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The relationship between intra-abdominal pressure and body acceleration during exercise

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Abstract

Objectives—High intra-abdominal pressure (IAP) may influence the development of pelvic floor disorders. We and others have used intravaginal pressure transducers to measure IAP in women during exercise and daily activities, but utilizing the transducer for long-term measurements creates compliance issues. Waist-worn accelerometers are prominent in research and may be a reliable alternative for approximating IAP. We hypothesized that there are pair-wise positive correlations between the mean maximal accelerometer vector magnitude and two IAP measurements: mean maximal IAP and area under the curve (AUC).

Methods—Twenty-five women who regularly participated in exercise performed 13 activities. IAP was measured with an intravaginal transducer and acceleration with a waist-worn accelerometer. We determined the mean maximal IAP, AUC for IAP, and mean maximal accelerometer vector magnitude for each activity and participant. The relationship between IAP and acceleration was determined by computing the Pearson correlation coefficient (R) and the 95% confidence interval for mean maximal accelerometer vector magnitude versus mean maximal IAP and mean maximal accelerometer vector magnitude versus AUC for IAP.

Results—The R was 0.7353 for mean maximal accelerometer vector magnitude versus mean maximal IAP (including walking) and 0.5059 for mean maximal accelerometer vector magnitude

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versus AUC for IAP (excluding walking). Walking at three speeds, analyzed separately, presented R values of 0.72208 for mean maximal IAP and 0.21678 for AUC.

Conclusion—Waist-worn accelerometers may provide a viable method for approximating mean maximal IAP in a population of women during most activities.

Keywords

Pelvic organ prolapse; pelvic floor disorders; accelerometry; physical activity; intra-abdominal pressure

INTRODUCTION

Pelvic floor disorders (PFDs) affect one in four women in the U.S.¹ Increasing age and an increasing number of vaginal childbirths are factors leading to increased likelihood of developing a PFD, but high intra-abdominal pressure (IAP) may also contribute to the development of a PFD. Many women who are at risk for a PFD or who have had corrective surgery are prescribed physical activity restrictions to limit the generation of high IAP. However, the restrictions are often based on intuition, as there is limited research into the IAPs generated by different activities.² Women, therefore, may be restricted in their ability to live active lifestyles despite a lack of data indicating which activities may be harmful to the pelvic floor.

One of the most significant barriers in gathering IAP data has been the methods utilized to measure IAP. Most often, invasive sensor-tipped catheters and fluid-coupled transducers placed in the bladder, rectum, urethra, or vagina that are connected to laboratory equipment have been employed to measure IAP.³ The tethering of the participant to the lab equipment restricts the ability of the participant to perform dynamic movements or movements outside of a laboratory setting, thus limiting the accuracy and relevance of measured IAP values and their correlations with typical physical activities. We and others have developed and validated wireless intravaginal transducers to measure IAP.^{4–6} Our device employs a piezoresistive semiconductor pressure sensor, embedded within a silicone capsule containing incompressible silicone gel. Additionally, the transducer contains wireless components that transmit data to an external base station worn on the waistband that records the IAP, device status, temperature, time, and potential error messages. Using the wireless intravaginal transducer, we have performed several physical activity studies to better understand the IAPs associated with different exercise and everyday activities.^{7–9} In order to better enable large-scale production of sensors, reduce power consumption, and increase the reliability of data recording, we transformed the wireless intravaginal transducer into a wired intravaginal transducer (WIVT) that was used in this study.¹⁰ The modification also included changing from the previous base station to an instrumentation module that is the size of a cell phone, connects directly to the WIVT, and records IAP data, time, and three components of the acceleration vector. The instrumentation module has been used previously to study partial weight bearing therapy for lower extremity fractures.¹¹ The WIVT is inserted like a tampon into the vagina and contains a tether and a data cable that require access to the external environment, causing two components to exit the vagina. The data cable connects directly to the instrumentation module on the waistband of clothing.

Both generations of the intravaginal transducer allow women to perform exercise and everyday activities without being tethered to laboratory equipment. However, use of either generation in real life situations over longer periods of time may be plagued by low compliance, given that the device must be removed during defecation, intercourse, and swimming and wearing the instrumentation module restricts to some extent the clothing choices available. Recording IAP in at-home situations over several days would allow for better understanding of IAPs generated throughout the day and how their normal IAPs may relate to the development or recurrence of PFDs. A more user friendly method that could approximate IAP would further research related to the relationship between PFDs and this potentially modifiable risk factor.

A waist-worn accelerometer is recommended for assessing duration, frequency and intensity of physical activity, and for assessing activity type, especially those involving ambulation.¹² Many studies utilize accelerometers for population physical activity surveillance, as well as to examine health outcomes associated with change in physical activity.^{13–16} As the intensity of physical activity increases, the magnitude of the acceleration also increases. We have found similar evidence that as the intensity of walking speeds increase, IAP increases.⁷ Furthermore, acceleration and IAP have been shown to exhibit a positive correlation when examining headward acceleration in aircrafts and the mechanics of the body during a squat lift.^{17, 18} Our hypothesis, therefore, is that there is a positive correlation between acceleration measurements from a waist-worn accelerometer and IAP measurements from the WIVT. Thus, the primary aims in the study were to study the correlation between mean maximal accelerometer vector magnitude and 1) mean maximal IAP and 2) area under the curve (AUC) for IAP.

MATERIALS AND METHODS

The study was approved by University of Utah Institutional Review Board (IRB), and all participants signed an informed consent form. Consistent with American College of Sports Medicine screening recommendations, and to reduce the impact of a wide range in age and body size, participants were 18 to 54 years, had body mass indices (BMIs) between 19 and 30 kg/m², and regularly participated in strenuous exercise.¹⁹ Regularly participating in strenuous exercise encompassed exercising at least three times a week and being able to complete 30 minutes of exercise consisting of walking, hiking, running, and weight lifting. Participants were excluded if they had incurred a musculoskeletal injury in the last 3 months, had undergone pelvic surgery other than hysterectomy, were currently using vaginal contraceptive or pessary, or responded “yes” to the question, “Do you have a bulging beyond your vagina?” Participants were excluded if they responded positively to any item on the Physical Activity Readiness Questionnaire (PAR-Q), which identifies participants who may have heart, bone, or joint problems that may be exacerbated by physical activity.²⁰ Participants also completed a history form detailing age, education, parity, smoking habits, hysterectomy, number of vaginal deliveries, and number of Cesarean deliveries.

The exercise sessions were conducted for one hour in an exercise physiology lab under the direct supervision of the research team. Only one participant was assessed at a time. Participants wore the WIVT and instrumentation module for all activities. The WIVT

contained a semiconductor pressure sensor and a microcontroller encapsulated in a medical grade silicone elastomeric capsule measuring 23.9 mm in diameter and 37.3 mm in length filled with incompressible silicone gel. A small diameter, flexible cable connected the WIVT to the instrumentation module through a standard concentric connector on the side of the instrumentation module, which recorded all data onto a microSD card and contained the triple-axis accelerometer. The accelerometer within the instrumentation module was an iNEMO inertial module: 3D accelerometer and 3D gyroscope (ACCEL-LSM330DLC) produced by STMicroelectronics (Geneva, Switzerland) that measured $\pm 2g$ (Figure 1). Both the WIVT and accelerometer sampled synchronously at 32 Hz. The WIVT was zeroed at atmospheric pressure for 30 seconds before insertion. The instrumentation module was clipped onto the waistband of participants' pants on the non-dominant hand side, and athletic tape was used to secure the cable to the ipsilateral hip. A member of the research team turned on the instrumentation module at the beginning of the exercise session and connected/disconnected the sensor cable at the instrumentation module before and after each exercise to serve as an event marker.

Height and weight were measured for each woman with minimal clothing and without shoes before beginning the exercise protocol. A weekly-calibrated laboratory scale measured weight and a wall stadiometer measured height. We calculated BMI in kg/m^2 from the measured height and weight for each participant.

After the WIVT insertion, the baseline pressure was recorded for 30 seconds in both supine and standing positions. Subsequently, participants completed 13 exercises that consisted of the first three stages of the Bruce treadmill walking fitness test²¹, 2-riser (20.3 cm) step-ups, 4-riser (30.5 cm) step-ups, lifting a 4.5 kg box with two hands from a 96.5 cm tall counter to the floor and back continuously, a static plank on forearms and toes, abdominal curl-ups, full sit-ups, pushups on knees, walking alternating lunges, walking alternating lunges with 4.5 kg dumbbells in each hand, and jumping jacks (Table 1). Each stage of the walking fitness test lasted for 3 minutes, while every other exercise lasted for 30 seconds. Activities were not randomized. Participants rested motionless for 10 seconds before and after each exercise while the instrumentation module was recording to ease identifying the start and end of each activity in the data stream. Activities involving repetitions occurred at specific rates (beats per minute (bpm)) controlled by a metronome. We assessed the complete data at the end of each exercise session and asked participants with incomplete data to return for an additional exercise session.

Using a customized MATLAB (R2013a, Mathworks, Natick, MA) script, we determined the maximal IAPs that were at least 1 second apart, maximal accelerometer vector magnitudes that were at least 1 second apart, and the IAP area under the curve (AUC) for each activity and participant according to standardized methods of measuring and analyzing IAP data established by Hamad et al.²² These methods identify maximal IAP peaks at least one second apart to minimize sampling bias due to multiple upward inflections in one peak, use a top-down approach to find maximal IAP peaks, and detail using visual inspection of waveforms to determine if finding the 3, 5, or 10 maximal IAP peaks for an activity best represents the overall maximal IAP for the activity. Once a waveform for a given activity is visually inspected to determine the appropriate number of maximal IAP peaks to be

analyzed, a software algorithm computes the mean maximal IAP for all other instances of the activity. In addition to mean maximal IAP, we examined AUC because this measurement takes into consideration both the duration over time and magnitude of IAP, helping to define the time associative properties of IAP during different activities. Although this analytical method is not routine for general physical activity assessment by accelerometry, we aimed to be consistent with our approach to assessing IAP.

For each 3-minute walking stage, we computed the highest 10 maximal IAPs and accelerometer vector magnitudes and for each of the other activities, in which participants completed at least five repetitions of an exercise over 30 seconds, computed the highest 5 maximal IAPs and accelerometer vector magnitudes. All activities were included in the analysis for mean maximal IAP, as this measurement is not time dependent. The three walking stages were not included in the analysis of AUC (a time-dependent measure) for all activities because they each lasted for 3 minutes, while all other activities lasted for 30 seconds. Rather, we analyzed AUC separately for the ten 30-second activities and for the three 3-minute activities.. In order to calculate the accelerometer vector magnitude, we computed the square root of the sum of the squares of 3 axial acceleration vector components (a_x , a_y , a_z) for every time point (Figure 2). Using all individual participant data for each activity, we then used a customized MATLAB (R2013a, Mathworks, Natick, MA) script to determine the Pearson's correlation coefficient (R) and the 95% confidence interval (CI) for the relationship between mean maximal accelerometer vector magnitude and mean maximal IAP for all activities (n=325) and the relationship between mean maximal accelerometer vector magnitude and AUC for all 30 second activities (n=250). The data from all 25 participants determined the overall mean maximal IAPs, overall mean maximal accelerometer vector magnitudes, and mean IAP AUCs for all 13 activities.

As there were no published data with which to guide a sample size calculation, we planned to complete the study procedures with 25 participants, which provides 90% power to determine that a correlation coefficient of 0.600 differs from zero, assuming alpha is equal to 0.05.²³

RESULTS

Twenty-seven women enrolled in the study with 25 completing the entire exercise session. Two participants were unable to complete the entire exercise session, and their data were removed from the analysis. Additionally, two women had incomplete data collection in the first exercise session and participated in a second exercise session that occurred within a week of the first exercise session. For these two women, all exercises were repeated and all data from the second exercise session replaced the data from the first exercise session. The mean age with standard deviation ($\pm$ SD) of participants was 26 ± 8 years (range 21–52), the mean BMI with SD was 22.8 ± 2.5 kg/m² (range 19.5–28.4), and 88% of women were nulliparous.

All mean maximal and AUC values, including laying and standing baselines, were compiled to determine overall average values for each exercise. Table 1 shows descriptive measurements for the IAP and accelerometer data, as well as descriptions of each activity.

We first examined the relationship between mean maximal IAP and mean maximal accelerometer vector magnitude for each individual exercise activity, including the three walking stages (Figure 3). Jumping jacks created the highest overall mean maximal IAP and overall mean maximal accelerometer vector magnitude, while abdominal curl-ups created both the lowest overall mean maximal IAP and overall mean maximal accelerometer vector magnitude. The R value between mean maximal accelerometer vector magnitude versus mean maximal IAP for all participant data (n=325) was 0.7353. The overall mean values for full sit-ups, plank, abdominal curl-ups, and 30.5 cm step-ups were outside the 95% CI limits of the correlation line, while the overall mean values for other exercises fell within the 95% CI limits.

The correlation between the AUC for IAP and the mean maximal accelerometer vector magnitude for the ten 30-second activities is demonstrated in Figure 4. As noted, mean AUC for IAP is a time-dependent measure and therefore the three walking stages were not included in this analysis because they each lasted for 3 minutes, while all other activities lasted for 30 seconds. Once again, jumping jacks generated the highest mean AUC for IAP and the highest overall mean maximal accelerometer vector magnitude, and abdominal curl-ups generated the lowest mean AUC for IAP and the lowest mean maximal accelerometer vector magnitude. The correlation between the mean maximal accelerometer vector magnitude and AUC for IAP for all participant data for these 10 activities (n=250) was 0.5059. Values for two of the exercise activities (full sit-ups and plank) were outside the 95% CI limits, while all other values were within the 95% CI limits.

The correlation between both the mean maximal IAP and the AUC for IAP with the mean maximal accelerometer vector magnitude for the three 3-minute walking stages (n=75) is shown in Figure 5, with R values of 0.7220 and 0.2167, respectively. As the walking stage increased in speed and grade, the overall mean acceleration vector magnitude and both overall mean IAP measurements increased linearly.

DISCUSSION

In this study of healthy, mostly nulliparous women, we found a high correlation between mean maximal IAP and mean maximal accelerometer vector magnitude assessed during a variety of activities. As expected, given the different constructs assessed by AUC and mean maximal measures, the correlations were lower between AUC for IAP and mean maximal accelerometer vector magnitude for both the 10 30-second activities and the three 3-minute walking stages.

The correlation between mean maximal accelerometer vector magnitude and mean maximal IAP, 0.7353, is high considering that acceleration and IAP are physiological measurements that exhibit inter-individual variability. We utilized the 95% CI limit of the correlation coefficient to provide information about the variability of the linear relationship. Four of the exercises (plank, full sit-ups, abdominal curl-ups, and 30.5 cm step-ups) were outside the 95% CI limit. Plank, abdominal curl-ups, and full sit-ups recruit abdominal muscles, producing increased IAP, but involve somewhat static positioning for the waist-worn accelerometer. Planks employ a completely static body position, while full sit-ups and

abdominal curl-ups only move the torso with limited movement at the waist. The static positioning of the waist creates low acceleration while the high recruitment of abdominal muscles creates high IAP, which likely explains the low correlation for the three activities. Placing the accelerometer at an anatomically superior location, such as the shoulder, may have caused the IAP from full sit-ups and abdominal curl-ups to exhibit a stronger positive correlation with the accelerometer, but in order to adhere to industry standards, we chose to place the accelerometer on the waist. All other exercises were within the 95% CI limit, indicating that for these exercises there was a strong correlation between acceleration and IAP. Mean maximal accelerometer vector magnitude may therefore be a strong predictor of mean maximal IAP, with the exception of static activities that recruit high abdominal muscle activity. However, the correlations between AUC for IAP and mean maximal accelerometer vector magnitude are lower than that between mean maximal IAP and mean maximal accelerometer vector magnitude, suggesting that accelerometry is not a predictor of the overall IAP generated during activities.

We separately examined the relationship between accelerometry and IAP for the walking stages. Again, the correlation between mean maximal accelerometer vector magnitude and mean maximal IAP was high, while the correlation between mean maximal accelerometer vector magnitude and AUC for IAP was low. The overall mean accelerometer measurements and overall mean pressure measurements appear to both increase at similar rates when walking speed and grade increases. However, when examining all walking measurements from all participants, only the mean maximal IAP correlates with mean maximal accelerometer vector magnitude. Our prior research found increases in mean maximal IAP and mean AUC for IAP with increased speed and grade.^{7, 8} The high correlation for mean maximal IAP and mean maximal accelerometer vector magnitude is important because walking is the most commonly reported physical activity by women.²⁴ Therefore, mean maximal accelerometer vector magnitude may be an excellent predictor of a woman's peak IAPs in real life scenarios involving upright movement.

Examining the raw waveforms for IAP and acceleration may provide further insight into why certain activities had higher positive correlations. Figure 6 shows descriptive IAP and acceleration waveforms in one participant for walking, the lifting task, and the full sit-ups for short periods of time. The walking waveforms (Figure 6a) show three steps, where each peak in IAP is a footstep. The corresponding acceleration waveform also shows three peaks and appears to be in phase with the IAP waveform, demonstrating why walking had such a high positive correlation. All three stages of walking exhibited similar waveforms. The waveforms for the lifting task (Figure 6b) do not mirror each other as well as during walking due to the presence of more peaks in the acceleration waveform, but the overall structure of the waveforms reflect each other. Full sit-ups (Figure 6c), one of the activities which had low positive correlation, have very little similarity in the waveforms for IAP and acceleration. The IAP waveform shows two full sit-ups in which the IAP raises at least 50 cmH₂O during the active full sit-up and returns to baseline during the short rest period after the full sit-up, while the acceleration remains around a constant value with small fluctuations during the entirety of the activity. The amount of variance between the IAP and acceleration waveforms helps to account for why activities like walking had higher positive correlations than activities like full sit-ups. In this study, we chose to test our hypothesis regarding the

relationship between mean maximal accelerometer vector magnitude and the mean maximal IAP and area under the curve (AUC) for IAP. Future studies comparing pressure and acceleration waveforms could use other analytical techniques such as Fourier transform analysis; however, these waveforms are not readily available to most researchers who use accelerometers.

Some of the activities in the current study have been studied previously, and our values for overall mean IAP measurements fall within the described ranges.^{25–27} Some variations in IAP values are due to differing measurement techniques for IAP, including transrectal microtip catheters and Foley catheters connected to arterial-line pressure transducers. Cobb et al. found that lifting 5 kg generated ~57 cmH₂O when squatting and ~36 cmH₂O when lifting weights off a counter, a range consistent with our counter to floor to counter lifting task.²⁵ Guttormson et al. determined that IAP increased with increasing weight being lifted from a table or the floor.²⁷ Interestingly, we did not observe a change in IAP measurements or accelerometer vector magnitude between normal lunges and weighted lunges with 9 kg, indicating that carrying up to 9 kg with an arm hang posture does not greatly affect IAP.

As seen in Table 1, there is substantial variability in IAP amongst women for each individual activity, consistent with the other studies evaluating this.^{7, 25, 27} Differences in body habitus, age, exercise technique, breathing and even heart rate affect IAP measurements to various degrees. As there is no simple method for directly measuring IAP in the abdominal cavity, IAP is indirectly measured using transducers such as that used in our study, which may add to imprecision in measurements. IAP measurements taken in the upper vagina may be affected by extraneous forces from the surrounding viscera and vaginal smooth muscle contractions. However, the placement of the WIVT in the upper vagina allows the sensor to detect forces placed on the pelvic floor because the abdominal cavity is a closed system, and IAP measured in the upper vagina has been shown to approximate measurements from rectal and bladder transducers.^{28, 29}

The accelerometer range in this study was $\pm 2g$, which may be too limited for more vigorous activities that women perform. The accelerometer in the instrumentation module is also not a conventionally utilized system in physical activity research. Future studies would benefit from employing commercially available waist-worn accelerometers, such as the ActiGraph GT9X Link. As mentioned previously, our approach to assessing acceleration in this study varies from the physical activity literature to be consistent with the IAP assessment, which is largely concerned with highest values. The majority of participants were young, nulliparous, Caucasian females, necessitating the need to evaluate a wider range of ethnicities, ages, and parity to better understand the relationship between IAP and accelerometry. Activities were performed in a controlled laboratory setting, which may not replicate real-world situations. However, others have shown that physical activity output data as measured by a tri-axial accelerometer were similar on a treadmill and on land.³⁰ Additionally, studies that go beyond determining a positive correlation and determine reliability are necessary to confirm that replacing IAP measurements with accelerometry measurements is viable. Further studies are needed to determine how this correlation can be attributed to individuals as compared to a pooled population.

In this study, we have evaluated the relationship between waist accelerometry and IAP measurements, a relationship that we do not believe has been previously explored. Mean maximal accelerometer vector magnitude is a strong predictor of mean maximal IAP but a weak predictor of AUC for IAP. Due to the high correlation found between IAP measurements and accelerometer measurements, waist-worn accelerometry may be a viable method for approximating maximal IAP data during many real life activities in a population of women. In turn, this may lead to a better understanding of the relationship of IAP and PFDs in the future. However, actual measurement of IAP appears to be necessary for static activities with high abdominal muscle recruitment and when assessing AUC for IAP.

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Figure 1.

Wired intravaginal transducer (WIVT) and instrumentation module with accelerometer setup. (a) Open instrumentation module. The instrumentation module contains the triple-axis accelerometer employed in the study and is waist-worn in the orientation shown. (b) Closed instrumentation module. The x-axis is along the length of the instrumentation module (vertical), the y-axis is along the width of the instrumentation module (mediolateral), and the z-axis runs through the depth of the instrumentation module (anteroposterior; out of the page). (c) Instrumentation setup. The entire instrumentation setup consists of the instrumentation module containing the accelerometer that is placed on the waist and the WIVT containing the pressure sensing elements that is inserted into the vagina.

Figure 2.

Raw waveforms of (a) intra-abdominal pressure (IAP) and (b) acceleration for the three stages of one participant's walking fitness test. Each walking stage lasted for 3 minutes, and each progressive stage had an increased grade and speed. The gray square markers indicate the respective 10 maximal IAP and acceleration values for each stage for one participant, and the dashed lines indicate changing to the next stage.

Figure 3.

Correlation between mean maximal intra-abdominal pressure (IAP) and mean maximal accelerometer vector magnitude. All data points for the 25 participants from the 13 activities were plotted and the Pearson correlation coefficient (R) and 95% confidence interval (CI) were determined. Each diamond datum represents one participant measurement for one exercise, each triangular datum represents the overall mean value for one exercise found by averaging all participants' data for an activity, and the dashed lines are the 95% CI for the correlation. Jumping jacks and abdominal curl-ups, respectively, had the highest and lowest overall mean maximal IAPs and overall mean maximal accelerometer vector magnitudes. Abdominal curl-ups, plank, full sit-ups, and 30.5 cm step-ups had overall mean values that fell outside of the 95% CI limits.

Figure 4.

Correlation between area under the curve (AUC) for intra-abdominal pressure (IAP) and mean maximal accelerometer vector magnitude for all activities excluding walking. All data points for the 25 participants from the 10 activities lasting 30 seconds were plotted and the Pearson correlation coefficient (R) and 95% confidence interval (CI) were determined. Each diamond datum represents one participant measurement for one exercise, each triangular datum represents the mean value for one exercise found by averaging all participants' data for an activity, and the dashed lines are the 95% CI for the correlation. Jumping jacks and abdominal curl-ups, respectively, had the highest and lowest mean AUC for IAP and overall mean maximal accelerometer vector magnitudes. Jumping jacks, full sit-ups, and plank had overall mean values that fell outside of the 95% CI limits.

Figure 5.

Correlation between mean maximal accelerometer vector magnitude versus (a) mean maximal intra-abdominal pressure (IAP) and (b) versus area under the curve (AUC) for IAP for the three walking stages only. All data points for the 25 participants from the three walking activities were plotted and the Pearson correlation coefficient (R) and 95% confidence interval (CI) were determined. Each diamond datum represents one participant measurement for one exercise, each triangular datum represents the mean value for one exercise found by averaging all participants' data for an activity, and the dashed lines are the 95% CI for the correlation.

Figure 6.

Intra-abdominal pressure (IAP) and acceleration raw waveforms for (a) walking, (b) lifting task, and (c) full sit-ups. The waveforms are in phase and similar during walking. The lifting task generated waveforms that have similar overall trends but differ in number of peaks, while full sit-ups created waveforms that do not reflect each other and have a poor correlation.

Table 1

Descriptive measures for baseline activities and exercise activities. Data are averaged for n=25 participants.

Activity	Time (minutes)/ Repetition Rate (bpm)	Overall mean maximal IAP (SD) cm H ₂ O	Range overall mean maximal IAP (max-min)	Mean AUC (SD) cm H ₂ O s	Range AUC (max-min)	Overall mean maximal acceleration (SD) g-force	Range overall mean maximal acceleration (max-min)
Laying Baseline	0.5/-	16.7 (4.8)	27.2–4.6	459.8 (136.0)	639.5–117.7	1.00 (0.03)	1.17–0.94
Standing Baseline	0.5/-	36.7 (7.3)	52.4–21.6	1021.0 (202.0)	1471.7–606.2	1.04 (0.03)	1.22–0.98
Walking stage 1 1.7 mph 10% grade	3/-	47.3 (7.5)	65.9–30.3	6200.6 (1090.9)	8441.4–3912.4	1.71 (0.14)	2.21–1.44
Walking stage 2 2.5 mph 12% grade	3/-	54.5 (7.6)	76.9–35.7	6212.2 (976.2)	7989.9–3840.3	1.91 (0.18)	2.72–1.60
Walking stage 3 3.4 mph 14% grade	3/-	68.5 (11.6)	102.0–46.0	6709.5 (1169.0)	9547.8–4173.2	2.27 (0.21)	3.10–1.96
20.3 cm Step-ups	0.5/24	59.7 (11.8)	98.3–43.1	1026.0 (194.9)	1365.0–730.2	2.16 (0.14)	2.60–1.88
30.5 cm Step-ups	0.5/24	68.7 (12.7)	101.1–48.5	1040.3 (199.3)	1392.1–692.0	2.38 (0.20)	2.92–2.12
Lifting task 4.5 kg	0.5/15	48.0 (10.8)	89.6–30.3	990.4 (188.9)	1470.9–656.0	1.75 (0.26)	2.41–1.29
Plank	0.5/-	49.1 (14.0)	94.8–23.3	1081.2 (313.4)	1895.9–459.7	1.24 (0.17)	1.86–1.07
Abdominal curl-ups	0.5/15	27.4 (13.5)	66.2–8.9	439.1 (190.0)	968.3–180.6	1.09 (0.06)	1.26–1.01
Full Sit-ups	0.5/15	64.1 (23.6)	133.1–28.6	945.6 (275.8)	1553.0–468.3	1.31 (0.22)	2.84–1.09
Pushups	0.5/25	45.3 (13.3)	83.6–24.5	908.4 (230.3)	1444.5–469.3	1.72 (0.52)	3.48–1.22
Lunges	0.5/40	56.8 (11.4)	87.9–39.6	1155.4 (197.8)	1629.7–860.5	1.96 (0.22)	2.55–1.55
Weighted Lunges 4.5 kg/hand	0.5/40	57.7 (11.7)	90.8–40.9	1169.7 (193.3)	1632.6–841.3	1.95 (0.26)	2.66–1.52
Jumping Jacks	0.5/60	124.0 (23.7)	188.6–77.5	1372.7 (241.1)	1977.8–1017.8	3.17 (0.31)	3.49–2.39

bpm beats per minute, IAP intra-abdominal pressure, SD standard deviation, AUC area under the curve, n=25