Relationship of Heart Rate, Perceived Exertion, and Intra-Abdominal Pressure in Women

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ABSTRACT

Background: Exercise increases intra-abdominal pressure (IAP) acutely, which may impact the pelvic floor of women. IAP during exercise demonstrates high variability among women but is not routinely assessed. Assessing less invasive measures related to IAP during exercise may facilitate study of how IAP impacts the pelvic floor.
Methods: The objective of this study was to investigate the relationship of heart rate and rating of perceived exertion (RPE) with IAP during a standard treadmill test. We describe the trend of IAP by predicted aerobic fitness during incremental exercise. IAP was measured using a validated transducer placed in the upper vagina. Heart rate and RPE were collected during the first 3 stages of the standard Bruce treadmill protocol. Relationships of heart rate and RPE with IAP were determined by Pearson correlation coefficients. Predicted aerobic fitness values for each participant were ranked in tertiles with IAP by treadmill stage.
Results: Twenty-four women participated in this study (mean age: 24.7 ± 5.4 years; body mass index: 22.5 ± 2.2 $kg{\cdot}m^{-2}$). There were significant relationships between heart rate and IAP (r = 0.67, $P < 0.001$) and RPE and IAP (r = 0.60, $P < 0.001$) across treadmill stages. Tertiles of predicted aerobic fitness and IAP displayed similar trends as other exercise measures such as heart rate and ventilation during incremental exercise.
Conclusion: Heart rate and RPE could be used as proxy measures of IAP during incremental exercise. Aerobic fitness may help explain IAP variability in women and provide context for future research on IAP and pelvic floor health. *Journal of Clinical Exercise Physiology*. 2020;9(3):97–103.

Keywords: pelvic floor, incremental exercise, exercise intensity, aerobic exercise, cardiorespiratory fitness

INTRODUCTION

Pelvic floor disorders are common and approximately 1 in 4 women in the United States report moderate to severe symptoms of at least 1 pelvic floor disorder (1,2). Urinary leakage is one of the most common pelvic floor disorder symptoms, which can be bothersome during exercise (3–5). For instance, previous research found 24.6% of nulliparous women aged 20 to 25 years who regularly attended gyms and engaged in high impact activities reported urine leakage (4). Some clinicians recommend that women restrict strenuous activity, such as impact activities and heavy lifting, in order to avoid large increases in intra-abdominal pressure (IAP) which are

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linked to pelvic floor disorder symptoms (6–9). However, these activity restrictions are not evidence-based. Despite symptom burden, women still exercise and are encouraged to be physically active for health-related benefits (10–12). Although some recommend restricting certain activities, the acute and chronic impact of various exercise modes and intensities on pelvic floor health is not entirely understood (10–14).

Exercise acutely increases IAP, defined as the measurement of pressure between the diaphragm and pelvic floor muscles. Increases in IAP during exercise are due to factors that stabilize the spine and trunk and during body acceleration (15–17). During exercise, diaphragm activation increases with upper limb movement and inspiratory muscle effort increases to stabilize the spine during movement and drive ventilation (15–18). These mechanisms are important for strenuous activity and lifting heavy loads (19,20). Activities with higher body acceleration, such as jumping and running, have higher IAP than activities with lower acceleration, such as walking (20). However, IAP increases linearly with walking speed, likely because of gradually increased body acceleration and postural changes requiring greater abdominal muscle contraction (20). Previous research has shown that IAP is directly related to level of exercise intensity (6,7,20). Therefore, it seems plausible that IAP may also be related to variables that are commonly used to measure exercise intensity.

IAP is highly variable between individuals, and equipment to measure IAP is not readily accessible (20). Alternative measures that correlate with IAP could serve as proxy indicators of when pelvic floor strain occurs during acute exercise. Further, such measures may assist clinicians with monitoring pelvic floor symptoms and further explain variability in IAP. Heart rate and perceived exertion are routinely assessed during exercise, and their pattern of increase across a range of exercise intensities is related to oxygen consumption (21,22). These traditional measures of exercise intensity and fitness may be related to IAP during exercise because of common factors such as muscular demand and body acceleration (23,24).

Considering the relationship between exercise and IAP and its potential influence on pelvic floor health, exploratory research is needed to better understand the relationships among variables assessed during acute, incremental exercise. Thus, the aim of this exploratory study was to investigate the relationships of IAP measured during the first 3 stages of the standard Bruce treadmill test with heart rate and perceived exertion in healthy adult women. Additionally, we aimed to describe the trend of IAP across treadmill stages by level of predicted aerobic fitness.

MATERIALS AND METHODS

Participants

All data collection and study procedures were approved by the University of Utah Institutional Review Board, and each participant provided informed consent. Participants were a convenience sample from a Mountain West University recruited by word of mouth and flyers. A sample size of N = 25 is adequate to detect a Pearson correlation coefficient of 0.526 or more with 80% power at the 5% significance level (*PASS 16* software, NCSS, LLC, Kaysville, Utah).

Participant inclusion criteria were based on a combination of the American College of Sports and Medicine (ACSM) screening guidelines (25) and the Physical Activity Readiness Questionnaire form to ensure safety of participants. Participants were included if they were between 18 to 54 years, had body mass indices (BMIs) between 19 and 30 $kg \cdot m^{-2}$, and responded affirmatively to regularly engaging in walking, hiking, running, and/or weight lifting with the ability to do these for at least 30 min (25). Participants were excluded if they incurred a musculoskeletal injury in the last 3 months, had undergone pelvic surgery other than a hysterectomy, were using a vaginal contraceptive or pessary, or responded *yes* to a screening question for pelvic organ prolapse (i.e., *Do you have a bulging beyond your vagina?*). Participants were excluded if they responded positively to any item on the Physical Activity Readiness Questionnaire, which identifies participants who may have heart, bone, or joint problems that may be exacerbated by physical activity (25). Participants completed a personal history form to report sociodemographic and clinical characteristics including age, education, parity, smoking habits, hysterectomy, and number of vaginal deliveries and/or Cesarean deliveries.

Data Collection Procedures

This study is secondary analysis of data from another study designed to study the association between body acceleration, a common objective measure to assess physical activity, and IAP in healthy, adult women (26). The original study was not designed to investigate hypotheses related to incremental exercise or physical fitness and IAP (26). Participants engaged in a 1-h supervised exercise session in an exercise physiology laboratory. At the start of the exercise session participants had height (cm) measured without shoes using a wall-mounted stadiometer (Accu-Hite Wall Stadiometer, Seca Corp, Hanover, Maryland) and weight (kg) assessed with minimal clothing measured using a weekly-calibrated BOD POD system electronic scale (COSMED The Metabolic Company, Rome, Italy). BMI ($kg \cdot m^{-2}$) was calculated from laboratory height and weight measurements. Prior to the exercise protocol, all participants were measured for percent of fat mass, percent of fat free mass, and body fat rating using air displacement plethysmography using the COSMED Bod Pod Gold Standard Body Composition Tracking System.

Participants wore a wired intravaginal transducer and instrumentation module during all activities in order to collect IAP (26). The vaginal transducer (described previously for its validity and reliability) contained a pressure sensor and a microcontroller encapsulated in a medical grade silicone capsule and was inserted into the vagina (20,27–29). The instrumentation module, containing hardware that stores IAP data, was clipped onto the waistband of participants' pants on the nondominant hand side, and athletic tape was used to secure the cable to the same side. Data for IAP were only recorded during exercises, and the instrumentation module was disabled between activities to eliminate recording IAP during transitions between exercise components.

After the insertion of the vaginal transducer, baseline pressure was measured for 30 seconds in supine and standing positions. After the baseline pressure measurements, participants completed 13 exercises in the same order (26). However, for this study, only the data collected during the first 3 stages of the Bruce treadmill walking fitness test were analyzed (21). The Bruce treadmill protocol is normally used to assess maximal aerobic fitness, particularly in clinical populations. In the original study, a test of maximal oxygen consumption was not conducted because it was not required to address that study's hypotheses (26). Therefore, in this study, only the first 3 stages, each 3 min in duration, were used as a submaximal oxygen consumption test. Heart rate was collected using a Polar Wearlink+ heart rate monitor (Polar Electro Oy, Kempele, Finland), and measurements were recorded at the end of the last minute of every stage during the walking test. Rating of perceived exertion (RPE) was collected at the end of each stage (23). Participants rested completely still for 10 seconds before and after the treadmill in order to clearly identify the start and stop of the protocol and the associated IAP during the exercise. For the current study, we analyzed the mean maximal IAP, heart rate and RPE during the treadmill using methods described elsewhere (20,26).

An estimate of aerobic fitness was calculated first by estimating an individual's maximal heart rate using the formula HRmax = 208 − (0.7 × age), for use in healthy men and women (30). The predicted VO_2max was estimated using either the second or the third stage from the first 3 stages of the Bruce treadmill test. The estimate of VO_2max was determined by selecting the stage at which individuals reached a steady-state submaximal heart rate (HR_{SM}) of 130 to 150 $b \cdot min^{-1}$ (22). For most women, the heart rate in stage 2 was used for predicting maximal aerobic fitness, although the heart rate in stage 3 was used for some. For participants whose heart rates did not fall exactly between the steady-state heart rate range of 130 to 150 $b \cdot min^{-1}$ during stage 2 or stage 3, the heart rate that was closest to 130 or 150 $b \cdot min^{-1}$ was selected for use in the prediction equation. The formula used to estimate predicted VO_2max was $\dot{V}O_2max = SM\dot{V}O_2 \times [(HRmax - 72)/(HR_{SM} - 72)]$ (31). The $SM\dot{V}O_2$ was determined by converting the estimated metabolic equivalent of task that was reached during each stage to the submaximal VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$).

Data Analysis

Demographic data were used to describe the sample population. Pearson correlation coefficients were calculated to determine relationships of IAP across all 3 stages of the treadmill protocol with heart rate and RPE. Previous literature has demonstrated a relationship between BMI and standing IAP (20,32). Therefore, a Pearson correlation was conducted between BMI and IAP at the third stage of the treadmill protocol to determine whether a partial correlation should be used to control for BMI in the correlations of IAP with heart rate and RPE. A scatterplot was used to visualize the relationship between IAP and predicted aerobic fitness during the first 3 stages of the Bruce protocol. Because of limited sample size, we were not able to statistically examine the difference in IAP between predicted VO_2max tertiles or between body fat mass and VO_2max tertiles. The tertiles by VO_2max values were used to visually display IAP trajectory during incremental aerobic exercise. A Pearson correlation was also calculated between predicted VO_2max and percent fat mass to confirm that our predicted values are reasonable. All statistical analyses were conducted using IBM SPSS Statistics Package Version 25.0 (Armonk, New York), and statistical significance was set at alpha level of 0.05.

RESULTS

There were 25 participants who completed the study and 24 were used in the final analysis. Initial screening of the data showed that 1 participant had an implausible heart rate measurement during the test that was associated with a heart rate monitor error. This participant was removed from the data set. No participants reported having undergone a hysterectomy. Participants had a mean age of 24.7 ± 5.4 years, mean weight of 63.9 ± 6.9 kg, mean BMI of 22.5 ± 2.2 $kg \cdot m^{-2}$, and mean percent fat mass of 24.8 ± 4.5. Further, most participants were white and identified as non-Hispanic or Latina (N = 22, 91.7% of women).

The correlation between BMI and IAP in the third stage of the treadmill test was not statistically significant ($r = 0.34$, $P = 0.09$), potentially because of the limited sample size. We show correlation results with and without controlling for BMI in Table 1. There was a statistically significant and positive linear relationship between heart rate and IAP during the submaximal VO_2 treadmill test during the first 3 stages of the Bruce protocol (Figure 1, Table 1). Similarly, there was a statistically significant positive linear relationship between RPE and IAP during the first 3 stages of the Bruce protocol (Table 1). The relationships between heart rate and RPE with IAP had minimal to no change when controlling for BMI (Table 1).

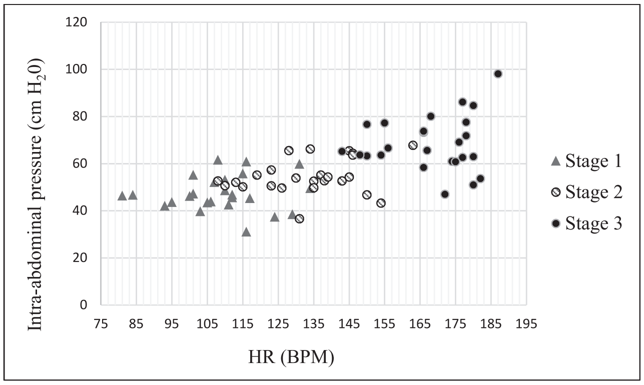

FIGURE 1. Intra-abdominal pressure and heart rate (HR) during all 3 stages of the Bruce treadmill protocol.

ORIGINAL RESEARCH

TABLE 1. Correlations between heart rate (HR), rating of perceived exertion (RPE), and intra-abdominal pressure (IAP) during the first 3 stages of the standard Bruce treadmill protocol.

	HR[a]	RPE	*P* Value
RPE	0.74	—	< 0.001
IAP	0.67	0.60[a]	< 0.001
IAP[b]	0.67	0.62[a]	< 0.001

[a]Correlation is significant at a 0.01 level (2-tailed)
[b]Partial correlation controlled for body mass index

Sixteen participants reached a steady-state heart rate during stage 2, and 8 participants during stage 3, for use in the prediction of maximal VO_2. There were 8 participants whose heart rates did not fall within the 130 to 150 b·min^{-1} range. This resulted in using the heart rate during stage 2 for 3 participants and the heart rate during stage 3 for 5 participants. The heart rate range for these participants were between 126 to 129 b·min^{-1} and 151 to 166 b·min^{-1}.

Maximal oxygen consumption and body composition typically demonstrate an inverse relationship (33). Since VO_2max was not directly assessed in this study, a correlation was conducted to confirm that there is an inverse relationship, although not significant, between the predicted VO_2max and percent fat mass in this sample ($r = -0.34$, $P = 0.09$).

Women were placed into ascending rank order by predicted maximal oxygen consumption, and then placed into 3 equal tertiles. The mean (± SD) predicted maximal oxygen consumption values in the 3 tertiles were as follows: tertile 1 = 38.2 ± 2.7 mL·kg^{-1}·min^{-1}; tertile 2 = 45.6 ± 1.8 mL·kg^{-1}·min^{-1}; tertile 3 = 52.9 ± 3.6 mL·kg^{-1}·min^{-1}. Figure 2 provides the plot of IAP by oxygen consumption tertiles during the submaximal test. This figure suggests that those in a higher VO_2 tertile experience lower IAP during each treadmill stage than those in a lower tertile. As noted, we did not formally compare the difference between tertiles because of the small sample size (N = 8 per tertile).

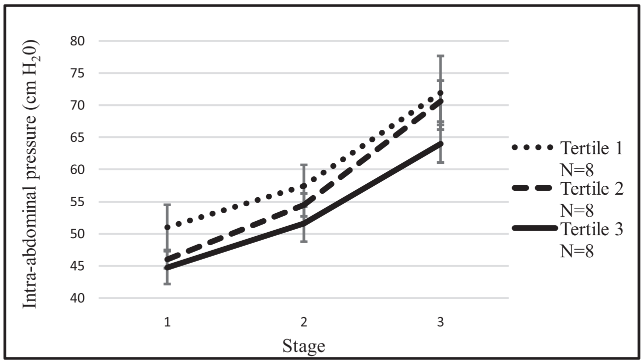

FIGURE 2. Intra-abdominal pressure during all 3 stages of the Bruce treadmill protocol by tertiles with corresponding error bars. Tertiles are from predicted maximal oxygen consumption.

DISCUSSION

Heart rate and RPE were significantly correlated with IAP across all 3 stages of the Bruce treadmill protocol (Figure 1, Table 1). The relationships of heart rate and RPE with IAP suggest that the increases in heart rate and RPE by treadmill stage display a linear trajectory. The trend of IAP increasing by category of predicted aerobic fitness across the first 3 stages of the Bruce protocol is visually similar to other variables generally assessed in metabolic testing (Figure 2). For tertile 1, women with the lowest predicted VO_2max in the sample appear to have a greater increase in IAP response across the 3 stages of walking intensity, while in tertile 3 women with the highest predicted VO_2max appear to have a more gradual increase in IAP response. This is a similar trend to the observations of heart rate during incremental aerobic exercise when people with different fitness levels are compared (34). Although these findings were based upon predicted aerobic fitness and the sample size was small, these patterns warrant further investigation of IAP response during incremental aerobic exercise.

IAP response has been described in other exercise settings, specifically during short (≤ 30 s) duration activities that involve impact or heavy lifting, but dynamic, continuous aerobic activities without significant impact have received much less attention (18,35,36). Dynamic, incremental aerobic exercise such as walking is common among active women (37). Ground forces and lower abdominal tissue movement likely influence the IAP response to activities with impact, such as running, making it challenging to know which part of dynamic exercise is eliciting the IAP responses (20,38). The progressive walking task in the current study induced much less impact than running, yet the heart rate and RPE indicated a vigorous exercise response. The progressive activity of the Bruce treadmill protocol, in which speed and grade increase the cardiovascular demand with each stage, also progressively engages the diaphragm and other respiratory and abdominal muscles, which alter the dimensions of the trunk. These factors increase IAP (18,39,40), which in this study followed a similar trend as heart rate and RPE in response to progressive walking. Therefore, it can be deduced that as cardiovascular effort increases, IAP also increases during progressive aerobic activity in this study using the Bruce treadmill protocol.

The individual variability in IAP during continuous aerobic activity is likely due to a combination of multiple physiological factors, as well as level of fitness. Although aerobic fitness appears a likely factor from our data, these are preliminary but support a larger study that includes maximal testing in a diverse group of women. Further study should continue examining IAP during aerobic exercise in order to identify specific factors that cause increases in IAP. The lack of evidence on IAP during aerobic exercise is likely partly due to the difficulty in assessment of IAP since specific, noncommercial equipment and software are required. If IAP responses during aerobic exercise can be estimated using standard fitness testing measurements, then measures such as heart rate and RPE may be useful proxy measures.

Findings from this study suggest that IAP values may be related to aerobic fitness. The IAP values in the present study ranged from 46.9 to 98.1 cmH_2O at the end of stage 3 of the Bruce treadmill protocol performed by young, healthy women. Taken out of context, these values do little to further our understanding of individual IAP response to continuous aerobic exercise. However, when divided into tertiles by ascending VO_2max values, the increase in IAP during the 3 treadmill stages appears similar to other response variables during incremental aerobic exercise (24,34). Further, indirect calorimetry will be needed to confirm our results with oxygen consumption and to study how increases in variables during dynamic aerobic exercise relate to IAP, since this has not been directly assessed. Ventilation patterns, notably during the Valsalva maneuver, elevate IAP, but this is not a pattern observed during prolonged ambulatory exercise (41).

Understanding the IAP response during incremental, continuous aerobic exercise in healthy adult women may influence decisions about exercise in women who experience stress urinary incontinence symptoms during exercise. Women with more severe urinary incontinence will experience urine leakage during coughing or strain at a lower IAP level than women with less severe urinary incontinence (42). While it is well known that a sizeable proportion of women experience urinary incontinence during exercise, it is not understood why some women do and others do not, or why the severity amongst incontinent women differs (43). After engaging in strenuous exercise, women with mild stress incontinence have experienced reduced maximal voluntary pelvic floor muscle contraction pressure, which is an indicator of pelvic floor muscle fatigue (44). Muscle fatigue during exercise could diminish the ability to contract the pelvic floor muscles and contribute to incontinence symptoms (44). Measures commonly assessed during fitness testing, such as heart rate and RPE responses, are additional, easily accessible measurements that may provide context for when incontinence occurs during exercise and aid in more personalized exercise recommendations for women to manage bothersome symptoms.

A strength of this study was the use of a standardized protocol to assess aerobic fitness, which is one of the most assessed aspects of fitness. Although maximal heart rate and aerobic fitness were not directly assessed, heart rate and RPE values were assessed directly during each stage of the treadmill test. Although our correlation between percent fat mass and predicted VO_2max was inversely correlated, it was statistically insignificant, which may be caused by a low statistical power ($r = -0.34$, $P = 0.09$).

The limitations in this study include that the study participants were not recruited to observe varying levels of physical fitness and the sample size is too small to formally compare women by aerobic fitness level. No a priori sample size calculation was done, in part because this study is a secondary analysis of previously collected data, and because no preliminary data were available with which to guide one. Further, no habitual physical activity data were collected. Aerobic fitness was predicted using a submaximal test since the original study was not designed to investigate fitness variables and participants did not perform a maximal oxygen consumption test. In a third of the sample, the heart rate responses did not fit within the ideal range of the prediction equation used. Additionally, other types of activity that increase heart rate but do not have a vertical acceleration component (i.e., rowing, swimming) do not have the same relationship of cardiovascular effort and IAP as walking did in this study (39,40). Therefore, these results cannot be generalized to activities without vertical acceleration. Participants were young and within a narrow range of BMI for exercise safety purposes. This sample was young, healthy women, which limits generalizability to women outside these BMI and age ranges and to men.

CONCLUSION

The integration of aerobic exercise physiology, IAP response to exercise, and common pelvic floor symptoms across the exercise intensity continuum is complex and warrants further examination. This study supports the need for future research to investigate whether there are differences in IAP responses to incremental exercise in those with low and high fitness levels. Fitness indicators that are commonly assessed during exercise, such as heart rate and RPE, could provide practical ways for women to provide more context for when leakage occurs during exercise and for clinicians to monitor symptoms during exercise. Understanding how fitness impacts IAP could aid in providing activity recommendations to women with, or at risk of, pelvic floor symptoms who are pursuing physically active lifestyles. This could potentially help clinicians determine, for example, whether a woman should improve fitness first using nonimpact activities, and then transition to impact activities. Additional research in this area will help clinicians provide personalized activity recommendations for women who experience leakage.

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