures and accelerometers be used in conjunction to obtain the most realistic measure of physical activity.[54–59]

Measures on physical activity intensity

Steps

Steps were measured by both activity trackers through a tri-axial accelerometer. Tri-axial accelerometers are used to determine a step based on subsequent acceleration and self-reported height, weight, and gender.

Third party wearables such as the Fitbit Charge HR and Hexoskin own proprietary algorithms yielding a "black box" which inadequately describes data processing information.[60] The self-reported information and acceleration then yield an estimate of stride length and set an acceleration threshold. The purpose of the threshold is to discriminate between a step and a non-step. The Fitbit Charge HR accelerometer is worn on the wrist and the Hexoskin accelerometer is located on the hip in a shirt pocket.

Heart rate

Predicted maximum heart rate was calculated using the age-dependent formula: $220 - \text{age}$.[61] Percent maximum heart rate range was determined for each subject based on the following formula:[62]

$$100 \times \frac{Average\ Hr\ on\ Job - Resting\ HR}{Predicted\ HRmax - Resting\ HR} = \text{Percent Maximum HR Range Required by the Job.} \quad (1)$$

The percent maximum heart rate range was used as an estimate of the mean percent of aerobic capacity (oxygen consumption) during the work shift.[62] Each participant's resting heart rate at work was defined as the lowest mean heart rate for a 60-sec time period while sitting during the work shift.

Energy expenditure

Energy expenditure was estimated by metabolic equivalent of task (METs) and calories burned. METs are a measure of intensity during physical activities that are determined by oxygen consumption at rest, 3.5 mL O_2 per kg body weight x min.[63] METs can generally be grouped by intensity: light (1.1–2.9), moderate (3.0–5.9), and vigorous (>6.0).[64] For example, a person running at five METs is expending five times more energy than their resting MET state. METs are estimated by the Fitbit Charge HR and described as "active minutes." Active minutes are estimated based on direct measures of heart rate, basal metabolic rate, and self-reported measures of height, weight, age, and gender. Once METs were measured by the Fitbit Charge HR, the investigators compared the self-reported activity logs to the MET values. In some cases, study investigators observed workers. In these circumstances, observational data were acknowledged as a qualitative "check" to ensure reasonable physiological measures were assigned by the Fitbit Charge HR. Both the Fitbit Charge HR and Hexoskin estimate caloric expenditure, which was also used in determining energy expenditure. Caloric expenditure is estimated from subject height, weight, age, gender, heart rate, and steps.

Activity logs

Participants were asked to complete paper activity logs every 30 min during their work shifts. The activity log asked participants to answer the following open-ended statements: time, task performed (e.g., sat at desk, made phone calls), equipment/tools used (e.g., phone, desk, chair). The activity log then asked respondents to indicate all that apply to the following statement: "The majority of my time was spent: sitting, standing, walking, carrying, lifting, climbing (stairs, etc.)." Daily activity logs also inquired about medication consumption with a Yes or No question. If the participant answered "Yes", there was a follow up question asking the type of medication (e.g., beta-blocker) and dose. Medication type and dose were evaluated by the investigators to determine whether heart rate would be affected. The activity logs were only used for qualitative information (e.g., comparing self-reported activities to physiological data).

Procedures

Introduction to the study and Institutional Review Board (IRB) consent for each participant

A brief greeting and verbal introduction to the study purpose and procedures were presented to participants. Before use, the Fitbit Charge HR and Hexoskin were programed to each user by entering the subject's height, weight, date of birth, and gender. This information was only obtained once and used for both the Fitbit Charge HR and Hexoskin through participant self-report. From this information, sizes of Hexoskin shirts to be worn by participants were determined. The IRB written consent was distributed to all participants.

Fitbit charge HR

Each participant was asked to wear a Fitbit Charge HR on their non-dominant wrist, as suggested by the manufacturer. Participants wore the activity tracker for one work shift. Participants were instructed not to: submerge the activity tracker in water (light splashing okay), tamper with the device once applied (e.g., do not loosen or tighten the wristband), or remove before the completion of their shift.

Hexoskin

The Hexoskin is a lightweight, quick-dry material that looks like a fitted tank top. Physiological sensors are located within the shirt material. The participant was

instructed to use a restroom or changing area to remove their shirt and put on the Hexoskin shirt. Hexoskin shirts for females have built-in bras, therefore female participants were asked to remove their bra or any other undergarment from the waist up that may interfere with the sensors. Before putting on the shirt, the investigator moistened the sensors with water. After putting on the Hexoskin shirt, participants were informed that they could wear their usual work clothes over the Hexoskin. Participants were instructed not to: remove the Hexoskin shirt before the completion of the work shift, shower with the Hexoskin shirt, tamper with the shirt or sensors while wearing, or remove the battery located in the shirt pocket. This allowed the activity tracking devices to obtain a working resting heart rate. Investigators were present at the end of each work shift to stop the sampling and collect the Fitbit Charge HR and Hexoskin activity trackers. After all activity trackers were removed, participants were offered a $20 participant incentive.

Per Hexoskin manufacturing instructions, provided elastic bands were attached to the shirt to reduce movement of the electrodes. Once participants were wearing the Hexoskin shirt, investigators attached a Hexoskin data logger, which activated sensor data collection. Before starting their work shift, participants were asked to sit quietly for 5 min.

Activity trackers were then synced to the online Fitbit and Hexoskin dashboard accounts to store and save the respective data. Raw Fitbit Charge HR steps data were recorded in 1-min intervals in Excel spreadsheets by a third-party software program (Fitabase), and subsequently aggregated to hourly sums. Raw Fitbit Charge HR heart rate values were recorded by Fitabase in 10–15 sec intervals, and then aggregated to 1-min averages. Hexoskin data were downloaded into Excel spreadsheets directly from the Hexoskin online dashboard. Hexoskin records heart rate and steps data at 256 Hz; therefore, timestamps were converted to a Unix timestamp to match the Fitbit Charge HR timestamp of one-second intervals. Hexoskin steps values were aggregated to hourly sums, and heart rate values were aggregated to 1-min averages. Time series of recorded data for heart rate values were filtered to be the same length between Fitbit Charge HR and Hexoskin activity trackers, as were the time series of recorded data for steps. Time series plots of 1-min average heart rate values and hourly steps were visually inspected to ensure that Fitbit Charge HR and Hexoskin devices were worn and collecting data for the entirety of each participant's work shift. Individual identifiers were matched between the Fitbit Charge HR and Hexoskin. Both activity trackers were connected via Bluetooth or direct connection to their respective software platforms of Fitabase and My Hexoskin Dashboard. To ensure that the data from both devices were synced, time codes generated from each tracking device were matched.

Statistical analysis

Workers were categorized into two groups: brewery workers and office workers. Data were analyzed using a two-sample t-test to investigate differences between group measures of steps, heart rate, mean percent maximum heart rate range, and energy expenditure. A two-factor repeated measures analysis of variance (ANOVA) was used to assess differences in mean hourly steps between Fitbit Charge HR and Hexoskin devices and between brewery and office groups. Similarly, a two-factor repeated measures ANOVA was used to assess differences in mean heart rate between the two devices as well as work groups while controlling for gender and weight. Because these are potentially confounding variables when evaluating heart rate, gender, and weight were controlled for as a binary and a continuous variable, respectively. Age and length of recorded data for heart rate could potentially confound differences in mean heart rate; however, age and length were not controlled for due to a lack of statistical significance between means of the two work groups. In the two-factor repeated measures design, the model is described by:

$$y_{ijk} = m + a_i + b_{j(i)} + t_k + (at)_{ik} + e_{ijk} \qquad (1)$$

where

yijk is the observed heart rate or step count for work group i (i = 1, …, a = 2), subject j (j = 1, …, r = 94), and device k (k = 1, …, b = 2),

μ is the grand mean,

αi is the effect for each group (office and brewery),

βj(i) is the random effect of the subject factor,

τk is the effect for each device (Fitbit Charge HR and Hexoskin),

$(\alpha\tau)$ik is the interaction effect for the combination of group and device,

εijk is the residual errors term,

μ, αi, τk, and $(\alpha\tau)$ik are fixed effects factors,

βj(i) are N(0, $\sigma 2\beta(\alpha)$) and εijk are N(0, $\sigma 2$), and

βj(i), εijk are all independent.

In the design evaluating differences in mean heart rate, additional terms controlling for subject weight and gender were added to the model. A mean value

of heart rate was calculated for each participant by averaging the 1-min interval heart rate time series, and a mean value of hourly steps were calculated by averaging the 1-hr interval steps time series.

To assess steps and heart rate reliability as measured by both devices, concordance correlation coefficients (CCC) for repeated measures were estimated using the "cccrm" R package. For heart rate and steps, a time series was constructed with variables for participant identification number, outcome value (heart rate and steps), method (Fitbit Charge HR and Hexoskin), and time. Hourly time series were used for both heart rate and steps to ensure comparability between CCC values. The appropriate intraclass correlation coefficient (ICC), which was estimated using the variance components of a linear mixed model, was used as an estimator of the CCC.

CCC values suggested four categories of reliability between the two activity trackers: poor ($r = 0.1-0.4$), moderate ($r = 0.4-0.59$), good ($r = 0.6-0.74$), and excellent ($r = 0.75-1.0$).[65] Bland-Altman plots were also generated to quantitatively evaluate device agreement and bias. In a Bland-Altman analysis, 95% of the mean differences between measurements must lie within the limits of agreement (mean difference ± SD) to satisfy the requirement of quantitative measurement agreement.[66,67] All statistical tests were run using R version 3.2.5. Statistical significance for all tests was determined at the alpha 0.05 level.

Results

Subjects

Data from two subjects in the brewery group were removed from the analyses due to device connection issues during data collection. The Hexoskin device data loggers for these two subjects failed to track activities because devices were not attached to the shirt correctly. Additionally, the data from one subject in the office group was removed due to self-reported consumption of medication that affected their heart rate. Two office subjects reported in their activity logs that they had walked the adjacent neighborhood during their lunch break. After speaking with the two subjects at the end of their work shift, it was determined that the lunch walk was not part of their normal daily work activity. They explained that since they were being recorded for physical activity, they wanted to increase their steps. Thus, data was removed for that period of time. Three subject's Fitbit Charge HR data were not used in the analysis because data were unable to be extracted from the device platform. Therefore, the final sample was 94 in total: 47 brewery and 47 office workers. Table 1 displays demographics of the study sample. There was no significant difference in subject age between brewery and office workers, whereas mean weight differed significantly between the two work groups.

Daily activity logs

Brewery workers did not complete activity logs as thoroughly as office workers. The response rate was low for answering the heart rate medication question in the daily logs such that 42% (24 brewery, 17 office) of subjects did not answer the question. Of those participants who responded to the heart rate medication question, 9% (four brewery, five office) of subjects answered yes to taking medication that affects heart rate. Upon review of the medications reported by the participants, it was determined that eight self-reported medications did not affect heart rate. However, stimulant medication consumption was reported by one subject and data for this participant was removed.

Comparison of Fitbit charge HR and Hexoskin

The Hexoskin and Fitbit Charge HR directly measured steps and heart rate (see Table 2). The CCC yielded a moderate reliability ($r = 0.53$) for measures of mean hourly steps and good reliability ($r = 0.61$) for measures of mean heart rate. Bland-Altman plots of Fitbit Charge HR and Hexoskin displayed agreement in objective measures of steps with 95% of the differences

Table 1. Participant demographics.

		Brewery		Office		
Number of males		42		18		
Number of females		5		29		
		Mean	SD	Mean	SD	Difference between means
Age (years)		36.77	7.42	39.17	10.36	−2.4
Weight (kg)*		84.15	15.04	72.49	16.25	11.66
Length of recorded data (minutes)	Steps (per hour)	472.34	87.23	450.64	67.22	21.7
	Heart rate (bpm)	498.47	83.10	481.30	61.58	17.17

*Significant at the 0.01 level.

Table 2. Comparison of Fitbit Charge HR and Hexoskin.

	Hexoskin		Fitbit		
	Mean	SD	Mean	SD	Difference between means
Steps (per hour)*	514.93	324.13	830.22	487.83	−315.29
Heart rate (bpm)*	86.47	7.84	80.33	8.75	6.14

*Significant at 0.001 level.

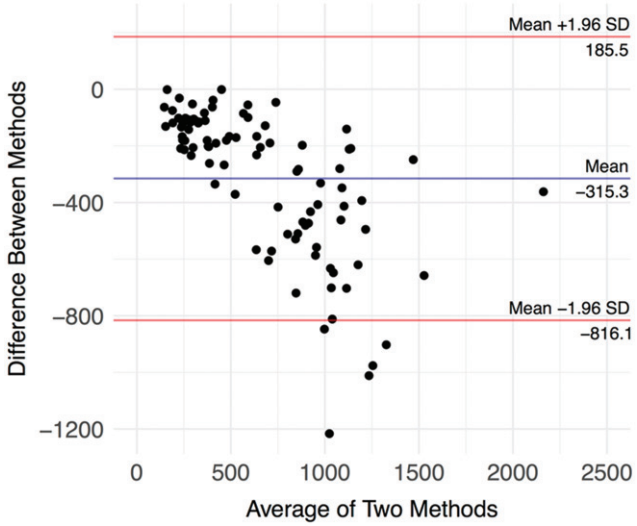


Figure 1. Bland-Altman plot analysis of hourly steps. Each point represents a participant. The x-axis shows the average of the two steps values measured for each participant using the Fitbit Charge HR and Hexoskin. The y-axis shows the difference between the two steps values (Fitbit Charge HR values subtracted from Hexoskin values). The middle horizontal line indicates the mean of differences (-315.3), and the upper and lower horizontal lines indicate the upper and lower limits of agreement (185.5, -816.1). The upper and lower limits of agreement were calculated by adding and subtracting 1.96 times the standard deviation of differences from the mean, respectively.

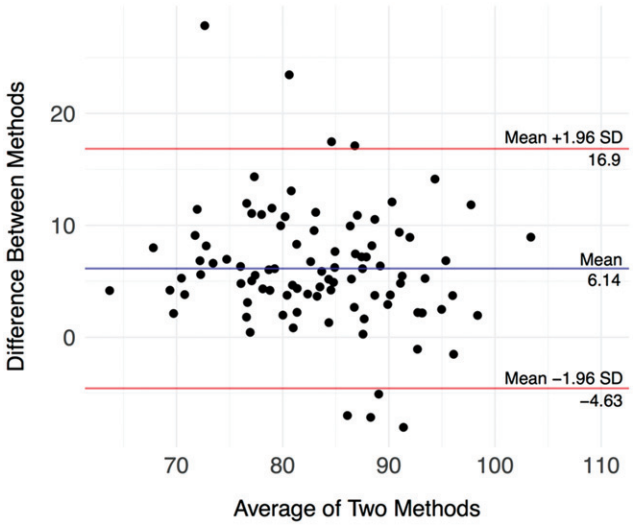


Figure 2. Bland-Altman plot analysis of mean heart rate. Each point represents a participant. The x-axis shows the average of the two heart rate values measured for each participant using the Fitbit Charge HR and Hexoskin. The y-axis shows the difference between the two heart rate values (Fitbit Charge HR values subtracted from Hexoskin values). The middle horizontal line indicates the mean of differences (-6.14), and the upper and lower horizontal lines indicate the upper and lower limits of agreement (16.9, -4.63). The upper and lower limits of agreement were calculated by adding and subtracting 1.96 times the standard deviation of differences from the mean, respectively.

F1 within the limits of agreement (Figure 1), while no agreement was indicated in objective measures of heart rate with 91% of differences within the limits of agreement (Figure 2). The Bland-Altman plot of steps suggest a trend of a larger difference between methods as the average increases, contrasting the more uniform distribution observed for measures of heart rate.

F2

Comparison of brewery and office workers

T3 Table 3 summarizes means, standard deviations, differences between means, and p-values for hourly steps, heart rate, percent maximum heart rate range, METs, and calories. In the two-factor repeated measures ANOVA, differences in mean hourly steps and heart rate between devices and work groups were tested. The device was repeated within subjects and work group was repeated between subjects. There was a significant main effect of work group on hourly steps, $F(90, 87) = 194.24$, $p < 0.0001$. Additionally, there was a significant interaction of device and work group on hourly steps, $F(87, 354) = 79.98$, $p < 0.0001$. The results indicate that if all other variables are ignored, the difference between steps per hour measured by the two devices for brewery workers is greater than the same difference among office workers. Figure 3 shows box- F3
plots of mean hourly steps measured by Fitbit Charge HR and Hexoskin, faceted by work group, and Figure F4
4 shows scatterplots of mean hourly steps for each participant measured by Fitbit Charge HR and Hexoskin, faceted by work group. There was not a statistically significant difference in hourly steps for work shift.

For mean heart rate, there was a significant main effect of device, $F(90, 46) = 121.35$, $p < 0.0001$, as well as work group, $F(1, 91) = 16.58$, $p = 0.0002$. There was a significant interaction of device and group on mean heart rate, $F(1, 91) = 5.87$, $p = 0.02$. The statistically significant interaction indicates that if all other variables are ignored, the difference between devices is greater among office workers as compared to brewery workers. However, there was not a significant main effect of gender or of weight. Figure 5 displays box- F5
plots of mean heart rate values measured by device,

Table 3. Comparison of brewery and office work groups.

		Brewery		Office		
		Mean	SD	Mean	SD	Difference between means
Hexoskin	Steps (per hour)**	727.53	294.86	302.34	181.92	425.2
	Heart Rate (bpm)*	88.9	13.45	84.11	13.77	4.79
	Percent Max HR Range**	23.04	4.96	17.88	5.09	5.16
	Calories**	2209.15	769.14	1387.28	611.9	821.87
Fitbit	Steps (per hour)**	1218.73	363.84	441.72	200.77	777
	Heart Rate (bpm)**	84.17	13.16	76.48	12.18	7.7
	Percent Max HR Range**	14.95	4.42	9.87	2.66	5.09
	Calories**	1871	598	885	272	985
	METs**	3	0.92	1.81	0.59	1.19

*Significant at 0.01 level.
**Significant at 0.001 level.

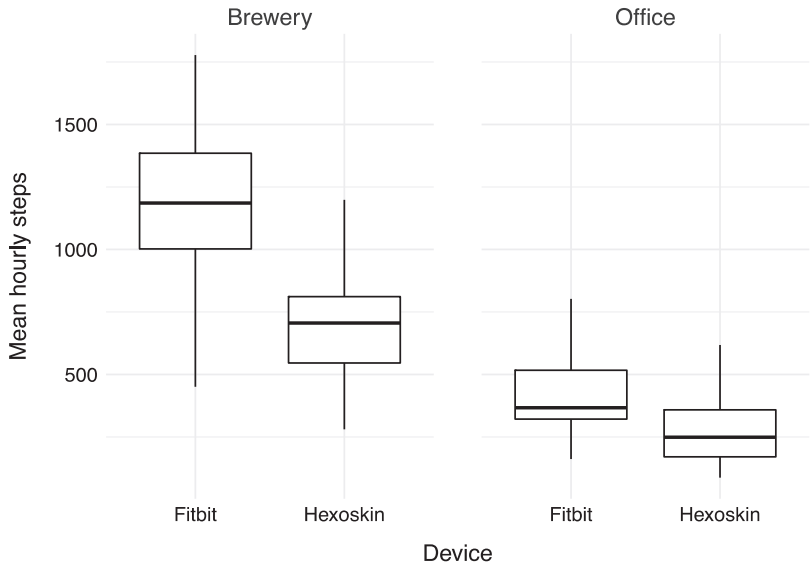


Figure 3. Boxplots of mean hourly steps for each participant in the study as measured by Fitbit Charge HR and Hexoskin. Plots are faceted by work group: brewery and office.

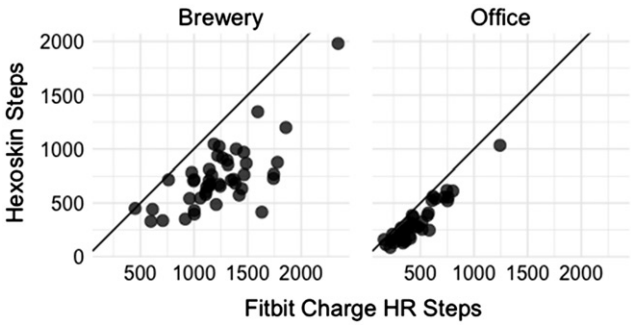


Figure 4. Scatterplots of mean hourly steps for each participant in the study as measured by Fitbit Charge HR and Hexoskin.

F6 faceted by work group. Figure 6 shows scatterplots of mean heart rate for each participant measured by device, faceted by work group.

Discussion

In the present study, significant differences were found between activity tracking devices in measures of mean hourly steps and heart rate. Fitbit Charge HR devices consistently measured a greater number of mean hourly steps than the Hexoskin. However, the Hexoskin consistently measured greater mean heart rate than the Fitbit Charge HR. There were also significant differences in activity levels among brewery and office workers. Brewery workers took more steps, had a greater mean heart rate and maximum percent heart rate range, and higher energy expenditure than office workers.

Activity tracking devices

Steps

Fitbit devices have been validated wearable devices for measuring steps under ideal conditions,[32,36,48,68,69] although location of device may influence results. However, best placement of device for most accurate tracking is still undetermined.[70] For example, studies have reported that steps can differ significantly between hip-worn and wrist-worn tri-axial accelerometers.[71,72] In this study, the Fitbit Charge HR and Hexoskin

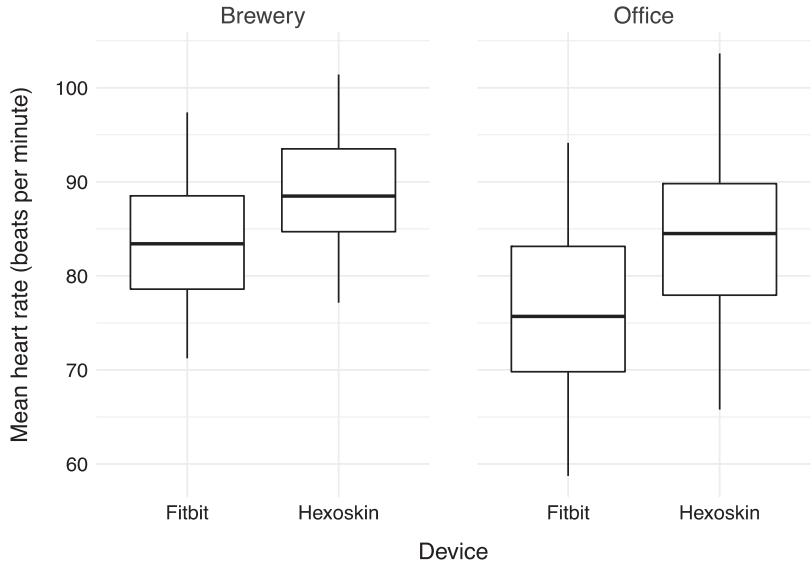


Figure 5. Boxplots of mean heart rate values (bpm) for each participant in the study as measured by Fitbit Charge HR and Hexoskin. Plots are faceted by work group: brewery and office.

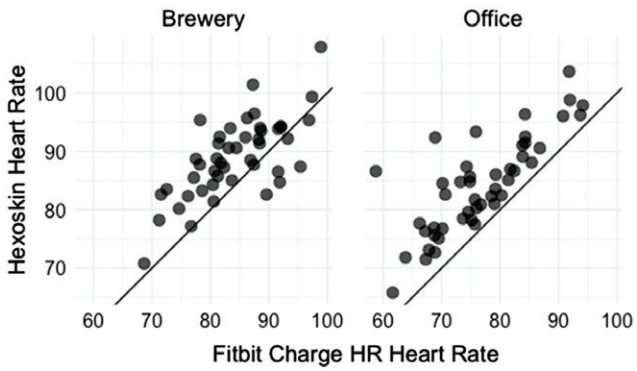


Figure 6. Scatterplots of mean heart rate for each participant in the study as measured by Fitbit Charge HR and Hexoskin.

measured significant differences in steps. This is potentially attributable to location of device (e.g., wrist-worn vs. hip-worn), but also field setting rather than a controlled laboratory. In a study conducted in the free-living environment, Chu et al.[71] reported that a wrist-worn Fitbit measured significantly more steps than a hip worn accelerometer even though devices had moderate correlation and good agreement.[71]

Consistent with Chu et al.,[71] the Fitbit Charge HR measured a greater number of hourly steps as compared to a hip-worn accelerometer even though devices showed good correlation and agreement. One possible explanation for difference in hourly steps may be that distal upper extremity motion activates the wrist-worn accelerometer and subsequently records steps while an individual is actually stationary. Tri-axial accelerometers record steps when there are changes in directional acceleration as with the swinging motions of the arms or with the vertical movement of the pelvis when walking. Examples of non-steps where a wrist-worn accelerometer could record a step(s) include being excessively active with arms while talking, pulling a beer tap handle, moving boxes, steering a forklift, etc. In all of the previous examples, an accelerometer positioned on the trunk or in proximity to the pelvis may not have recorded steps. For these reasons, intensity levels can be difficult to determine because distal upper extremity motions may not elevate heart rate or involve much movement from the torso or hips.

Heart rate

Literature presents mixed findings in the determination of heart rate validity and reliability among wrist-worn wearables and electrocardiograms. Results of most activity tracking validity studies are dependent on a multitude of factors (e.g., validity criteria, activity levels, laboratory tests, individual differences, etc.). One validation study reported the Fitbit to be an accurate measure of heart rate when compared to an electrocardiogram from start to moderate activity levels, although not as accurate during vigorous activity.[34] Another study reported the Fitbit to be an accurate device at rest, though it was not reliable during other intensities when compared to an electrocardiogram.[73] During a study of high intensity activities, the Fitbit was reportedly less accurate than other objective measures and consequently not validated.[74] In the present study, there were significant differences between devices in measures of heart rate, but good correlation.

Comparison of brewery and office workers

The results of this study are consistent with previous OPA studies and demonstrate significant differences in activity levels among occupational groups, specifically in measures of steps. Steele and Mummery[30] measured physical activity among professional, white collar, and blue collar workers using pedometers for 3 workdays. Similar to the present study, they reported significant differences in steps among blue collar (active) and white collar (sedentary) workers. Pedometers were also used to evaluate OPA by Miller and Brown,[75] where steps were significantly higher for blue collar workers for a week. Thorp et al.[76] measured OPA in call center workers for 8 days using an accelerometer and had similar findings of significantly reduced number of steps as compared to non-desk workers.

However, practicality of OPA measurement methods should be considered. Wearable technology like the Hexoskin are not always feasible to wear daily in the workplace, and other hip worn accelerometers are typically less invasive. Brighenti-Zogg and colleagues[77] assessed OPA among three work groups (low, moderate, high activity) using SenseWear mini armbands (tri-axial accelerometer) and a physical activity questionnaire. Their results also indicated significant differences between work groups. Present study findings were consistent with OPA literature of steps, though length of data collection differed significantly in this study as compared to others. Two major reasons for this include organizational lack of support for a study lasting more than one work shift and the invasiveness of the Hexoskin. Many study participants expressed that it was very noticeable during their work shift and sometimes caused discomfort.

Previously cited research differs from this study in respect to Fitbit measures of heart rate in office workers. Surprisingly, the magnitude of difference between devices was greater in office workers than in brewery workers. It is unclear why office workers yielded the greatest discrepancy, though it could be attributable to device awareness. Office workers primarily had desk jobs, therefore the activity tracking devices may have been more noticeable throughout the day while sitting, than if worn by an active worker. This awareness may have prompted office workers to be more physically active while wearing the devices. Another reason may be that the office workers in this study sample had job tasks that were stressful, consequently elevating heart rate. The Hexoskin consistently measured higher mean heart rate values for workers in both groups as compared to the Fitbit Charge HR. The reason for this difference is ambiguous; however, it is possible that the Hexoskin's electrocardiogram technology may result in more accurate readings than the Fitbit Charge HR. Though differences in measures could also be attributable to free-living conditions and length of work shift.

As expected, mean heart rates and the percent maximum heart rate range required for the job tasks were greater among brewery than office workers. This finding indicates that brewery workers performed job tasks that required greater cardiovascular effort than office workers. It has been suggested that if percent maximum heart rate range required by the job exceeds 33%, workers are likely to become physically fatigued.[62] Both devices indicated that percent maximum heart rate range required for brewery workers, was below the 33% threshold level of fatigue.

Investigators must determine to which degree devices should be accurate and whether good correlation or agreement is "good enough" to define OPA. While Bland-Altman plots displayed agreement in steps and non-agreement in measures of heart rate, the bias indicated by the line of equality was not considered statistically significant in either plot. However, while not statistically significant, trends in variability observed in the Bland-Altman plot of steps could suggest meaningful differences between devices. The mean difference between methods of -315.3 steps per hour is important to consider given that this is within one standard deviation of the mean hourly steps recorded by office workers (see Table 3). The trend of an increasing difference between the two devices displayed by the Bland-Altman plot of steps additionally suggests that differences between the two devices is likely to become more pronounced as the average number of steps recorded increases. Giavarina[67] states that Bland-Altman plots are not meant to interpret whether one device should be used over another, but should be used to quantify bias. For this reason, it is difficult to draw practical conclusions from Bland-Altman plots without a priori threshold limits established. This alone provides motive for additional research in determining acceptable devices and practical levels of OPA.

In different work environments, this study did not clarify whether the Fitbit Charge HR or Hexoskin is the preferred device to measure physical activity. Smart clothing like the Hexoskin may be useful and necessary for athlete use, but is not a practical measure of physical activity for the average worker. If commercial devices like the Fitbit can be used to reasonably measure OPA, the general working

population may be more likely to wear the device and provide abundant sources of data.

Limitations

Activity tracking devices

The Fitbit Charge HR tri-axial accelerometer is located on the wrist. As mentioned previously, this is a limitation because wrist-worn activity tracking devices have the potential to measure additional activity with exaggerated arm movement, as compared to a hip-worn accelerometer.[78] Additionally, the Fitbit devices may be a potential source of bias and encourage additional OPA. As described in the results section, two participants changed their behavior due to activity tracking device wear.

The Hexoksin was minimally invasive because it was worn beneath all clothing and undergarments. However, women were sometimes hesitant to wear the Hexoskin due to concerns with built-in bra support. The Hexoskin is designed for athletes, who typically have a lean and athletic build and the majority of workers are not likely to share the same anatomical shape of an athlete.

Heart rate

A true resting heart rate was not measured during this study, yielding a limitation. Resting heart rate is the least amount of blood that your heart pumps at rest.[43] Traditionally, resting heart rates are measured in a cool, quiet location with limited distractions. In the work environment, quiet and distraction-free locations for measurement of resting heart rate can be difficult to find. It was not feasible to ask subjects to rest in a quiet room for a resting heart rate to be measured. To address this limitation, a working resting heart rate was measured for each participant by defining the lowest mean heart rate at work for a 60-sec time period.

Healthy worker effect

Participants were recruited internally by management at their organization, rather than by the investigators due to organizational preference. This recruitment method may have contributed to a healthy worker effect bias, eliciting participation and interest from workers with already active or healthy lifestyles.

Length of data collection and work shift

Data were collected during one work shift, which ranged from 5–12 hr depending on job tasks. Investigators were not informed of employee shift length until day of data collection. It is acknowledged that activity levels and intensity likely vary between a 5-hr and 12-hr shift, however, the free-living environment is dynamic and cannot always be controlled.

Implications

Investigators can apply several strategies to improve the measurement of OPA. By continuing to evaluate activity levels in varying occupations, measures, and methodology associated with OPA will continue to improve. Highly active occupations such as firefighting, professional logging, and construction roofing are jobs that require highly intensive physiological demands. Having the capacity to accurately measure physical activity among workers with noninvasive activity tracking would be an important step toward understanding and redesigning tasks in the workplace. By continuing to assess OPA across a variety of activity levels and job types, it is likely that an optimal level of OPA per occupation can be identified. Wearable devices are improving rapidly, therefore new devices should continuously be validated against proven methods (electrocardiograms). If workplaces and job tasks were designed based on OPA level, we may have a healthier workforce.

Conclusion

This study found significant differences in activity levels between brewery and office workers during a single work shift. Observed differences in mean hourly steps and heart rate between brewery and office work groups suggest that there are important differences in the respective physiological demands of each occupational work group. Due to the invasiveness of the Hexoskin, it is not recommended that it be used to measure OPA for extended periods of time. However, the Fitbit Charge HR may need to undergo more rigorous testing in the workplace before endorsement is established.

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No potential conflict of interest was reported by the authors.

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