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Research Article

Validity of Ratings of Perceived Exertion in Patients with Type 2 Diabetes

Abstract

Purpose: To examine whether a subjective measure of moderate-intensity exercise (12-13 on Borg's ratings of perceived exertion scale; RPE) corresponds to the target heart rate for moderate-intensity exercise (40-59% heart rate reserve; %HRR) and to determine the characteristics of those for whom RPE does not appropriately estimate exercise intensity.

Methods: 3582 individuals with type 2 diabetes (age: 58.3±6.8 years; BMI: 35.9±5.9 kg/m^2) underwent a maximal exercise test and minute-by-minute HR and RPE were recorded. Linear regression was used to determine the %HRR corresponding to an RPE of 12 and 13 for each individual.

Results: At an RPE of 12 or 13, 57% of participants fell within the target 40-59% HRR range, while 37% and 6% fell above and below this range, respectively. Participants with a %HRR ≥60% (above range) were more likely to be female (OR: 1.19; 95% CI: 1.01,1.40), African American (OR: 1.65; 95% CI: 1.35, 2.02) or Hispanic (OR: 1.57; 95% CI: 1.27, 1.95), have a higher BMI (OR: 1.03; 95% CI 1.01, 1.04) and HR_{max} (OR: 1.02; 95% CI: 1.01, 1.02), and lower fitness (OR: 0.90; 95% CI: 0.85, 0.94) and RPE_{max} (OR: 0.68; 95% CI: 0.63, 0.73), compared to those within the target 40-59%HRR range (*p*-values'<0.05).

Conclusions: RPE appropriately gauges exercise intensity in approximately half of overweight individuals with type 2 diabetes; however, more than one-third of participants were at an increased risk of exercising at a higher than prescribed intensity when using RPE. Future studies should continue to examine the characteristics of individuals for whom RPE appropriately estimates exercise intensity and for those whom it does not.

Introduction

Regular exercise is associated with physiological and psychological health benefits [1-5], and is particularly important for individuals with type 2 diabetes, given the effect of exercise on body mass, insulin action and glucose control [6]. Implementation of an individually tailored exercise program may be necessary to optimize these health benefits. For example, exercise should be performed at intensity great enough to elicit a physiological training effect, but not too vigorous that it would increase the likelihood of abnormal clinical signs or symptoms, or increase the risk of musculoskeletal injury in high-risk populations [7]. Exercise regimens are often prescribed based on patient-reported subjective measures of intensity or the degree of physiological stress induced, often measured by heart rate; however, the relationship between subjective reporting and the physiologic response in type 2 diabetes, where neuropathy and other diabetes related factors may alter the relationship, has not been established.

The American College of Sports Medicine (ACSM) recommends that individuals with diabetes engage in 150 minutes/week (5 days/week) of moderate-intensity exercise in bouts lasting ≥10 min with no more than 2 consecutive days between bouts [6,7]. Furthermore, moderate-intensity exercise is defined as 40-59% heart rate reserve (HRR) or 40-59% oxygen uptake reserve (VO_2R). However, assessing heart rate (HR) or oxygen consumption (VO_2) is not practical in many situations; therefore more convenient methods for monitoring exercise intensity are often utilized. For example, the ratings of perceived exertion (RPE) scale has been shown to be an accurate and reliable tool for monitoring and self-regulating exercise intensity in selected populations [8,9]. Although subjective, the RPE scale has been shown to correlate with physiological variables such HR, ventilation, respiration, oxygen uptake, and blood lactate [10-12]. Additionally, an RPE of 12-13 on Borg's RPE scale [13] range 6-20, has been suggested to correspond with 40-59% HRR, the physiological threshold for defining moderate intensity activity [14]. However, there are limited data examining the correspondence between these methods for monitoring exercise intensity among individuals with type 2 diabetes.

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It is possible that symptoms associated with diabetes (i.e., pain, peripheral neuropathy, etc.) might influence one's subjective exercise experience. For example, women with type 2 diabetes were found to report a greater effort at low exercise workloads compared to those without type 2 diabetes [15]. Moreover, autonomic neuropathy, which is highly prevalent in this population, could influence maximal heart rate, thereby impacting %HRR and the concordance between these measures and RPE.

In a small sample (n=23), Colberg et al. [16] examined the validity of using %HRR or RPE to prescribe and monitor exercise intensity in adults with type 2 diabetes. A highly linear relationship between %HRR and %VO_2R (r=0.98) and between RPE and %VO_2R (r=0.94) was reported, suggesting that RPE and %HRR can appropriately monitor exercise intensity in individuals with diabetes, regardless of the presence of diabetic autonomic neuropathy. However, this study was limited by a small sample size, with further division of these subjects into those with (n=13) and without diabetic autonomic neuropathy (n=10). Further, the data presented were purely correlational, and did not assess whether the clinical cut-points for moderate-intensity exercise are appropriate in this population and whether there were any factors which influenced the association between HR and RPE.

The primary aim of this paper is to examine whether an RPE of 12-13, a subjective measure of moderate-intensity exercise, corresponds to 40-59% HRR, a physiological measure of moderate-intensity, during a maximal graded exercise test in individuals with type 2 diabetes who were not currently on β-adrenergic blocking medication (β-blockers). Based on the current literature, we hypothesized that the RPE and %HRR ranges for moderate-intensity exercise would appropriately correspond with one another. To increase the generalizability of these findings to clinical practice, this study also examined the characteristics of individuals for whom RPE appropriately estimated exercise intensity and for those whom it did not.

Methods

Participants

Data were obtained from participants enrolled in the Look AHEAD trial, a multi-center randomized clinical trial examining the long-term effects (up to 13.5 years) of an intensive lifestyle intervention program on cardiovascular morbidity and mortality in overweight or obese persons with type 2 diabetes. Characteristics of the 5,145 subjects enrolled in the Look AHEAD trial have been previously reported [17]. In short, participants had type 2 diabetes, were 45-76 years of age, had a BMI ≥25 kg/m^2 (or ≥27 kg/m^2 if taking insulin), HbA_{1c} ≤11%, triglycerides <600mg/dL, and systolic and diastolic blood pressure ≤160 and ≤100 mmHg, respectively. All participants provided written informed consent, and study procedures were approved by each center's institutional review board.

A total of 3991 individuals were considered in the analyses after excluding participants who reported using β-blockers given that β-blockers have been shown to blunt the HR response. Participants were further excluded for not achieving a maximal effort on the graded exercise test (GXT) as determined by the technician (n=168) or if the test was stopped by the physician due to EKG abnormalities or abnormal clinical signs or symptoms (n=215). If EKG abnormalities were observed, yet the physician did not terminate the test, these individuals were also included in the analyses given that they met the criteria for randomization into the Look AHEAD trial. This suggests that these individuals only had mild-to-moderate abnormalities that would not preclude them from safely engaging in exercise. Finally, participants missing HR data or RPE data at any given stage of the GXT (n=128) were also excluded from the analyses; thus ending with a total sample of n=3582 participants who were included in the following analyses (Note: some participants were excluded for more than one reason mentioned above and thus were included under multiple categories).

Graded exercise test

Prior to undergoing the graded exercise test, participants were instructed to talk with their physician whether they needed to reduce their insulin/sulphonyl urea dose on the day of testing. On the exercise testing day, participants completed a maximal GXT where the treadmill speed was determined based upon the preferred speed of the participant as well as their HR response during the first minute of a baseline test. The available speeds were 1.5, 2.0, 2.5, 3.0, 3.5, or 4.0 mph (2.41, 3.22, 4.02, 4.83, 5.63, 6.44 km/hr respectively). Using the pre-determined speed, the GXT began at a 0% grade which increased by 1% every minute until test termination at volitional fatigue or at the point where American College of Sports Medicine (ACSM) test termination criteria were observed [7]. During the test, participants were prohibited from holding onto the hand rails, except for brief balance. Heart rate was assessed using a 12-lead electrocardiogram (EKG) every minute during the final 10-15 seconds of each exercise stage and at the point of test termination. Maximal fitness was calculated using the grade and speed of the treadmill at test termination and was expressed in metabolic equivalents (METs) [7]. Heart rate recovery was calculated as maximal HR minus HR at two minutes post-test termination. Participants were instructed to take all medications as usual prior to this test.

Measurement of % heart rate reserve and ratings of perceived exertion

During each stage (every minute) of the GXT and at test termination, participants used the Borg scale to rate their RPE [13]. This scale has previously been shown to be valid and reliable in both healthy and clinical populations, as well as obese adults [18-21]. Before beginning the test, clinic staff read each participant a standardized script to explain and anchor the RPE scale. This RPE scale considers a rating of 6 to be "no exertion at all" whereas a 20 is considered to be "maximal exertion".

Resting HR (HR_{rest}) was measured via EKG on the day of the exercise test following a 5 minute rest period with the subject placed in a supine or semi-supine position. Although resting HR is sometimes measured in a seated position, prior studies, including the original Karvonen study, have used a supine HR measurement in the calculation of HRR [22,23]. Maximal HR (HR_{max}) was recorded at the point of test termination when the subject indicated that they had achieved volitional fatigue. Heart rate reserve for each individual was calculated as follows: ($HRR=HR_{max} - HR_{rest}$).

Additional assessment measures

Fasting serum glucose and HbA_{1c} were analyzed by the Central Biochemistry Laboratory (Northwest Lipid Research Laboratories, University of Washington, Seattle, WA) using methods described elsewhere [17]. Use of insulin and other diabetes medications were determined via standardized interviewer-administered questionnaires and participants were asked whether a physician has ever diagnosed diabetic neuropathy. Waist circumference was measured at the level of the iliac crest to the nearest 0.1 cm using the Gulick II tape measure and the average of two measures was used to represent the waist circumference. Physical activity (expressed in kcal/wk) was assessed using Paffenbarger Physical Activity Questionnaire (PPAQ) [24], but was only assessed at approximately half of the study sites given that this was a process measure and was not a primary aim of the larger trial.

Data analysis

The HR and RPE during each stage of the GXT were used to develop individual regression lines for each participant. Using this regression equation, the percent heart rate reserve (%HRR) was calculated for each participant at an RPE of 12 using the following equation: $\%HRR_{RPE=12} = [(HR_{RPE=12} - HR_{rest}) / (HR_{max} - HR_{rest})]$. Similar methods were used to calculate the %HRR at an RPE of 13. The %HRR which corresponded to both an RPE of 12 and 13 was identified and then used to determine if it fell within the target 40-59% range. Participants were then categorized into 1 of 3 groups: Below target: < 40%HRR at both an RPE of 12 and 13; at target: 40-59%HRR at an RPE of 12 or 13, and above target: ≥60%HRR at an RPE of 12 and 13. The percentage of participants falling into each of these categories was computed and a Pearson correlation was used to examine the relationship between HR and RPE throughout the GXT. Demographic variables (e.g., BMI, waist circumference, age, gender, race/ethnicity, lab measures, etc.), diabetes-specific variables (e.g., diabetes medication use, neuropathy, duration of diabetes, etc.), and exercise-related variables (e.g., HR_{max}, fitness, RPE_{max}, physical activity, etc.) were compared between the 3 %HRR groups using bivariate Analysis of Variance (ANOVA). In order to determine characteristics of those above and below target for %HRR, those variables which significantly differed across groups were entered as independent variables into two separate logistic regression models. Backwards selection methods were utilized. All analyses were performed using SAS version 9.2 (SAS Institute, Cary, NC).

Results

Demographic characteristics of the 3582 participants are shown in table 1. On average, participants were 58.3 ± 6.8 years of age, had a BMI of 35.9 ± 5.9 kg/m^2, and 62.1% were Caucasian. Moreover, the majority of participants had relatively "poor" fitness (max METs = 7.3 ± 2.0 METs) and 70% of participants reported engaging in <1000 kcal/week of leisure time physical activity [25].

There was a linear relationship (r=0.62, p<0.001) between HR and RPE throughout the GXT. At maximal effort, the mean HR_{max} was 154.3 ± 12.9 bpm which is equivalent to 95.7 ± 7.2% of age-predicted maximal heart rate (calculated as 220-age). Additionally, the mean RPE at maximal effort was 19.4 ±1.0.

Figure 1 illustrates the variability in %HRR at a self-reported RPE of 12 and 13. %HRR was normally distributed with a mean of 55% at an RPE of 12 and 62% at an RPE of 13. Fifty-seven percent of participants fell within the target 40-59%HRR range at an RPE of 12 or 13. However, 37% were exercising above the physiological threshold for moderate intensity (≥ 60% HRR; "Above target" group) at both an RPE of 12 and 13. The mean exercise intensity for these individuals was 69.0%HRR and 74.4%HRR at an RPE of 12 and 13 respectively. Six percent of participants fell below the moderate-intensity threshold at an RPE of 12 and 13 (<40%HRR; "Below target" group). When participants who may not have reached a true maximal effort (defined as maximal RPE < 17; n=106 or HR_{max} <85% of age-predicted maximum; n=63) were excluded from the analyses, the results were unchanged.

In Table 1, demographic information and diabetes-specific and GXT-related variables for each of the 3 groups (at, below, and above %HRR target) are shown. Those variables which significantly differed across groups were then entered as independent variables in two separate logistic regression models to examine whether those with a %HRR below (Model 1) and %HRR above (Model 2) the appropriate 40-59% HRR range differed from those individuals for whom RPE and %HRR appropriately corresponded with one another. Table 2 displays the odds ratio and 95% confidence interval for each of the variables mentioned below that were found to be significant in these regression models. Participants with a %HRR <40% ("Below target") were more likely to be American Indian, Asian or Hispanic compared to Caucasian, have a higher maximal fitness level, and have a lower HR_{max} and higher RPE_{max} during the GXT, compared those with a HRR in the 40-60% range. Moreover, participants who had a %HRR ≥ 60% at an RPE of 12 and 13 ("Above target") were more likely to be female, African American or Hispanic compared to Caucasian, have a higher BMI, lower fitness level, higher HR_{max}, and lower RPE_{max} during the GXT, compared to those for whom RPE appropriately corresponded with %HRR ("In target"). No diabetes-specific factors (e.g., diabetes duration, presence of neuropathy, medication usage, etc.) differed between those for whom RPE and % HRR appropriately corresponded with one another and those for whom it did not.

Discussion

The primary aim of this study was to examine the correspondence between physiological (%HRR) and perceptual (RPE) clinical cut-points for monitoring exercise intensity in overweight individuals with type 2 diabetes. Fifty-seven percent of participants fell within the target physiological 40-59% HRR range for moderate-intensity exercise at an RPE of 12 or 13 and only a small proportion (6%) fell below this range. However, about one-third of participants were exercising at an intensity ≥ 60% HRR when their reported RPE was a 12 and 13. This is of concern, suggesting that for many individuals with characteristics similar to those of the sample examined in this study, prescribing exercise based upon RPE may result in exercising at intensity above the recommended threshold.

The lack of correspondence between RPE and %HRR observed in a substantial proportion (43%) of our sample has also been reported in healthy adults [10,26,27] and cardiac patients [26,28,29]. For example, Whaley et al. [26] reported that 39% and 32% of healthy

Table 1: Demographic, diabetes-specific, and GXT-related variables stratified by physiological heart rate response (%HRR) at an RPE of 12 and 13 for participants not using Beta-blockers.

	All (n= 3582)	Below target (n=220)	In target range (n=2021)	Above target (n=1341)	p-value diff across groups
Demographic Factors					
BMI	35.9 (5.9)	34.9 (6.3)[a]	35.4 (5.6)[b]	36.9 (6.2)[a,b]	<0.0001
Waist circumference (cm)	113.5 (13.8)	112.3 (13.8)[a]	113.1 (13.6)[b]	114.5 (14.2)[a,b]	0.0052
Age (years)	58.3 (6.8)	57.9 (7.5)	58.6 (6.7)[a]	58.0 (6.8)[a]	0.0462
Gender (% female)	62.0	55.5[a]	58.4[b]	68.4[a,b]	<0.0001
Ethnicity (%)					<0.0001
African American/Black (not Hispanic)	15.6	10.0	13.1	20.5	
American Indian/Native American/Alaskan Native	5.8	13.2	5.5	5.1	
Asian Pacific Islander	1.0	3.2	1.0	0.7	
Caucasian	62.1	60.0	66.2	56.1	
Hispanic	13.5	12.7	12.1	15.9	
Other/Mixed	1.9	0.9	2.1	1.8	
Education					0.0005
<13 years	20.4	23.3	18.4	22.9	
13-16 years	37.3	32.9	36.7	39.1	
>16 years	42.3	43.8	44.9	38.1	
PA (kcal/wk)	856.9 (1103.1)	952.7 (1053.3)	879.5 (1175.9)	815.6 (1002.68)	0.3915
Diabetes-related variables					
HbA_{1c} (%)	7.3 (1.2)	7.3 (1.3)	7.3 (1.2)	7.3 (1.2)	0.6082
Blood Glucose (mg/dL)	152.8 (45.5)	154.8 (48.2)	152.4 (45.2)	153.0 (45.4)	0.7394
Duration of diabetes (years)	6.7 (6.4)	6.8 (6.4)	6.6 (6.5)	6.6 (6.3)	0.9487
Insulin Use (% using)	14.9	14.6	14.9	14.9	0.9877
Diabetes Medication (% using)	87.6	82.7	87.5	88.4	0.0584
Neuropathy present (%)	11.5	11.4	12.2	10.4	0.3012
History of CVD	8.2	5.5	8.5	8.3	0.3020
GXT-related variables					
%HRR for RPE of 12	54.6 (17.6)	14.8 (29.6)[a]	49.3 (7.5)[a]	69.0 (9.3)[a]	<0.0001
%HRR for RPE of 13	61.2 (15.9)	25.9 (25.4)[a]	56.4 (6.7)[a]	74.4 (9.5)[a]	<0.0001
Resting HR (bpm)	79.6 (11.8)	80.3 (12.3)	79.8 (11.8)	79.3 (11.7)	0.3506
HR_{max} (bpm)	154.3 (12.9)	151.6 (12.7)[a]	153.8 (12.8)[a]	155.6 (13.0)[a]	<0.0001
% age-predicted HR_{max}	95.5 (7.2)	93.5 (6.5)[a]	95.3 (7.2)[a]	96.1 (7.3)[a]	<0.0001
Heart Rate Recovery	41.5 (15.9)	41.5 (14.7)	41.5 (18.0)	41.5 (12.5)	0.9992
RPE_{max} (6-20 scale)	19.4 (1.0)	19.7 (0.7)[a]	19.5 (0.8)[a]	19.1 (1.3)[a]	<0.0001
Max fitness (MET)	7.3 (2.0)	7.9 (2.0)[a]	7.5 (2.0)[a]	7.0 (1.9)[a]	<0.0001

All values expressed as Mean (SD) or %; Values with similar superscripts (e.g.,[a] and [a]) indicates that those groups are significantly different from one another. Below target: < 40% HRR for both RPE of 12 and 13; In target range: 40-59% HRR; Above target: ≥60% HRR for RPE of 12 and 13

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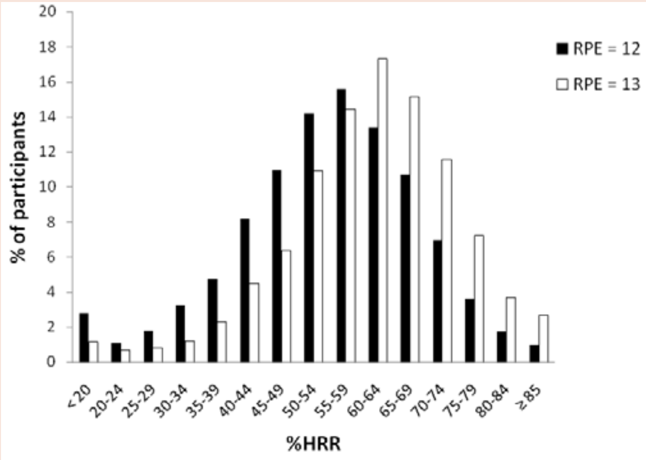

Figure 1: Variability in physiological responses (%HRR) to exercise at an RPE of 12 and 13.
RPE: ratings of perceived exertion; %HRR: percent heart rate reserve

Table 2: Logistic regression models comparing individuals for whom RPE does and does not appropriately coincide with %HRR for moderate-intensity.

Variable	OR (95% CI)	P-value
MODEL 1 (Below target vs. In target)		
Max fitness (MET)	*1.137 (1.056, 1.225)*	*0.0007*
Race/Ethnicity		*0.0002*
AA vs. Caucasian	0.920 (0.572, 1.482)	
AI vs. Caucasian	2.589 (1.650, 4.062)	
Asian vs. Caucasian	2.971 (1.215, 7.261)	
Hispanic vs. Caucasian	1.160 (0.752, 1.788)	
Other/Mixed vs. Caucasian	0.470 (0.112, 1.979)	
HR_{max}	*0.979 (0.967, 0.990)*	*0.0005*
RPE_{max}	*1.441 (1.140, 1.821)*	*0.0022*
MODEL 2 (Above target vs. In target)		
BMI	*1.026 (1.012, 1.040)*	*0.0003*
Max fitness (MET)	*0.895 (0.854, 0.938)*	*<0.0001*
Race/Ethnicity		<0.0001
AA vs. Caucasian	*1.652 (1.351, 2.020)*	
AI vs. Caucasian	*1.048 (0.756, 1.451)*	
Asian vs. Caucasian	*1.094 (0.484, 2.471)*	
Hispanic vs. Caucasian	*1.574 (1.272, 1.947)*	
Other/Mixed vs. Caucasian	*0.951 (0.560, 1.614)*	
Female	*1.187 (1.007, 1.399)*	*0.0407*
HR_{max}	*1.015 (1.009, 1.021)*	*<0.0001*
RPE_{max}	*0.678 (0.628, 0.731)*	*<0.0001*

Model 1: Probability group is "Below target" (<40% HRR at RPE of 12 and 13) compared to "In target" (40-60% HRR at RPE of 12 and 13); Model 2: Probability group is "Above target" (≥60% HRR at RPE of 12 and 13) compared to "In target" (40-60% HRR at RPE of 12 and 13); AA = African American, AI = American Indian,

subjects and cardiac patients respectively reported an RPE above or below the expected value at 60% HRR. Thus, it is unlikely that the observed variability in the current study is specific to the presence of diabetes. The current findings also suggest that the concordance between HR and RPE was not associated with any of the diabetes-specific factors examined (e.g., presence of neuropathy, blood glucose, insulin usage, or HbA1c). This suggests that within individuals with diabetes, factors such as diabetes medication usage, the severity of the diabetes, or the presence of neuropathy likely do not influence the relationship between %HRR and RPE. However, this study did not assess autonomic neuropathy, and thus future studies should examine whether the presence of autonomic neuropathy influences the relationship between RPE and HR in those with diabetes, given that autonomic neuropathy impacts involuntary body functions such as heart rate. Also, studies comparing individuals with and without diabetes are also needed to definitively determine whether the presence of diabetes impacts the validity of the RPE scale.

Given that %HRR is calculated using maximal HR, failure to achieve a true physiological maximal effort on the GXT or unfamiliarity with the RPE scale could possibly explain why 37% of the current sample had a HR greater than expected at an RPE of 12 or 13. Secondary analyses revealed that individuals who perceived exercise to be less difficult actually had a higher maximal HR compared to those for whom %HRR and RPE appropriately corresponded to one another, suggesting that failure to exert a maximal effort on the GXT likely did not explain the current findings. Those with a %HRR ≥ 60% had a lower maximal RPE despite a higher maximal HR, suggesting the possibility that these individuals may not have fully understood the anchoring of the RPE scale. Whether this is also the case in other samples warrants further investigation.

From a practical perspective, is also important to examine whether there are any demographic factors which influence the correspondence between RPE and %HRR cut-points for moderate-intensity exercise. The current findings suggest that there was a trend for individuals with a HR above the 40-59% HRR range at an RPE of 12 and 13 (HRR ≥ 60%) to be female and significantly more likely to be African American or Hispanic compared to males and Caucasians respectively. Our findings are in agreement with Hunter et al. [30] who reported that African American women had a lower RPE compared to Caucasian women during a maximal exercise test. Although it is unclear why this is the case, previous research suggests that African Americans have lower blood lactate concentrations during exercise and are more resistant to fatigue compared to Caucasians [31-34]; thus possibly explaining why they may have perceived exercise to be easier. Other studies also suggest that Hispanics underreport pain, due to cultural differences and an increased emphasis on stoicism (i.e., accepting pain without complaining) [35,36]. Thus, these ethnic differences could offer a possible explanation for why these minority subgroups were more likely to have a higher %HRR at the same RPE. Moreover, prior studies suggest that there are gender differences related to pain and perception of exercise [37,38], which is along the lines of what was found in the current study.

Fitness and BMI also influenced the correspondence between HR and RPE in the current study. For every 1 unit increase in BMI and for every 1 MET decrease in fitness, individuals were 3% and 9% more likely respectively to have a HRR ≥ 60% at an RPE of 12 or 13 compared to those who fell in the appropriate 40-59% HRR range. These findings are contrary to Hulens et al. [39] who reported that obese individuals, specifically those with severe obesity, perceive exercise to be more difficult than less obese or non-obese individuals. They also differ from those by Hunter et al. [30] who reported that subjects who were most active perceived exercise to be least difficult; however this study included only women and was plagued by a small sample size (n=74). Although we do not have a clear explanation for these discrepant findings, it is possible that social desirability or social approval was more prominent among the more obese and less fit individuals in the current study, due to possible insecurities surrounding their greater weight and lower fitness levels. Also, the GXT was performed as a screening measure required for entrance into this study; thus it is possible that these individuals underreported how hard they were exercising to appease the research staff. These discrepant findings suggest that future studies should investigate the influence of fitness and BMI on the validity of the RPE scale. Whether or not there were any other physiological differences (e.g., differences in lactate thresholds) or psychological differences (e.g., reaching maximal effort sooner than expected) between those for whom RPE and %HRR did and did not appropriately correspond with one another cannot be determined from the current data.

Although the current data stems from a larger study which was not designed specifically to examine the relationship between %HRR and RPE, this paper is strengthened by the large number of individuals with type 2 diabetes who performed a maximal exercise test with HR and RPE data collected at the end of each stage. However, there are several limitations. First, this study is limited by the lack of objectively measured, physiological parameters (i.e., respiratory exchange ratio, blood lactate concentrations, plateau in oxygen consumption, etc.) needed to confirm a true maximal effort on the GXT. However, the mean HR_{max} was calculated to be 96% of the age-predicted HR_{max} and the mean RPE at maximal effort was 19.4, both of which suggest that a maximal effort was likely achieved across the entire sample. Second, individuals unable to complete a GXT and those using β-blockers were excluded from the analyses; thus the results may not be generalizable to those individuals. Third, medication use prior to undergoing the graded exercise test was not rigorously controlled. While this may enhance the generalizability of our findings, this may also be considered as a potential confounder. This should be considered in future studies of clinical populations when examining perceptual responses to exercise." Fourthly, we acknowledge that it may be unclear whether participants achieved steady state heart rates by the end of each GXT stage given that the stages were only 1 minute in duration. However, the increase in workload at the end of each stage was modest (1% grade, ~0.4 MET), as was the average increase in HR from stage-to-stage (4 bpm). These data would suggest that the heart rates collected were close to, if not steady state values. Finally, some may argue that the findings from the current study would not generalize to steady state exercise given that a GXT was used to assess the correspondence between HR and RPE. However, previous studies demonstrate that an individual's perceptual response to a GXT can be used to accurately prescribe exercise intensity during steady state exercise [40] and the majority of studies in this area have used a GXT to assess the relationship between HR and RPE [16,26,41]. Birk et al. [42] also reported a very close relationship between HR and RPE between a GXT and exercise training at an 11-14 RPE range; thus we believe that the current findings can translate to clinical practice.

Conclusions

To our knowledge, this is the largest study to date to examine the correspondence between RPE and HR-derived cut-points for moderate-intensity exercise. RPE appears to be an acceptable method for regulating exercise intensity in more than half of overweight individuals with type 2 diabetes. However, caution should be taken when using RPE to universally prescribe exercise intensity in this population, given that there are a substantial proportion of individuals for whom RPE may underestimate exercise intensity. Findings from this study reveal that individuals who may be at greatest risk for this occurring include women, African Americans and Hispanics, those who are more obese and less fit. This is of concern given that persons with diabetes are considered a "high risk" population [7]; thus it is possible that engagement in exercise that is above that prescribed threshold could be potentially dangerous if proper screening and/or education is not employed. Prior to prescribing exercise, clinicians and exercise physiologists should consider assessing the correspondence between HRR and RPE in those individuals at greatest risk for underestimating exercise intensity when using RPE. Given the potential variability in RPE between individuals during exercise, additional research is needed to better understand for whom RPE provides an appropriate measure of exercise intensity.

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Conflict of Interest Statement

Dr Jakicic reported serving on the scientific advisory board for Alere Wellbeing, has received an honorarium for a scientific presentation from Jenny Craig and from the Nestle Nutrition Institute, and has served as the Principal Investigator on research grants awarded to the University of Pittsburgh from the Beverage Institute for Health and Wellness and Body Media, Inc. The remaining authors have no conflicts of interest to report.

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