Submaximal markers of exercise intensity

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Numerous approaches have been used to improve the science and art of exercise prescription, and particular challenges exist in the prescription of exercise intensity. Traditionally, work in the area has been the province of exercise physiologists interested in the improvement of training programmes for athletes, as opposed to the more widespread recent interest in health-related fitness and physical activity for all. The generalized approach to the provision of guidelines for exercise prescription has meant that individuals have, at best, prediction equations which provide a wide band of heart rate between which they can work to derive health benefits. This paper explores some of the commonly employed submaximal markers of exercise intensity and proposes a number of approaches for improvements beyond generalized equations.

Keywords: exercise intensity, heart rate, lactate threshold, perceived exertion.

Introduction

In recent years, there has been an increased interest in the physiological and psychological benefits of participation in regular physical activity (Blair et al., 1992; Pate, 1995; US Department of Health and Human Services, 1996). Although public health agencies have helped to foster a groundswell of interest in physical activity by outlining the health benefits of participation, there are still numerous gaps in our understanding of the specifics of exercise prescription. Although considerable work has been undertaken in areas such as cardiac rehabilitation, the gaps in our knowledge are particularly pronounced for some population groups. Recent work has also considered the metabolic bases of potential benefits for sedentary individuals who participate in regular activity, independent of the more traditional cardiovascular (physiological) orientation. The advice in this area is non-specific – for example, to participate in long-duration, low-intensity exercise to improve metabolic fitness (Despres, 1994).

Traditional guidelines for exercise prescription have come from the American College of Sports Medicine (ACSM). Early work in the area was oriented to the improvement of athletic performance through physical fitness (Karvonen et al., 1957) in contrast to the current public health focus on the enhancement of health status. Furthermore, the need to use maximal tests of physiological parameters was stressed in the earlier prescription literature. The realization that maximal testing is not feasible for many individuals and situations has led to an interest in the relevance and application of submaximal measurements. Therefore, exercise intensity is expressed as a percentage of an individual’s measured or predicted maximal oxygen uptake (V\text{O}_2\text{max}), maximal heart rate (HR\text{max}) or heart rate reserve.

Numerous approaches have been used to assess the relevance of, and relationship between, various submaximal markers of exercise intensity. These have included heart rate monitoring, measurement of blood lactate and pH, metabolic equivalent (MET) values, respiratory exchange ratio and rating of perceived exertion. Of particular relevance to exercise prescription for the wider population is the use of non-invasive submaximal markers of exercise intensity. Given the potential health risks associated with over-exertion by sedentary individuals, monitoring heart rate is arguably the best safeguard against cardiac complications and other injuries.

After wider assessments have been undertaken, heart rate monitoring can also assist individuals to work at an intensity that enables progressive overload, maximize the use of a chosen energy system, or enhance body composition. A further advantage is the ability to provide motivational support via instantaneous...
feedback throughout an activity session. The focus of this paper is to consider the relative merits of current guidelines for the prescription of exercise intensity, specifically by considering the usefulness of generalized prediction equations. A further aim is to assess the potential use of selected submaximal markers of intensity to improve exercise prescription.

Exercise intensity: An overview

The specific goals for exercise prescription vary with an individual's interests, needs, background and health status. In all cases, prescription involves the designation of a mode, frequency, duration and intensity of physical activity (ACSM, 1995). Of these parameters, by far the most difficult to prescribe is intensity (Hills and Byrne, 1998). The difficulty arises when one attempts to determine an appropriate starting exercise intensity, and the monitoring and adjustment of prescription remains a challenge over time (Pollock et al., 1995). The perennial question is: At what intensity should one work to gain the desired benefit, be this a specific component of physiological or metabolic fitness? Strategies have included direct measurement of maximal values, a prediction of maximal values from a submaximal test, or the estimation of exercise intensity from generalized prediction equations (Hills and Byrne, 1998). Although a direct determination of a maximal value, for example heart rate, may be the most accurate method, the use of this approach is somewhat controversial. Similarly, predictions from generalized equations may be grossly inadequate. It is difficult to ensure that particular groups (for example, of a given age, sex, fitness level and disability), let alone individuals, receive the necessary exercise advice in safe and scientific terms.

The ACSM, and more recently other health agencies, have provided exercise prescription guidelines for adults. Table 1, adapted from Pollock et al. (1995), outlines the historical trends in prescription with reference to cardiorespiratory and musculoskeletal fitness. These general recommendations have widespread acceptance but their lack of precision has been referenced (Pollock et al., 1995; Hills and Byrne, 1998). There are no specific exercise intensity guidelines for the elderly, the overweight and obese, and other special groups. The authors contend that the lack of specificity in relation to exercise intensity guidelines is a problem that is not limited to particular populations, but holds true for all individuals.

Beyond the generalized equations for exercise intensity, there is a paucity of specific, scientifically based guidelines. What options are available? What are the advantages and disadvantages of the prescription models that are in use? How can these generalized equations be improved to provide a more useful level or threshold of intensity, rather than broad heart rate zones to reflect intensity?

### Table 1 Standards, guidelines and position statements regarding physical activity for adults

<table>
<thead>
<tr>
<th>Year</th>
<th>Frequency</th>
<th>Intensity</th>
<th>Duration</th>
<th>Mode</th>
<th>Weight training</th>
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<tbody>
<tr>
<td>1978 ACSM position statement</td>
<td>3–5 days week⁻¹</td>
<td>60–90% HR&lt;sub&gt;max&lt;/sub&gt;, 50–85% VO&lt;sub&gt;2&lt;/sub&gt;max or HR reserve</td>
<td>15–60 min continuous</td>
<td>Traditional aerobic activities</td>
<td>Not stressed</td>
</tr>
<tr>
<td>1990 ACSM position stand</td>
<td>3–5 days week⁻¹</td>
<td>60–90% HR&lt;sub&gt;max&lt;/sub&gt;, 50–85% VO&lt;sub&gt;2&lt;/sub&gt;max or HR reserve</td>
<td>20–60 min continuous</td>
<td>Aerobic activities</td>
<td>1 set 8–12 reps, major muscle groups, 2 days week⁻¹</td>
</tr>
<tr>
<td>1995 ACSM guidelines</td>
<td>3–5 days week⁻¹</td>
<td>50/60–90% HR&lt;sub&gt;max&lt;/sub&gt;, 40/50–85% VO&lt;sub&gt;2&lt;/sub&gt;max or HR reserve</td>
<td>20–60 min continuous</td>
<td>Aerobic activities (expanded)</td>
<td>1 set 8–12 reps, major muscle groups, 2 days week⁻¹</td>
</tr>
<tr>
<td>1995 AHA exercise standards</td>
<td>Minimum 3 days week⁻¹</td>
<td>50–60% VO&lt;sub&gt;2&lt;/sub&gt;max or HR reserve</td>
<td>Minimum 30 min</td>
<td>Health promotion activities</td>
<td>1 set 10–15 reps, 8–10 exercises, 2–3 days week⁻¹</td>
</tr>
<tr>
<td>1995 CDC/ACSM public health statement /¹</td>
<td>Daily</td>
<td>Moderate</td>
<td>Accumulate 30 min day⁻¹</td>
<td>Health promotion activities</td>
<td>Addressed, not specific</td>
</tr>
</tbody>
</table>

*Note: ACSM = American College of Sports Medicine; AHA = American Heart Association; CDC = Centres for Disease Control and Prevention; VO<sub>2</sub>max = maximal oxygen consumption; HR<sub>max</sub> = maximum heart rate; reps = repetitions. *See Fletcher et al. (1995); †see Pate (1995).
The generalized nature of prescription of exercise intensity

The widespread use of generalized prediction equations has inherent dangers, particularly for certain sub-populations, such as obese and hypertensive individuals, as well as those with cardiovascular disease. The delineation of a threshold of intensity in exercise prescription could help to minimize cardiac, musculoskeletal and psychological complications. More importantly, there are also numerous limitations associated with the routine use of an exercise test that requires an untrained individual to exercise to exhaustion to ascertain a questionable broad window of intensity at which one is encouraged to exercise. The alternative option, the use of equations to predict maximum performance capacity, has consequently gained widespread acceptance, thereby avoiding tests to maximum. Equations to determine maximum heart rate, heart rate reserve or maximal oxygen uptake have been devised, but variation may exist in the heart rate response of individuals of differing levels of body fitness or cardiovascular function. Research concerning the appropriateness of prediction equations derived on normal-weight populations for other populations has been limited. A selection of equations used to predict one variable, maximum heart rate, is presented in Table 2.

Maximal versus submaximal exercise testing to determine exercise intensity

Maximal testing is required to measure maximal values, but submaximal tests can be used to estimate these values. There are two schools of thought regarding the relative merits of maximal testing to determine exercise capabilities. Some believe that all individuals should be tested to maximum; however, others suggest that the risks of testing outweigh the benefits. Furthermore, maximal testing may be contraindicated, as it is impossible for some sedentary individuals to complete and unsafe for others. Brooks et al. (1996) have suggested that maximal tests indicate peak as opposed to maximal values.

Submaximal tests have been devised and modified over a number of years to cater for such concerns, as well as to avoid the high cost of equipment and the time-consuming nature of maximal testing (Porcari et al., 1989). The primary aim of submaximal cardiorespiratory tests is to determine the relationship between an individual’s heart rate response and oxygen consumption during progressive exercise, then to use the relationship to predict $\dot{V}O_2$ max. Heart rate responses to submaximal exercise are based on the incorrect assumption that maximum heart rate is relatively constant among individuals of a particular age. Therefore, the prediction of aerobic power calculated in this manner may be subject to considerable error.

Submaximal physical fitness tests are a low risk when accompanied by appropriate pre-test screening, such as the Physical Activity Readiness Questionnaire. Tests can also be administered safely by qualified personnel in non-medical settings. The ACSM (1995) stated that, 'virtually all sedentary individuals can begin a moderate exercise program safely...'. Although this statement may be true, it may have more relevance if all individuals knew what was meant by 'moderate' intensity, and if this was placed in the context of an individualized exercise intensity or heart rate threshold. Blair et al. (1992) have cited a number of shortcomings in our knowledge of ‘how much physical activity is good for health’. These include the effects of activity on some individual health conditions and the precise dose of activity required for specific benefits. Of particular relevance to the discussion in the present paper is another of the key issues raised by the same group: the role, if any, of intensity of effort.

One prescription is not appropriate for everyone. The ability to individualize prescription, and to account for progressive overload based on dose-response, is of particular relevance. Current public health recommendations for unfit and sedentary adults emphasize the importance of accumulating 30 min of moderate physical activity on most days of the week to gain significant health benefits. If this prescription was followed by such individuals, the volume and intensity of effort may not be enough to enable improvements. A more specific approach may ensure commitment, adherence, safety and satisfaction in the activity completed rather than distaste of physical activity. A generic prescription should not be seen as a panacea for physical activity participation, but as an icebreaker beyond which a submaximal marker such as heart rate is routinely used to guide adjustments in exercise intensity. Perhaps 30 min of physical activity per day should be a goal,
but over and above the non-negotiable work and household duties of a normal day. The opportunity to consider a ‘quick-fix’ in terms of physical activity is not enough. To use an analogy, we already have fast food, we certainly do not need fast exercise!

**Submaximal markers**

Exercise intensity is best quantified using physiological variables such as oxygen consumption, heart rate, rating of perceived exertion or METs. Oxygen consumption is the most commonly used parameter to measure cardiorespiratory function, including one’s response to exercise, but it is not as practical as heart rate monitoring, because exercise prescription on the basis of oxygen uptake requires knowledge of an individual’s $\dot{V}O_2$ max.

If the direct determination of, for example, maximal oxygen consumption is considered unwarranted or impractical for many individuals, and attempts to predict the maximum value and then infer exercise prescription landmarks are similarly lacking, what options are available? These issues are a challenge to the field. An important goal in exercise prescription should be to explore submaximal markers of exercise intensity to improve prescription beyond the generalized equations for training heart rate zones currently in use. Table 3 provides a summary of markers commonly used to establish training zones (to develop cardiorespiratory fitness).

The landmark study of Karvonen et al. (1957) first identified a minimal level of exercise intensity or threshold above which a training effect was possible. Karvonen et al. proposed a threshold of 60% of heart rate reserve. Whereas this threshold may be appropriate for young individuals of average fitness, de Vries (1971) found considerable differences with respect to fitness and age. For example, de Vries suggested that the threshold for men in their 60s and 70s was 40% of heart rate reserve. The heart rate ranges for percentages of $HR_{\text{max}}$ and heart rate reserve at various ages are depicted in Fig. 1. Assuming the limits of these percentages are based on reasonable assumptions, the range is such that it is only necessary to work within a lower and upper margin. Where in the range does one work? It would be extremely useful to be able to advise individuals of a heart rate threshold rather than the general advice of exercising higher in one’s range as fitness improves.

**Heart rate**

With modern technology, heart rate is the easiest of the physiological variables to measure in the field, and $\dot{V}O_2$ and heart rate are closely related and linear over

<table>
<thead>
<tr>
<th>Physiological marker</th>
<th>Training zone</th>
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<tr>
<td>Maximum heart rate</td>
<td>60–90% $HR_{\text{max}}$</td>
</tr>
<tr>
<td>Heart rate reserve (HRR)</td>
<td>50–85% HRR</td>
</tr>
<tr>
<td>Maximal oxygen uptake</td>
<td>50–85% $\dot{V}O_2$ max</td>
</tr>
<tr>
<td>Rating of perceived exertion</td>
<td>12–15 on RPE scale ('somewhat hard' to 'hard')</td>
</tr>
<tr>
<td>Metabolic equivalent</td>
<td>60–70% MET maximum</td>
</tr>
</tbody>
</table>

Table 3 Commonly used markers of exercise intensity to develop cardiorespiratory fitness in adults (ACSM, 1995)
much of the range. There is general agreement that changes in heart rate are more consistent during exercise than at rest, and that there is greater linearity in the relationship between heart rate and $\dot{V}O_2$ when resting values are not included.

Prescription of exercise intensity based on prediction equations of heart rate ($\%HR_{\text{max}}$ and heart rate reserve) are subject to a wide range of variability. For example, the variation in the most commonly used prediction equation ($220 – \text{age}$) has been calculated as $\pm 10 – 12$ beats min$^{-1}$ in normal subjects (ACSM, 1995).

Of particular concern is the wide range provided when one follows the current guidelines. For example, the appropriate range of relative exercise intensity for aerobic conditioning is identified as between 60 and 90% of $HR_{\text{max}}$ (ACSM, 1995). Furthermore, it is suggested that poorly conditioned subjects may respond to a significantly lower intensity of exercise than this. Exercise prescription guidelines for fat loss, rather than aerobic conditioning, are even more general. ‘Low-intensity, long-duration’ exercise is recommended, and emphasis is placed on the expenditure of 1260–2100 kJ per session. Total energy expenditure (regardless of intensity) is of primary importance for fat loss, at least in the short term (Ballor et al., 1990). But the intensity required to maximize both energy expenditure and appropriate metabolic adaptations, which is still able to be tolerated by the relatively untrained individual, has not been determined.

Although the relative intensity of exercise can be addressed through prescription based on a percentage of maximal values, these values may not be the most appropriate measure of endurance capacity, as they are not measures of a level of intensity able to be maintained for prolonged periods of time. It may be more appropriate to measure a submaximal marker of intensity that is related to the level of exercise and may reflect more closely the ability to sustain a given work rate, as well as any changes in exercise capacity.

**Lactate threshold**

The lactate threshold is the work rate at which blood lactate first begins to increase above resting levels. This is in contrast to the anaerobic threshold, which represents the point beyond which there is a rapid rise in blood lactate above about 4 mmol l$^{-1}$. The lactate threshold has also been referred to as the ‘aerobic threshold’ and is used to determine appropriate training intensities (Belman and Gaesser, 1990; Aellen et al., 1993; Casaburi et al., 1995). The lactate threshold is highly correlated with endurance performance, and is independent of $\dot{V}O_2$ max and gender (Tanaka et al., 1990; Evans et al., 1995) and is a trainable physiological variable in both untrained and highly trained individuals (Belman and Gaesser, 1990; Casaburi et al., 1995; Weltman, 1995). Therefore, the lactate threshold is able to provide a submaximal marker of exercise intensity that is relative to the training status of the individual. The lactate threshold may also represent a level of maximal sustainable energy expenditure at a tolerable workload.

An equation to predict the heart rate that corresponds to the lactate threshold may be a practical format to increase the accuracy of submaximal exercise prescription. The effects of various conditions on the heart rate–lactate threshold relationship are not well understood. Therefore, it is unclear whether a single equation would be possible, thereby avoiding the need for population-specific equations.

**Rating of perceived exertion**

Perceived exertion may be described as a psycho-physical measure of an individual’s perception of exercise intensity, commonly expressed in scales such as the Borg 6–20 (Noble et al., 1983; Borg, 1985). The rating of perceived exertion (RPE) is a useful submaximal indicator of intensity because of its relative simplicity. The measure does not require sophisticated equipment, as is the case for physiological variables. Additionally, the RPE response to graded exercise correlates highly with cardiorespiratory and metabolic variables such as $\dot{V}O_2$, heart rate, ventilation and blood lactate concentration (ACSM, 1995). As perceived exertion and heart rate increase as exercise intensity rises, the measurement of one parameter enables the prediction of the other. Some of the shortcomings of the procedure include the subjectivity of the measure and the need for a true relationship between the RPE and heart rate to be known for an individual before RPE can be used accurately. However, once this relationship is understood, individuals may then rely less on heart rate and more on RPE (ACSM, 1995). In this respect, Williams and Eston (1989) have described RPE as a more accurate indicator of intensity than any other single psychological or physiological factor.

In summary, it is reasonable to suggest that the development of predictive equations to define an individual’s threshold for exercise intensity based on age and heart rate, plus ratings of perceived exertion and blood lactate at given work rates, has considerable merit. The derivation of such an equation(s) would take the guesswork out of exercise prescription and enable accurate, safe and efficient levels of intensity at which one could exercise. This would eliminate the need for extensive testing protocols that are unrealistic for most individuals and potentially dangerous for some.
References


