# $\dot{V}O_2$ reserve and the minimal intensity for improving cardiorespiratory fitness

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**ABSTRACT**

SWAIN, D. P., and B. A. FRANKLIN. $\dot{V}O_2$ reserve and the minimal intensity for improving cardiorespiratory fitness. *Med. Sci. Sports Exerc.*, Vol. 34, No. 1, 2002, pp. 152–157. **Purpose:** The American College of Sports Medicine has stated that aerobic training needs to occur at a minimum threshold intensity of 50% $\dot{V}O_{2max}$ for most healthy adults and at 40% $\dot{V}O_{2max}$ for those with a very low initial fitness. Recently, the concept of $\dot{V}O_2$ reserve (%$\dot{V}O_2$R, i.e., a percentage of the difference between maximum and resting $\dot{V}O_2$) has been introduced for prescribing exercise intensity. This analysis was designed to determine the threshold intensity for improving cardiorespiratory fitness expressed as %$\dot{V}O_2$R units. **Methods:** Previous studies in healthy subjects ($N = 18$) that evaluated the results of training at low-to-moderate intensities (i.e., ≤ 60% $\dot{V}O_{2max}$) were identified. The original studies described the intensity of exercise variously as %$\dot{V}O_{2max}$, %HRR, %$HR_{max}$, or as a specific HR value. In each case, the intensity was translated into %$\dot{V}O_2$R units. **Results:** Exercise training intensities below approximately 45% $\dot{V}O_2$R were consistently ineffective at increasing $\dot{V}O_{2max}$ in studies that used subjects with mean initial $\dot{V}O_{2max}$ values $> 40$ $mL \cdot min^{-1} \cdot kg^{-1}$. In studies using subjects with mean initial $\dot{V}O_{2max}$ values $< 40$ $mL \cdot min^{-1} \cdot kg^{-1}$, no intensity was found to be ineffective. For this latter group of subjects, the lowest intensities examined were approximately 30% $\dot{V}O_2$R. **Conclusion:** Although evidence for a threshold intensity was not strong, this analysis of training studies supports the use of 45% $\dot{V}O_2$R as a minimal effective training intensity for higher fit subjects and 30% $\dot{V}O_2$R for lower fit subjects.

**Key Words:** MAXIMUM OXYGEN CONSUMPTION, OXYGEN UPTAKE, OXYGEN UPTAKE RESERVE, AEROBIC CAPACITY, EXERCISE TRAINING, EXERCISE PRESCRIPTION

In their landmark paper on exercise prescription in 1957, Karvonen et al. (23) reported that a threshold exercise intensity existed for the improvement of cardiorespiratory fitness. The lowest intensity that produces a training effect can be termed a "threshold" if intensities below this level fail to produce improvement. Karvonen et al. found that an intensity of at least 70% of the difference between maximal and resting heart rate (i.e., 70% of heart rate reserve, HRR) was required to produce a training effect in young male adults (an observed decrease in heart rate at a fixed submaximal work rate, which suggested an increase in maximum oxygen consumption, $\dot{V}O_{2max}$). Subsequent research has led the exercise science community to revise the intensity threshold downward. In its 1990 position stand (1), the American College of Sports Medicine (ACSM) suggested a threshold intensity for training at 50% of HRR or $\dot{V}O_{2max}$ for most adults and 40% of HRR or $\dot{V}O_{2max}$ for individuals with a low initial level of aerobic fitness. Thus, it appears that the threshold training intensity may vary according to the pretraining $\dot{V}O_{2max}$, or level of habitual physical activity.

Recent research has demonstrated that %HRR does not provide equivalent exercise intensities to %$\dot{V}O_{2max}$ but is instead equivalent to a percentage of the difference between maximum and resting oxygen consumption, i.e., to a percentage of oxygen consumption reserve, %$\dot{V}O_2$R (33,34). Thus, in its 1998 position stand (28), the ACSM revised its exercise prescription recommendations to use %$\dot{V}O_2$R, rather than %$\dot{V}O_{2max}$, as a means for establishing exercise intensity.

A considerable discrepancy can exist between %HRR or %$\dot{V}O_2$R units and %$\dot{V}O_{2max}$ units. At rest, an individual is by definition at 0% of both HRR and $\dot{V}O_2$R but is at some finite value above 0% of $\dot{V}O_{2max}$. This latter value is inversely related to fitness, in that an individual with an aerobic capacity of 10 metabolic equivalents (METs; 1 MET = 3.5 $mL \cdot min^{-1} \cdot kg^{-1}$) is at 1/10 or 10% of $\dot{V}O_{2max}$ at rest, whereas an individual with an aerobic capacity of only 5 METs is at 1/5 or 20% of $\dot{V}O_{2max}$ at rest. Maximum exercise elicits 100% of HRR, $\dot{V}O_2$R, and $\dot{V}O_{2max}$ for individuals of all fitness levels. Thus, at intensities between rest and maximum, the discrepancy between %HRR or %$\dot{V}O_2$R units and %$\dot{V}O_{2max}$ units varies with both the fitness level of the individual and the specific intensity within the range between rest and maximum (33,34). For example, an individual with a 5-MET capacity would be at 52% of $\dot{V}O_{2max}$ when at 40% of HRR or $\dot{V}O_2$R, whereas an individual with a 10 MET capacity would be at 46% of $\dot{V}O_{2max}$ when at 40% of HRR or $\dot{V}O_2$R. Note that a discrepancy of 12 percentage units (52% vs 40%) when at 40% of HRR translates into a 30% discrepancy in the actual exercise intensity (12/40 = 30%).

Changing the basis of exercise prescriptions from %$\dot{V}O_{2max}$ to %$\dot{V}O_2$R has the advantage of placing clients of varying fitness levels at equivalent relative intensities above rest and provides more accurate translations of intensity,

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expressed as $\dot{V}O_2$, into target heart rates using the %HRR method. However, the use of %$\dot{V}O_2R$ raises a question. Because %$\dot{V}O_2R$ and %$\dot{V}O_{2max}$ are not equivalent units of intensity, if there is a threshold intensity for aerobic training at 40–50% of $\dot{V}O_{2max}$, what is this threshold in %$\dot{V}O_2R$ units? This is an important question to address, because many of the initial studies, such as the one by Karvonen et al., established exercise intensity as a % of HRR, which more accurately reflects %$\dot{V}O_2R$ rather than %$\dot{V}O_{2max}$. Other studies used varied methods to establish exercise intensity. This analysis was undertaken to translate the training intensities in previous studies to %$\dot{V}O_2R$ units to determine threshold intensities for improving cardiorespiratory fitness among subjects with varied baseline $\dot{V}O_{2max}$ values.

## METHODS

The following steps were used to include research studies that evaluated the impact of low-to-moderate exercise training intensities on the $\dot{V}O_{2max}$ of healthy adults. First, references in the ACSM's 1990 and 1998 position stands (1,28) regarding the intensity threshold were obtained. Second, a MEDLINE search was performed using the search words "exercise," "training," and "maximum oxygen consumption." Third, the reference lists of articles obtained in the first two steps were cross-referenced for additional studies.

Only studies that measured pre- and post-training $\dot{V}O_{2max}$ and that had at least one group of subjects who exercised at an intensity that approximated 60% or less of $\dot{V}O_{2max}$ were included for analysis. Criteria for the attainment of $\dot{V}O_{2max}$ varied. Most studies used the widely accepted criteria of a plateau in oxygen consumption and/or a respiratory exchange ratio $\geq$ 1.10 (2–4,7,9,17,20,25,29–31), although some of these also included a criterion regarding age-predicted maximal heart rate (2,20,25,29,30) or the attainment of a high blood lactate concentration (30,31). The remaining studies used volitional fatigue as the criterion for maximal effort (8,11,12,14,24) or did not state any criteria (18,19). In almost all studies, the mode of exercise during the maximal test was the same as during exercise training. The exceptions were one study that trained with walking or jogging but tested on a cycle ergometer (31) and one study that trained on a cycle ergometer and did not state the mode during testing (18). Several early studies were not included in the analysis because they did not measure $\dot{V}O_{2max}$ but reported improvements in fitness as reductions in heart rate at a fixed submaximal workload or by increases in physical work capacity at a given submaximal heart rate.

The following methods were used to translate the exercise intensity used in training studies to %$\dot{V}O_2R$ units. Some studies reported the intensity as %HRR (2,3,12,14,24,30), and these were assumed to provide equivalent values in %$\dot{V}O_2R$ units (33,34).

Other studies reported the intensity as %$\dot{V}O_{2max}$ (4,7,9,17,19,20,31). In these cases, the intensity percentage was multiplied by the reported mean value of $\dot{V}O_{2max}$ for the subjects to obtain the gross $\dot{V}O_2$ during exercise training in $mL \cdot min^{-1} \cdot kg^{-1}$. %$\dot{V}O_2R$ was then determined by the formula: %$\dot{V}O_2R$ = (gross exercise $\dot{V}O_2$ $-3.5$)/($\dot{V}O_{2max}$ $-3.5$), in which the value 3.5 $mL \cdot min^{-1} \cdot kg^{-1}$ was assumed to be the average resting $\dot{V}O_2$ of the subjects.

One study reported the exercise intensity for different training groups as various speeds of walking (11). Each walking speed was translated to a gross exercise $\dot{V}O_2$ by using the ACSM metabolic equation for walking (15), and this value was converted to a %$\dot{V}O_2R$ as described above.

Some studies reported the exercise training intensity as a % of maximal heart rate (8,25,29), whereas one reported specific heart rates (18). In the latter case, %$HR_{max}$ was calculated by dividing the specified exercise heart rates by an estimate of mean maximal heart rate. Because no age was reported for the subjects in this study, and they were identified to be "university students," a mean age of 20 yr and a maximal heart rate of 200 $beats \cdot min^{-1}$ were assumed for the group. Once exercise intensity was expressed as %$HR_{max}$ for all of these studies, the intensity was converted to %$\dot{V}O_2R$ by using the formula: %$\dot{V}O_2R$ = 1.667(%$HR_{max}$) $-70\%$. This formula was derived from data obtained in a study that evaluated the heart rate/$\dot{V}O_2$ relationship (32). A nearly identical formula was derived from a separate data set by Howley (22). Both Howley and the current authors found that fitness level has only a minimal effect on the relationship between %$HR_{max}$ and %$\dot{V}O_2R$, thus supporting the use of this formula for the conversion of intensities in the current analysis.

## RESULTS

Table 1 presents a summary of the studies that were evaluated, with specific reference to subject demographics, initial or baseline $\dot{V}O_{2max}$, the mode, frequency, duration and overall length of the training program, the reported training intensity, the training intensity translated to %$\dot{V}O_2R$, and the percentage improvement in $\dot{V}O_{2max}$ after training. Fifteen of the 18 studies compared the effects of training at two or three intensities. Within studies, the low-intensity groups generally performed a greater duration or frequency of exercise to accomplish the same total amount of work as did the higher-intensity groups. Between studies, the duration, frequency, and total length of the training programs varied, making comparisons between studies tenuous at best.

A careful examination of Table 1 reveals a clear difference in training response between subjects with baseline $\dot{V}O_{2max}$ values above and below 40 $mL \cdot min^{-1} \cdot kg^{-1}$. These results have been collated in Table 2. Groups with initial $\dot{V}O_{2max}$ values below 40 $mL \cdot min^{-1} \cdot kg^{-1}$ always exhibited significant improvements in $\dot{V}O_{2max}$ after training, even with exercise intensities as low as 28–32% $\dot{V}O_2R$. Groups with mean initial $\dot{V}O_{2max}$ values above 40 $mL \cdot min^{-1} \cdot kg^{-1}$ exhibited an intensity-dependent response, in that those who exercised at intensities below 46% $\dot{V}O_2R$ consistently demonstrated a lack of improvement, whereas those who exercised at intensities above this value consistently experienced improvements in $\dot{V}O_{2max}$. To establish that a threshold

TABLE 1. Summary of low-to-moderate intensity training studies, with reported intensity converted to %$\dot{V}O_2R$.

| Study | *N* | Age | Sex | Initial $\dot{V}O_{2max}$ | Mode | Freq. (*N*/wk) | Duration (min) | Length (wk) | Reported Intensity | %$\dot{V}O_2R$ | % Increase in $\dot{V}O_{2max}$† |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Davies and Knibbs (9) | 9 | 18–38 | M | 50.8 | Cycle | 1, 3 or 5 | 5, 10 or 20 | 8 | 80% $\dot{V}O_{2max}$ | 79 | 3* |
| | 9 | | | 47.0 | | ! | ! | | 50% $\dot{V}O_{2max}$ | 46 | NS |
| | 9 | | | 47.0 | | | | | 30% $\dot{V}O_{2max}$ | 24 | NS |
| Gledhill and Enyon (18) | 8 | 18–22? | M | 39.4 | Cycle | 5 | 20 | 5 | 150 bpm | 55 | 14* |
| | 8 | | | 38.9 | | | | | 135 bpm | 43 | 13* |
| | 8 | | | 41.5 | | | | | 120 bpm | 30 | NS |
| Edwards (12) | 6 | 17–21 | F | 26.2 | Walk | 7 | 15 | 4 | 63% HRR | 63 | 34 |
| | 6 | | | 27.3 | | | | | 47% HRR | 47 | 26 |
| Burke and Franks (8)‡ | 4 | 16–18 | M | 44.6 | Cycle | 3 | 15 | 10 | 85% $HR_{max}$ | 72 | 9* |
| | 4 | | | 44.1 | | | 22 | | 75% $HR_{max}$ | 55 | 9* |
| | 4 | | | 41.4 | | | 35 | | 65% $HR_{max}$ | 38 | NS |
| Kearney et al. (24)‡ | 13 | 17–22 | F | 38.5 | Walk/jog | 3 | 14 | 9 | 65% HRR | 65 | 23 |
| | 14 | | | 38.4 | Walk | | 18 | | 50% HRR | 50 | 14 |
| Blair et al. (4)‡ | 5 | 18–26 | M | 43.5 | Cycle | 5 | 19 | 10 | 80% $\dot{V}O_{2max}$ | 78 | 9 |
| | 8 | | | 43.5 | | | 35 | | 50% $\dot{V}O_{2max}$ | 46 | 8 |
| Badenhop et al. (2) | 14 | 60+ | M/F | 20.6 | Cycle | 3.1 | 25 | 9 | 60% HRR | 60 | 15 |
| | 14 | | | 21.1 | | | | | 38% HRR | 38 | 16 |
| Gaesser and Rich (17)‡ | 7 | 20–30 | M | 43.3 | Cycle | 3 | 25 | 18 | 83% $\dot{V}O_{2max}$ | 81 | 20 |
| | 9 | | | 37.7 | | | 50 | | 45% $\dot{V}O_{2max}$ | 39 | 17 |
| Seals et al. (30) | 11 | 60–69 | M/F | 25.4 | Walk | 4.6 | 27 | 26 | 40% HRR | 40 | 11 |
| Gossard et al. (19)‡ | 23 | 40–60 | M | 32.2 | Jog | 5 | 37 | 12 | 72% $\dot{V}O_{2max}$ | 69 | 17* |
| | 21 | | | 33.3 | Walk/jog | | 52 | | 51% $\dot{V}O_{2max}$ | 45 | 8 |
| Foster et al. (14) | 9 | 67–89 | F | 13.7 | Walk | 3 | 25 | 10 | 60% HRR | 60 | 15 |
| | 7 | | | 12.6 | | | 34 | | 40% HRR | 40 | 13 |
| Hagberg et al. (20) | 16 | 70–79 | M/F | 22.5 | Walk | 3 | 40 | 13 | 60% $\dot{V}O_{2max}$ | 53 | 15 |
| Belman and Gaesser (3) | 8 | 65–75 | M/F | 24.3 | Walk | 4 | 30 | 8 | 75% HRR | 75 | 7 |
| | 9 | | | 25.4 | | | | | 35% HRR | 35 | 7 |
| Duncan et al. (11)‡ | 16 | 20–40 | F | 30.6 | Walk | 5 | 36 | 24 | 8.0 kph | 49 | 16* |
| | 12 | | | 32.4 | | | 45 | | 6.4 kph | 37 | 9 |
| | 18 | | | 31.8 | | | 60 | | 4.8 kph | 28 | 4 |
| King et al. (25)‡ | 77 | 50–65 | M/F | 26.9 | Walk/jog | 3 | 40 | 52 | 81% $HR_{max}$ | 65 | 5 |
| | 74 | | | 27.5 | | 5 | 30 | | 67% $HR_{max}$ | 42 | 4 |
| Probart et al. (29) | 10 | 70+ | F | 21.2 | Walk | 3 | 20 | 26 | 70% $HR_{max}$ | 47 | 8 |
| Suter et al. (31)‡ | 28 | 40 ± 9 | M | 38.1 | Jog | 2.4 | 38 | 26 | 75% $\dot{V}O_{2max}$ | 72 | 8 |
| | 28 | 42 ± 7 | M | 35.3 | Walk | 3.0 | 40 | | 50% $\dot{V}O_{2max}$ | 44 | 7 |
| Branch et al. (7)‡ | 10 | 20–40 | F | 29.2 | Cycle | 3.4 | 39 | 12 | 80% $\dot{V}O_{2max}$ | 77 | 21 |
| | 8 | | | 29.8 | | 3.3 | 62 | | 40% $\dot{V}O_{2max}$ | 32 | 17 |

† All increases are statistically significant except those indicated as "NS".
! Davies and Knibbs used 9 possible combinations of frequency and duration at each intensity.
* Significant difference from lowest intensity group.
‡ Total work between groups was held constant.

training intensity exists, there must be studies that placed subjects at a low intensity and obtained no improvement in $\dot{V}O_{2max}$. Thus, a threshold was found only for groups with mean initial $\dot{V}O_{2max}$ values above 40 $mL \cdot min^{-1} \cdot kg^{-1}$, at approximately 45% $\dot{V}O_2R$.

Table 1 reveals a trend for greater percentage improvements in $\dot{V}O_{2max}$ when training at higher versus lower exercise intensities. Five of the 15 studies that compared two or more progressive intensities found a statistically greater improvement in the higher-intensity group (and three of these five studies controlled the total amount of work between groups). Of the 10 remaining studies, 8 exhibited a nonsignificant greater improvement in the higher-intensity group (and 7 of these 8 studies controlled the total amount of work between groups). If there were no intensity effect, the 10 studies should not show a preponderance of results in the same direction.

## DISCUSSION

The 1957 study by Karvonen et al. (23) is a landmark contribution to the field because it established the use of heart rate reserve for exercise prescription. The authors also observed that intensities below 70% of HRR were ineffective for the development of aerobic fitness in healthy young men. However, only six subjects participated in the experiment, and only three of these trained at an intensity less than 70% of HRR. Moreover, the maximum oxygen consumption of the subjects was not measured. Thus, although the study serves as the foundation for later work, it did not firmly establish a threshold intensity.

TABLE 2. Collation of exercise groups based on initial $\dot{V}O_{2max}$ and training intensity expressed as %$VO_2R$.

| Initial $\dot{V}O_{2max}$ | <30 $mL \cdot min^{-1} \cdot kg^{-1}$ | 30–40 $mL \cdot min^{-1} \cdot kg^{-1}$ | >40 $mL \cdot min^{-1} \cdot kg^{-1}$ |
|---|---|---|---|
| Exercise intensity† (%$\dot{V}O_2R$) | 77 | 72 | 81 |
| | 75 | 69 | 79 |
| | 65 | 65 | 78 |
| | 63 | 55 | 72 |
| | 60 | 50 | 55 |
| | 60 | 49 | 46 |
| | 53 | 45 | 46 NS |
| | 47 | 44 | 38 NS |
| | 47 | 43 | 30 NS |
| | 42 | 39 | 24 NS |
| | 40 | 37 | |
| | 40 | 28 | |
| | 38 | | |
| | 35 | | |
| | 32 | | |

† All training intensities resulted in statistically significant increases in $\dot{V}O_{2max}$, except those noted as "NS".

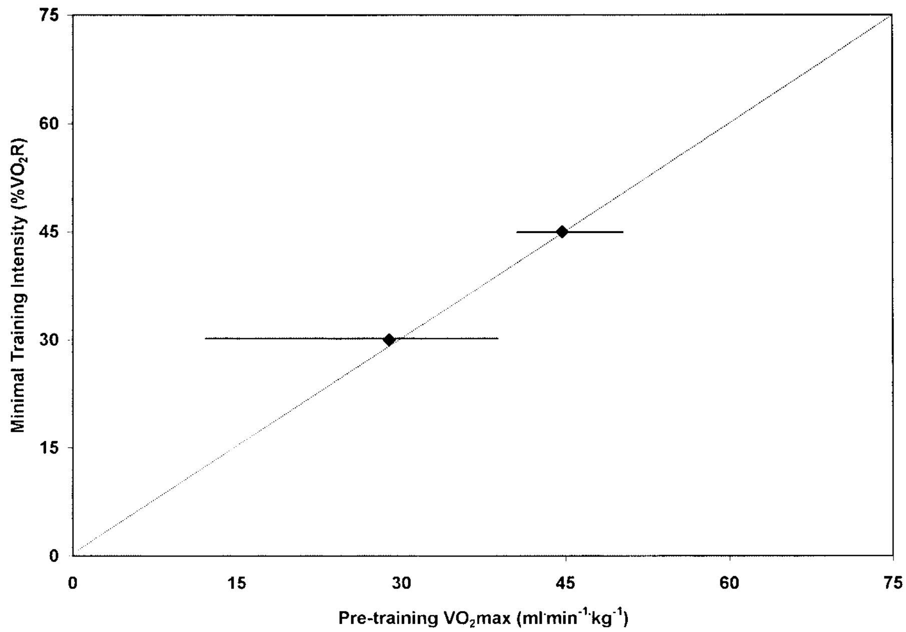


**FIGURE 1—The minimal effective training intensities identified in this analysis for low fit subjects (mean $\dot{V}O_{2max}$ of ~29 mL·min$^{-1}$·kg$^{-1}$, range of mean values from earlier studies 13–39), and moderate-to-high fit subjects (mean $\dot{V}O_{2max}$ of ~45 mL·min$^{-1}$·kg$^{-1}$, range 41–51).**

The current analysis suggests that a threshold intensity may exist at approximately 45% of $\dot{V}O_2$R for individuals who begin training with an aerobic capacity greater than 40 mL·min$^{-1}$·kg$^{-1}$. However, the three studies that reported no improvement in $\dot{V}O_{2max}$ after training (8,9,18) had only four to nine subjects per group. If a greater number of subjects had been tested, statistically significant improvements in $\dot{V}O_{2max}$ may have been attained. Also, if the training regimens had been greater in terms of frequency, duration, or total length, this might have produced greater results. These three studies utilized a total volume of approximately 100 min·wk$^{-1}$ for 5, 8, or 10 wk. However, of the studies which evaluated similarly low intensities in less fit subjects, three used comparable volumes (78, 102, and 120 min·wk$^{-1}$) and overall lengths (8–10 wk) and did achieve statistically significant increases in $\dot{V}O_{2max}$ (2,3,14), lending support to a threshold for the higher fit subjects. Nevertheless, it is difficult from a statistical perspective to have a high degree of confidence in a negative result, i.e., the failure to obtain a significant improvement. Rather than stating that 45% of $\dot{V}O_2$R represents a true threshold for this population, it might be more appropriate to simply state that exercise training above 45% of $\dot{V}O_2$R generally results in improved aerobic capacity. Thus, this training level may be considered the minimal effective intensity for this population of moderate-to-high fit subjects.

No threshold intensity was apparent for less fit subject groups, as all studies using subjects with aerobic capacities less than 40 mL·min$^{-1}$·kg$^{-1}$ found statistically significant increases in $\dot{V}O_{2max}$, regardless of training intensity. However, training intensities below 30% of $\dot{V}O_2$R were not routinely evaluated. It would be accurate to simply state that training intensities of 30% or more of $\dot{V}O_2$R routinely resulted in improved aerobic capacity. This level of training may currently be considered the minimal effective intensity for this population of low fit subjects. Additional research with lower training intensities could revise this value. As illustrated in Figure 1, the minimal effective training intensities identified in this analysis vary in a direct manner with the pretraining aerobic capacity. The trends found in this analysis suggest that severely deconditioned subjects may respond to very low training intensities, whereas highly conditioned subjects may require greater training intensities to produce improvements in $\dot{V}O_{2max}$.

The current analysis of threshold intensities is limited by the indirect means of estimating %$\dot{V}O_2$R values in previous studies. Those studies that reported exercise intensity as a percentage of HRR are likely to be most accurately translated into %$\dot{V}O_2$R values, given the equivalence of these terms. Studies that reported exercise intensity as a percentage of $\dot{V}O_{2max}$ should provide fairly accurate translations into %$\dot{V}O_2$R units, as the only assumption needed to make this conversion is that mean resting $\dot{V}O_2$ for the subjects was 3.5 mL·min$^{-1}$·kg$^{-1}$. The least accurate translations are likely to be for those studies that reported exercise intensity as a specific heart rate, or as a percentage of $HR_{max}$. Nevertheless, even these studies should provide reasonable estimates of the range of intensities in %$\dot{V}O_2$R units, if not precise values. A further limitation in this analysis is that all of the translations of intensity into %$\dot{V}O_2$R units used group mean values. It would be more accurate to convert data from individuals, had such data been available, and report the mean of the resulting intensity translations. Thus, present findings should be considered preliminary until they are confirmed or refuted by training studies that establish exercise intensity in %$\dot{V}O_2$R units.

Previous reviews have concluded that there is a threshold intensity for the improvement of $\dot{V}O_{2max}$ (1,28) but not all reviewers have agreed that a threshold exists (5). Much of the early work supporting a threshold used small sample sizes and did not measure $\dot{V}O_{2max}$ (10,13,23). Of all studies that have supported a threshold, only the three presented in Table 1 measured $\dot{V}O_{2max}$ (8,9,18), and of these, only one expressed the exercise intensity as a percentage of $\dot{V}O_{2max}$ (9). Thus, it is understandable that controversy existed over both the presence of a threshold and the value of that threshold in $\%\dot{V}O_{2max}$ units. The current analysis has established that a reasonable level of support exists for a threshold at 45% of $\dot{V}O_2R$ for subjects of a moderate-to-high initial fitness level (defined here as > 40 $mL \cdot min^{-1} \cdot kg^{-1}$), although it would be prudent to refer to this as an effective minimal training intensity rather than as a threshold *per se*.

If one wishes to compare the $\%\dot{V}O_2R$ recommendations from this analysis with the earlier ACSM $\%\dot{V}O_{2max}$ guidelines, one must recognize that the discrepancy between $\%\dot{V}O_2R$ units and $\%\dot{V}O_{2max}$ units is affected by both aerobic capacity and the intensity of exercise (33,34). This discrepancy is greater for individuals with lower aerobic capacity, and it is greater at lower intensities than at higher intensities. This analysis found that the minimal effective training intensity for subject groups with $\dot{V}O_{2max}$ values below 40 $mL \cdot min^{-1} \cdot kg^{-1}$ was approximately 30% $\dot{V}O_2R$. The average $\dot{V}O_{2max}$ for all of these groups was 28.9 $mL \cdot min^{-1} \cdot kg^{-1}$. Translating the training intensity to $\%\dot{V}O_{2max}$ units yields: $[0.30(28.9 - 3.5) + 3.5]/28.9 = 38\%$ of $\dot{V}O_{2max}$. This value compares favorably with the ACSM's earlier position that 40% of $\dot{V}O_{2max}$ is the threshold for adults with an initially low fitness level (1). This analysis found that the minimal effective training intensity for subject groups with $\dot{V}O_{2max}$ values above 40 $mL \cdot min^{-1} \cdot kg^{-1}$ was approximately 45% $\dot{V}O_2R$. The average $\dot{V}O_{2max}$ for all of these groups was 44.7 $mL \cdot min^{-1} \cdot kg^{-1}$. Translating the training intensity to $\%\dot{V}O_{2max}$ units yields: $[0.45(44.7 - 3.5) + 3.5]/44.7 = 49\%$ of $\dot{V}O_{2max}$. This value compares favorably with the ACSM's earlier position that 50% of $\dot{V}O_{2max}$ is the threshold for most healthy adults (1).

This analysis found fairly strong support for the thesis that training at higher intensities results in greater percentage improvements in aerobic capacity than does training at lower intensities, even when the lower intensity exercise is performed with a sufficient duration to accomplish the same total amount of work (i.e., duration was varied inversely with intensity so that work output was held constant). A preponderance of the 15 studies that compared more than one training intensity found that the higher intensity resulted in either significantly greater gains ($N = 5$) or a trend for greater gains ($N = 8$). Taken together, these results imply that the studies that did not reach statistical significance would have done so if they had used larger sample sizes.

Wenger and Bell (35) evaluated studies that included much higher intensities than those reviewed in the current analysis and concluded that the greatest gains in $\dot{V}O_{2max}$ occur when training is performed at intensities of 90–100% of $\dot{V}O_{2max}$. Due to convergence at very high intensities, 90–100% of $\dot{V}O_{2max}$ is approximately equal to 90–100% of $\dot{V}O_2R$. However, the safety of high-intensity exercise has been challenged, due to the potential for cardiovascular complications (16) and musculoskeletal injury, and because extremely vigorous intensities are likely to discourage participation.

Relative to exercise benefits, increased cardiorespiratory fitness has traditionally been emphasized more than the potential for improved health and disease prevention. Consequently, many lay persons consider exercise as being synonymous with vigorous physical activity, like jogging or running. There are, however, numerous health benefits that can be derived from more moderate exercise intensities, including favorable changes in body composition, bone density, glucose tolerance, and coronary risk factors, as well as a reduction in cardiovascular-related mortality. Thus, it appears that many health benefits of exercise may occur at lower levels or intensities of exercise than are generally prescribed for cardiorespiratory conditioning, especially if the frequency and/or duration of training are increased appropriately.

A critical question, however, is whether higher training intensities evoke greater health benefits when the total amount of work or calories expended is controlled. Results from the Harvard Alumni study suggest an important role for higher intensities (26). Activity performed at intensities below 4 METs ("light") was not associated with a reduction in all-cause mortality, regardless of the total number of calories expended per week, whereas activity performed from 4 to nearly 6 METs ("moderate") was somewhat beneficial, and activity performed at ≥ 6 METs ("vigorous") was highly correlated with reduced mortality. Other studies have suggested that vigorous intensities may not necessarily offer additional advantages in treatment of hypertension (21), and improvements in high-density lipoprotein cholesterol and reduction in fat stores (6). High-intensity exercise may elicit favorable changes in body composition, but if the primary purpose of the training program is to promote reductions in body weight and fat stores, then regimens of greater frequency and duration at moderate intensities are recommended. Although the potential added value of vigorous intensity over moderate or light intensities of exercise is still under debate, recent public health statements (27) suggest that regular, moderate-intensity physical activity, compatible with the minimal effective intensities identified in the present study, provides substantial health benefits.

## CONCLUSIONS

This analysis has found that individuals who begin training with an aerobic capacity greater than 40 $mL \cdot min^{-1} \cdot kg^{-1}$ can expect improvements in $\dot{V}O_{2max}$ by using training intensities of at least 45% of $\dot{V}O_2R$, provided sufficient training frequency and/or duration are employed. Individuals with baseline aerobic capacities below 40 $mL \cdot min^{-1} \cdot kg^{-1}$ obtain improvements in $\dot{V}O_{2max}$ with training intensities as low as 30% of $\dot{V}O_2R$. A further conclusion is that higher intensities of training are generally more effective at improving $\dot{V}O_{2max}$; however, unconventionally vigorous exercise may not be recommended in consideration of injury, cardiovascular complications, and compliance issues.

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