Exercise Prescription Methods

COUNTERPOINT: Theoretical and Empirical Basis for Equating Heart Rate Reserve with $\dot{V}O_2$ Reserve

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ABSTRACT

In 1998, the American College of Sports Medicine recommended the use of % heart rate reserve (HRR) and % oxygen consumption reserve ($\dot{V}O_2R$) for providing equivalent exercise intensities based on limited research regarding the relationship of HR and $\dot{V}O_2$ from rest to maximal exercise. It further emphasized that the percentage of aerobic capacity, or %$\dot{V}O_2$max, does not provide equivalent intensities to %HRR and that this discrepancy is greater for individuals with lower levels of cardiorespiratory fitness, especially at low exercise intensities. This point/counterpoint examines additional research to evaluate these relationships. *Journal of Clinical Exercise Physiology*. 2021;10(3):97–101.

INTRODUCTION

In 1957, Karvonen et al. (1) introduced a systematic approach for prescribing exercise intensity as a percentage of the difference between resting and maximum heart rate (HR), known as the heart rate reserve (HRR) method. This methodology was rapidly adopted by the field of exercise science. Although Karvonen et al. (1) did not measure oxygen consumption ($\dot{V}O_2$) in their study, it was generally assumed that %HRR values provided equivalent exercise intensities as the same values of %$\dot{V}O_2$max. Accordingly, the American College of Sports Medicine (ACSM) stated these variables were equivalent in a 1990 position stand (2), despite the fact that Davis and Convertino (3) had previously demonstrated that %HRR is equivalent to a percentage of the difference between resting and maximum $\dot{V}O_2$, which they termed % net $\dot{V}O_2$max and is today referred to as %$\dot{V}O_2$ reserve ($\dot{V}O_2R$).

In 1998, the ACSM modified their recommendations in a position stand stating, "the ACSM is now relating HRR to $\dot{V}O_2R$ rather than to a percentage of $\dot{V}O_2$max. Using $\dot{V}O_2R$ improves the accuracy of the relationship, particularly at the lower end of the intensity scale. It is incorrect to relate HRR to a level of $\dot{V}O_2$ that starts at zero rather than a resting level. This change makes [the ACSM's position stand] more scientifically accurate" (4). Among the research studies cited in support of this statement, Panton et al. (5) found that percentages of HRR were significantly lower than percentages of $\dot{V}O_2$max across a range of exercise intensities in older adults, and Swain and Leutholtz (6) reported that %HRR values were significantly lower than %$\dot{V}O_2$max values in younger adults but were statistically similar to %$\dot{V}O_2R$ values. The latter study determined regressions of %HRR versus %$\dot{V}O_2R$ and %HRR versus %$\dot{V}O_2$max and found that the mean regression with %$\dot{V}O_2R$ was coincident with the line of

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Table. Studies that examined %HRR versus $\%\dot{V}o_2R$

Author, y	Population	Mode	Main Finding
Davis and Convertino, 1975 (3)	Healthy men	T	%HRR = $\%\dot{V}o_2R$
Swain and Leutholtz, 1997 (6)	Healthy adults	C	%HRR = $\%\dot{V}o_2R$
Swain et al., 1998 (18)	Healthy adults	T	%HRR closer to $\%\dot{V}o_2R$ than to $\%\dot{V}o_2max$
Brawner et al., 2002 (13)	Cardiac patients	T	%HRR = $\%\dot{V}o_2R$
Byrne and Hills, 2002 (14)	Obese adults	T	%HRR = $\%\dot{V}o_2R$
Colberg et al., 2003 (15)	Diabetic patients	C	%HRR = $\%\dot{V}o_2R$
Dalleck and Kravitz, 2006 (16)	Healthy adults	E, T	%HRR = $\%\dot{V}o_2R$
Hui and Chan, 2006 (22)	Healthy children	T	%HRR closer to $\%\dot{V}o_2max$ than to $\%\dot{V}o_2R$
Lounana et al., 2007 (17)	Elite male cyclists	C	%HRR = $\%\dot{V}o_2R$
Davenport et al., 2008 (19)	Pregnant women	T	%HRR closer to $\%\dot{V}o_2R$ than to $\%\dot{V}o_2max$
Pinet et al., 2008 (20)	Obese adults	T	%HRR closer to $\%\dot{V}o_2R$ than to $\%\dot{V}o_2max$
Cunha et al., 2010 (21)	Healthy men	T	%HRR = both $\%\dot{V}o_2R$ and $\%\dot{V}o_2max$
Ferri Marini et al., 2021 (23)	Healthy adults	C	%HRR closer to $\%\dot{V}o_2max$ than to $\%\dot{V}o_2R$

C = cycle ergometer; E = elliptical machine; T = treadmill.

identity, i.e., the slope was 1 and the y intercept was 0, while the regression with $\%\dot{V}o_2max$ differed significantly from this relation. Moreover, the discrepancy of the regression with $\%\dot{V}o_2max$ from the line of identity increased with decreasing aerobic capacity, or cardiorespiratory fitness (CRF) (6). In other words, when a person is at rest, the person is by definition at 0% of HRR but is at some percentage of $\dot{V}o_2max$ above 0. The $\%\dot{V}o_2max$ value at rest is inversely proportional to one's $\dot{V}o_2max$. That is, given a resting $\dot{V}o_2$ of approximately 3.5 $mL{\cdot}min^{-1}{\cdot}kg^{-1}$, individuals with $\dot{V}o_2max$ values of 17.5, 35, or 70 $mL{\cdot}min^{-1}{\cdot}kg^{-1}$ (i.e., 5, 10, or 20 metabolic equivalents [MET]) must be at 20%, 10%, and 5% of $\dot{V}o_2max$ when resting, respectively. Given that individuals with a low $\dot{V}o_2max$ have a 20% difference between %HRR and $\%\dot{V}o_2max$ when resting, exercise levels at low intensities will have substantial differences between %HRR and $\%\dot{V}o_2max$, whereas %HRR and $\%\dot{V}o_2R$ values will be theoretically equal. This theory was confirmed by the Swain and Leutholtz (6) study. The use of %HRR and $\%\dot{V}o_2R$ was again recommended by the ACSM in its 2011 position stand (7).

THE LITERATURE

Several studies have compared the linear regression of %HRR versus $\%\dot{V}o_2R$, and most of these also performed regressions of %HRR versus $\%\dot{V}o_2max$. As described below, most of these studies confirm that %HRR and $\%\dot{V}o_2R$ provide equivalent or nearly equivalent values, while there is a clear discrepancy between %HRR and $\%\dot{V}o_2max$ values.

We identified 18 studies that determined regressions of %HRR versus $\%\dot{V}o_2R$. Fourteen of these studies, including Swain and Leutholtz in 1997 (6), used $\%\dot{V}o_2R$ as the independent variable (x axis) and %HRR as the dependent variable (y axis) for physiological reasons, i.e., percentage of heart rate employed corresponds to the intensity of exercise, expressed as the relative oxygen requirement. Four of the 18 studies (8–11) reversed the axes, making %HRR the independent variable. Although it is possible to mathematically transpose the resulting regression equation, doing so will not yield the equation that would be obtained by plotting the data with $\%\dot{V}o_2R$ as the independent variable. This transposition would only yield the proper equation if every data point fell exactly on the line; with increasing scatter in the data, the resulting equation becomes dramatically different from the equation obtained by replotting the data. Thus, these 4 studies were not included in our final analysis. One additional study examined the HR and $\dot{V}o_2$ responses of cardiac transplant recipients (12). The hearts of transplant patients have been sympathetically denervated and demonstrate a markedly attenuated HR response to exercise. The mean values of resting and maximum HR were not provided in the study, making it difficult to gauge the potential value of the study's HR-$\dot{V}o_2$ analysis, and this report was not considered further.

The remaining 13 studies that obtained regressions on %HRR versus $\%\dot{V}o_2R$ are summarized in the Table. Seven studies found that %HRR versus $\%\dot{V}o_2R$ was not significantly different from the line of identity (3,6,13–17). Five of these 7 studies also calculated regressions of %HRR versus $\%\dot{V}o_2max$ and found that the relationship was significantly different from the line of identity (6,13,14,16,17). Three of the remaining 6 studies found that neither %HRR versus $\%\dot{V}o_2R$ nor %HRR versus $\%\dot{V}o_2max$ were coincident with the line of identity, but in each of these studies, the line for $\%\dot{V}o_2R$ was a significantly closer match than the line for $\%\dot{V}o_2max$ (18–20). One study had paradoxical results in which, when using a Bruce treadmill protocol, both the %HRR versus $\%\dot{V}o_2R$ and %HRR versus $\%\dot{V}o_2max$ regressions were coincident with the line of identity, which should be physiologically and mathematically impossible (21). Finally, 2 studies found that neither the %HRR versus

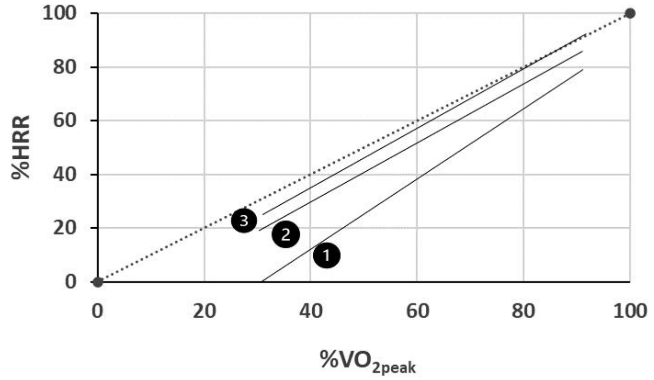

Figure. %HRR versus %$\dot{V}o_2$max in 3 populations. Dotted line: Line of identity. 1: Regression for heart failure patients, $\dot{V}o_2$max of 16.5 mL·min^{-1}·kg^{-1}; %HRR = 1.26(%$\dot{V}o_2$max) – 34.9; Brawner et al., 2002 (13). 2: Regression for overweight adults, $\dot{V}o_2$max of 27.0 mL·min^{-1}·kg^{-1}; %HRR = 1.05(%$\dot{V}o_2$max) – 11.4; Pinet et al., 2008 (2). 3: Regression for elite cyclists, $\dot{V}o_2$max of 70.9 mL·min^{-1}·kg^{-1}; %HRR = 1.07(%$\dot{V}o_2$max) – 5.7; Lounana et al., 2007 (17). All 3 regressions were significantly different from the line of identity.

%$\dot{V}o_2$R nor the %HRR versus %$\dot{V}o_2$max regressions were on the line of identity, but the regression for %$\dot{V}o_2$max was closer (22,23). In aggregate, 10 studies support the use of %HRR and %$\dot{V}o_2$R over %HRR and %$\dot{V}o_2$max, while 2 studies support the opposite. A closer examination of the opposing studies is warranted.

All but these 2 studies collected HR and $\dot{V}o_2$ over the same length of time at the end of each stage of exercise (that duration varied between studies, but not within studies). However, Hui and Chan in 2006 (22) used the last 30 seconds of each 3-minute stage for HR and the last 60 seconds for $\dot{V}o_2$, while Ferri Marini et al. in 2021 (23) stated that the last 60 seconds of each 2-minute stage was used for $\dot{V}o_2$ but did not state the duration for HR, implying that it was 15 seconds based on other statements in the methodology. HR and $\dot{V}o_2$ continuously rise during 2- to 3-minute stages of incremental exercise. Therefore, measuring the HR during a shorter period than $\dot{V}o_2$ at the end of the stage will result in relatively greater HR values. In most studies, when %HRR is plotted against %$\dot{V}o_2$max (see the Figure), the resulting regression falls below the line of identity. If the HR values are inflated in each stage of exercise, this would tend to move the regression with %$\dot{V}o_2$max upward, making it more like the line of identity. Moreover, since the %HRR versus %$\dot{V}o_2$R regression normally falls on the line of identity, inflated HR values would move it above that line. These results are precisely what was found for the regressions in Hui and Chan, 2006 (22), and Ferri Marini et al., 2021 (23), the only 2 studies that found %$\dot{V}o_2$max is more closely related than %$\dot{V}o_2$R to %HRR.

Another consideration is whether resting data were included in the regressions. Swain and Leutholtz, 1997 (6), included resting values because they were part of the continuous data collection from rest to maximum exercise. Ferri Marini et al., 2021 (23), argued that including resting data will bias the intercept of the %HRR versus %$\dot{V}o_2$R regression toward 0. This is certainly true. It is also true that not including the resting data ignores the theoretical basis for the %HRR versus %$\dot{V}o_2$R relationship and thus biases the regression in a different manner. Ferri Marini et al. (23) did not include resting data in their analyses. Hui and Chan (22) did not state whether they included resting data. Of the 10 studies supporting the %HRR versus %$\dot{V}o_2$R relationship, 4 included resting data (6,16–18), 4 did not (3,13,14,19), and the remaining 2 provided insufficient information to clarify this issue (15,20). Accordingly, we suspect this is a moot point.

One of the most important findings of Swain and Leutholtz, 1997 (6), was the effect of CRF on the %HRR versus %$\dot{V}o_2$max relationship. Theoretically, as described earlier, one expects that individuals with a low aerobic capacity will have a more marked discrepancy between %HRR and %$\dot{V}o_2$max than individuals with greater levels of CRF, especially at low intensities of exercise. Six of the 13 studies in the Table evaluated whether CRF had such an effect. All 6 found that individuals with lower fitness had larger discrepancies. Swain and Leutholtz, 1997 (6), reported that subjects with $\dot{V}o_2$max values less than 30 mL·min^{-1}·kg^{-1} had a %HRR versus %$\dot{V}o_2$max regression that was further from the line of identity than subjects with greater than 50 mL·min^{-1}·kg^{-1}. Brawner et al., 2002 (13), found that heart failure patients with a $\dot{V}o_{2peak}$ of 16.5 mL·min^{-1}·kg^{-1} were further from the line of identity than cardiac patients without heart failure who had a $\dot{V}o_{2peak}$ of 19.4 mL·min^{-1}·kg^{-1}. Pinet et al., 2008 (20), found that regressions were increasingly further from the line of identity for more obese groups with $\dot{V}o_{2peak}$ values of 27.0, 25.9, and 22.4 mL·min^{-1}·kg^{-1}. Swain et al., 1998 (18), Byrne and Hills, 2002 (14), and Dalleck and Kravitch, 2006 (16), found that the aerobic capacity of subjects was inversely related to the intercept of the %HRR versus %$\dot{V}o_2$max regression, i.e., lower fit subjects had a greater discrepancy. The Figure illustrates the %HRR versus %$\dot{V}o_2$max relationship in 3 groups with widely disparate $\dot{V}o_2$max values. Interestingly, Ferri Marini et al. in 2021 (23), with data on more than 500 subjects that ranged from 15.2 to 54.9 mL·min^{-1}·kg^{-1} in $\dot{V}o_2$max, did not investigate this critically important point. The theoretical basis of the %HRR versus %$\dot{V}o_2$max relationship predicts larger discrepancies for lower fit individuals, especially at low exercise intensities, and this should have been tested if the authors wished to demonstrate the superiority of %HRR versus %$\dot{V}o_2$max over the currently accepted 1:1 relationship of %HRR versus %$\dot{V}o_2$R to prescribe and monitor aerobic exercise intensity.

CONCLUSIONS AND PRACTICAL APPLICATIONS

At rest, %HRR and %$\dot{V}o_2$R are 0 by definition, while %$\dot{V}o_2$max ranges from about 5% to more than 20%, being lower for individuals with high aerobic fitness, higher for those with low aerobic fitness. These statements are mathematical facts. The discrepancy between %HRR and %$\dot{V}o_2$max at rest extends into the low to moderate exercise intensity range, being quite large for patients and clients with low aerobic fitness. Most available studies have confirmed this discrepancy during exercise and reinforce the notion that $\%\dot{V}o_2R$ provides equivalent or nearly equivalent intensities of exercise to %HRR.

Research on the HR-$\dot{V}o_2$ relationship has traditionally been conducted using incremental exercise tests of either a continuous or discontinuous nature, with stage durations less than or equal to 5 minutes. To our knowledge, no one has systematically examined the relationship of HR and $\dot{V}o_2$ during typical aerobic exercise sessions that last 20 to 60 minutes. As body temperature rises during exercise, HR and $\dot{V}o_2$ will invariably increase in a phenomenon known as cardiovascular drift. One study had 8 male cyclists perform a 1-hour bout of steady-state exercise at 70% of maximum power output and found that $\dot{V}o_2$ increased from 3.26 $L{\cdot}min^{-1}$ to 3.43 $L{\cdot}min^{-1}$ from the 10th to the 60th minute, whereas HR increased from 153 to 164 $b{\cdot}min^{-1}$ over the same period (24). Although the study did not evaluate %HRR or $\%\dot{V}o_2R$, it illustrates the challenge scientists and practitioners face. To accurately evaluate the "equivalency" of %HRR to either $\%\dot{V}o_2R$ or $\%\dot{V}o_2max$ for the purpose of exercise prescription, studies involving multiple trials of 20 to 60 minutes in duration would need to be performed on large numbers of young, middle-aged, and older subjects, with and without chronic disease, using different population groups. This is not particularly feasible, nor is it necessary for developing exercise prescriptions.

In practice, it is generally recommended to prescribe exercise intensity via the HRR method (7), using the rating of perceived exertion as an adjunctive intensity modulator. For coronary patients with exertional signs or symptoms of myocardial ischemia, the peak exercise HR should be greater than or equal to 10 $b{\cdot}min^{-1}$ below the ischemic electrocardiogram or angina threshold. Alternative methods also include a calculated exercise workload based on $\dot{V}o_2$. When this methodology is employed, the intensity should correspond to that normally derived via HRR using the $\%\dot{V}o_2R$ method. However, all practitioners should recognize that any prescribed exercise intensity—whether via $\%HR_{max}$, %HRR, $\%\dot{V}o_2R$, or $\%\dot{V}o_2max$—is merely the first step. The patient or client should be observed during exercise and the intensity adjusted accordingly, using hemodynamic responses, clinical signs or symptoms, and the rating of perceived exertion. This approach has long been recommended as the "art" of exercise prescription.

If there really is a timely and emergent issue about exercise prescription that we need to "rethink," perhaps it is how we get more people worldwide to become more physically active on a regular basis since the current COVID-19 pandemic has decreased physical activity by 33% and simultaneously increased sitting time by 28% (25).

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