Prediction of maximal heart rate in individuals with mental retardation

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ABSTRACT

FERNHALL, B., J. A. MCCUBBIN, K. H. PITETTI, P. RINTALA, J. H. RIMMER, A. L. MILLAR, and A. DE SILVA. Prediction of maximal heart rate in individuals with mental retardation. Med. Sci. Sports Exerc., Vol. 33, No. 10, 2001, pp. 1655–1660. Purpose: It is well known that individuals with mental retardation (MR), especially those with Down syndrome (DS), have low maximal heart rates (MHR). We evaluated the ability to predict MHR in individuals with MR and DS in comparison with persons without MR. Methods: Subjects completed a maximal exercise test on the treadmill with metabolic and HR measurements. Stepwise multiple regression was used to develop prediction equations for subjects with MR (N = 276; 97 with DS) and without (N = 296) MR, ranging in age from 9–46 yr. Results: Subjects with MR exhibited significantly lower MHR (177 vs 185 beats·min⁻¹) and VO₂peak (33.8 vs 35.6 mL·kg⁻¹·min⁻¹). In subjects with MR, age was a poor predictor of MHR, Y = 189 − 0.59 (age) (R² = 0.30, SEE = 13.8 beats·min⁻¹; P < 0.01), but age was a better predictor for subjects without MR, Y = 205 − 0.64 (age) (R² = 0.52, SEE = 9.9 beats·min⁻¹; P < 0.01). A large sample Z test indicated that these regression coefficients were significantly different (P < 0.01). However, adding DS to the regression improved the prediction for subjects with MR, Y = 210 − (0.56 age) − (15.5 DS) (R² = 0.57; SEE = 11.8 beats·min⁻¹; P < 0.01). Conclusion: MHR can be predicted with similar accuracy in subjects with and without MR, provided DS is accounted for in the equation for the subjects with MR. Key Words: PEAK EXERCISE, PREDICTION FORMULAS

Maximal heart rate (MHR) is an important physiologic variable that is used as a guide to estimate effort and clinical efficacy during exercise tolerance testing (1,12,16). MHR is also used as the basis for exercise prescription (25). MHR is often predicted, and many variables influence peak values. These include type of exercise, fitness level, gender, and body composition, although age is the most important factor (13,17). The formula 220 − age is probably the most commonly used. However, it produces a conservative estimate of MHR (1).

Although not generalized across the population, the majority of individuals with mental retardation (MR) have low maximal heart rates during all forms of exercise tolerance testing (7–10,22,23), and they also exhibit low levels of cardiovascular fitness (8,22). Individuals with Down syndrome (DS) exhibit more exacerbated reductions in MHR compared with their peers without DS (8,11,21,22). Typically, individuals with DS show a 20–25% lower than expected MHR, whereas persons with MR without DS typically exhibit 8–12% lower than expected values (8,21). The low MHR of persons with MR cannot be explained by just poor effort during the exercise testing, as these low values are found even in the presence of objective criteria for maximal effort (8,10).

The reduction in maximal heart rate observed in individuals with MR, with or without DS, creates a practical problem for exercise and fitness professionals. The standard formula of 220 − age significantly overpredicts maximal heart rate, even though this formula provides a conservative estimate of MHR. Thus, standard exercise prescriptions that use age-predicted MHR are inaccurate in populations with MR. This can be of great concern, because physical fitness and work capacity are related to both vocational productivity and to early institutionalization in this population (6,14,22). In addition, individuals with MR are typically not physically active on their own, but need structured, supervised programs to improve physical fitness (20,24). Consequently, exercise prescriptions are important for this population and are often implemented by practitioners with limited exercise backgrounds who rely on standard exercise prescriptions on the basis of predicted MHR.

Exercise testing can enhance the exercise prescription and be used to guide and monitor improvement in physical fitness (1). In most fitness environments, maximal exercise testing is not feasible and submaximal tests are commonly used instead. Submaximal tests are also safer than maximal tests; thus, they can offer an attractive alternative for populations with disabilities (20,22). However, the most
commonly used submaximal tests rely on the relationship between submaximal heart rate and work rate, and maximal capacity is calculated by extrapolating the submaximal values to a theoretical value corresponding to predicted MHR (1). These tests overestimate the work capacity of persons with MR, especially those with DS, largely because of the lower MHR in this population (3,22).

In nondisabled populations, predicted MHR is used as a guide to estimate exertional levels and effort during maximal exercise tolerance testing, in order to improve sensitivity (1). In addition, determinations of chronotropic incompetence is derived from predicted compared with observed MHR (12). Considering that there has been a trend toward deinstitutionalization over the past 30 yr (20), most individuals with MR live in the community, and the most common form of chronic disease in this population is cardiovascular disease (14). Thus, in the future it is likely that community and specialty physicians will see more patients with MR who may need to be evaluated using exercise testing. It would be important for the clinical community to have a more accurate formula for estimating MHR in persons with MR as a guide during such testing.

Considering some of the difficulties of exercise testing and prescription of individuals with MR (discussed above), there is a need for a population-specific formula to estimate MHR in this population. Consequently, the purpose of this study was to develop a prediction equation of MHR for individuals with MR, and to compare the accuracy of prediction with a sample of nondisabled individuals of similar age.

METHODS

Subjects

This was a retrospective multicenter study including six centers in the United States and one in Brazil. For subjects with MR, centers were selected if they had followed the procedures described by Fernhall and Tymeson (10) and Pitetti et al. (22) for exercise testing of individuals with MR. Individual exercise test records were obtained for each subject, containing descriptive data and the results of the maximal exercise test. All subjects with MR were diagnosed with mild mental retardation, meaning that they had IQ scores between 52 and 70 with deficits in two or more adaptive behaviors as defined by the American Association on Mental Retardation (18). Although all subjects were diagnosed with mild MR, IQ scores were only released for 144 subjects. There were 276 subjects with MR, of which 97 were also diagnosed with DS, between the ages of 9 and 46 yr, with an average age of 21.8 ± 8.4 yr. Subjects were recruited from schools, special summer programs, local group homes, and sheltered workshops. None of the subjects were institutionalized. All subjects received medical clearance to participate in vigorous exercise, and none exhibited medical complications making exercise contraindicated. Furthermore, all subjects were screened for musculoskeletal complications and coordination problems that would interfere with treadmill walking. None of the subjects were taking any medication affecting the heart rate or metabolic response to exercise. Informed consent was obtained from each subject and his or her legal guardian when indicated.

The data for the comparison group were collected from a database of 548 exercise tolerance tests conducted for research purposes on healthy individuals using a treadmill protocol. Metabolic and heart rate data were collected during all these tests. There were 296 subjects (of the total group of 548) within the same age range as the group with MR, and all of these 296 subjects were included in the current study. The average age of this group was 31.1 ± 9.3 yr. All subjects were screened before testing to ensure that they were apparently healthy, and exhibited no signs or symptoms of any cardiac, pulmonary, metabolic, or musculoskeletal disease. None of these subjects were taking any medications that affected their heart rate or metabolic responses to exercise. All subjects signed informed consent before testing.

Test Protocol

Subjects with MR. All of the centers used a familiarization protocol that has been previously described (10,22). Briefly, subjects visit the laboratory on one or more occasions before testing, to become familiarized with the laboratory setting and staff. During these visits, they practiced walking on the treadmill and breathing through a mouthpiece. The treadmill speed at which each individual could comfortably walk was determined during one of these practice sessions. Subjects were tested using a treadmill walking protocol using individualized speed and grade determined on the basis of subject capabilities. The speeds used were between 2.0 and 3.5 mph. The speed was held constant throughout the test and the starting grade was 0% for 1–3 min. The grade was then increased by 2.5–4.0% every 1–3 min depending on the ability of the subject. Tests were terminated because of subject exhaustion manifested by an inability to keep up with the treadmill speed (the subjects were unable to walk close to the front of the treadmill and the test was stopped before they slid off the back). This protocol has been shown to be both valid and reliable for testing individuals with MR of various ages, including those with DS (6,8–10).

Subjects without disabilities. Subjects without disabilities typically visited the laboratory only one time. They were taught to walk on the treadmill and completed a brief period of treadmill walking accommodation before testing. They were then tested using either a modified Bruce protocol or an individualized protocol. The individualized protocol consisted of comfortable jogging (at an individualized pace) for 5 min, followed by 2-min stages, where the speed was increased 1 min·mile⁻¹ for the first two stages. The speed was then held constant and grade was increased 2.5% every 2 min until subjects became too fatigued to continue and could not keep up with the treadmill speed.
Measurements

Oxygen uptake was measured through open circuit spirometer at all study locations. Expired air was collected and analyzed for oxygen, carbon dioxide, and minute ventilation using either a metabolic cart (Beckman MCC, Sensormedics 4400 or Vmax, and Quinton Q-Plex), or through analyzing air collected in meteorologic balloons (Beckman LB-2 carbon dioxide and Beckman OM-11 oxygen analyzers, and Parkinson-Cowan meter). At all study locations, the gas analyzers were calibrated with a known gas, and the volume measurement device was calibrated with a known volume before each test; 1-min averages were used for data analyses.

Heart rate was recorded from 3-, 6-, or 12-lead electrocardiograms or from a heart rate monitor (Polar). Measurements were obtained every minute throughout the exercise test and at peak exercise.

Statistical Analyses

Possible mean differences between individuals with MR and the group without MR were evaluated for all exercise measurements using a one-way ANOVA. To evaluate predictors of maximal heart rate, stepwise multiple regression analyses were used, using heart rate as the dependent variable, and age, body weight, IQ (in the group with MR), gender, and the presence of DS (in the MR group) as possible predictor variables. The multiple regressions were conducted independently on each group, as the group without disabilities was used as a comparison group to evaluate the possible differences in predictability of maximal heart rates between groups. Regression coefficients were compared between groups using a large sample Z test.

RESULTS

The comparison group was slightly older, taller (168 ± 9 cm vs 161 ± 14 cm), and heavier (75.5 ± 23.6 kg vs 63.5 ± 18.0 kg) than the group with MR (P < 0.05). The mean responses to the exercise tolerance tests are presented in Table 1. All of the maximal responses were significantly higher in the comparison group (P < 0.05).

The scatterplots between age and maximal heart rate are presented in Figure 1. Panel A shows the relationship between age and maximal heart rate for the group with MR, and panel B shows the relationship for the comparison group. The regression coefficient was significantly higher for the comparison group (P < 0.01). See Table 2 for further details.

Table 2. Regression equations.

For individuals with MR:

\[ HR_{\text{max}} = 189 - 0.59 \times \text{age} \]  
\[ R = 0.30, \text{SEE} = 13.8, P < 0.01 \]

For individuals without MR:

\[ HR_{\text{max}} = 205 - 0.64 \times \text{age} \]  
\[ R = 0.52, \text{SEE} = 9.9, P < 0.01 \]

\[ HR_{\text{max}} \] is maximal heart rate; DS, Down syndrome.
TABLE 3. Mean measured and predicted maximal heart rate.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Subjects with MR</th>
<th>Subjects without MR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured maximal HR</td>
<td>177 ± 14.6</td>
<td>185 ± 11.5*</td>
</tr>
<tr>
<td>Predicted maximal HR</td>
<td>198 ± 8.5</td>
<td>189 ± 9.3*</td>
</tr>
<tr>
<td>(220 – age)</td>
<td>178 ± 8.6</td>
<td>185 ± 5.9*</td>
</tr>
<tr>
<td>Predicted maximal HR</td>
<td></td>
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<tr>
<td>Formulas from Table 2</td>
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* P < 0.05; subjects with MR significantly lower than subjects without MR.

DISCUSSION

This is the first study to develop prediction equations for MHR for individuals with MR and compare the predictability of MHR in this population to a nondisabled comparison group. Our data show that MHR can be predicted with similar accuracy in both populations, but age alone was not a good predictor in the group with MR. By adding the term for DS (Table 2), the explained variance was significantly improved, coupled with a decrease in the standard error of the estimate. With the term for DS, it appears that the strength of the MHR prediction is similar for individuals with and without MR.

The formulas presented in Table 2 show that the predicted MHR of an individual with MR, but without DS, would be between 7 and 9 beats-min\(^{-1}\) lower than the prediction provided by our formula for the group without MR, for individuals between 20 and 40 yr of age. The 220 – age formula would yield an MHR 7–17 beats-min\(^{-1}\) higher for an individual with MR without DS. The predicted MHR for an individual with DS would be 22–24 beats-min\(^{-1}\) lower compared with the group without MR. However, the 220 – age formula would overpredict MHR by 24–32 beats-min\(^{-1}\) for an individual with DS. These comparisons show the importance of developing a specific prediction equation for individuals with MR that account for the presence of DS, as the commonly used formula 220 – age grossly overpredicts MHR for individuals with MR. This is further demonstrated by the mean comparisons of MHR shown in Table 3.

Our data were consistent with previous findings for individuals with MR. Several studies have shown similar MHR and \(\dot{V}O_2\)peak values for individuals with MR, both with and without DS (8,10,11,21,23,26). In fact, the great majority of studies on individuals with MR have shown that this population exhibits low MHR and low \(\dot{V}O_2\)peak values (6,22). Consequently, the fact that our population-specific formula predicts a lower MHR compared with the 220 – age formula for people with MR is consistent with previous reports. Our formula developed on the comparison group is also similar to other formulas reported in previous studies (1,5,12,13,17).

The regression coefficients in our study are slightly lower than what has been reported in some previous investigations. For instance, Sheffield et al. (27) reported a regression coefficient of 0.76 between age and MHR in 95 women between 19 and 69 yr of age. More recently, Fairbarn et al. (5) reported an R value of 0.45 between age and MHR in 95 women between 19 and 69 yr of age. In a large review study, Londeree and Moeschberger (17) found an R value of 0.84 between age and MHR in men and women 5–81 yr of age. Since the age ranges in these studies were much greater than the age range in our study, it is likely that the truncated range in data points contributed to the lower R value in our study. This notion is supported by data from Fairbarn et al.(5), who reported an R value of 0.45 between age and MHR in women between 20 and 49 yr of age, and to our knowledge, no data on subjects with MR over 50 yr of age. Thus, availability of older subjects with MR is a limitation in our study. However, other studies on nondisabled individuals with large sample sizes and large age ranges have found regression coefficients similar to those in the present study (2,12).

The accuracy of prediction was similar in the present study to what is reported in the literature. A 95% confidence
interval of 35–45 beats-min\(^{-1}\) is typically reported (2,12,17,27), which is similar to the 95% confidence interval of 45 beats-min\(^{-1}\) for subjects with MR and 36 beats-min\(^{-1}\) for the nondisabled subjects in our study. It is important to realize that this is a large 95% confidence interval; thus, prediction of MHR is hardly exact. This may be an especially important consideration if the predicted MHR is to be used for exercise prescription. However, there appears to be little difference between the accuracy of predicting MHR between subjects with and without MR.

Maximal heart rate is obviously influenced by the subject’s effort during exercise testing; thus, it is important to ensure that a maximal effort was produced. Most of the early studies on prediction of MHR used standard clinical exercise testing, and did not provide any data on subject effort (4,12,13,17,27). We asked our subjects to continue exercising until they could no longer keep up with the treadmill speed, and it was thus not possible for them to exercise any further. We then used measurements of oxygen uptake as a secondary measure of effort. As shown in Table 1, the mean RER indicates that our subjects reached exhaustion, since an RER if 1.0 or higher, depending on age, has been used to document maximal effort (15). We did not attempt to ensure that each subject reached a plateau in oxygen uptake before stopping the test. Thus, it is probable that some, or many, subjects did not reach a “true” maximal oxygen uptake. It is unlikely that this would invalidate our results because most subjects in our study produced a “maximal effort,” if not a maximal oxygen uptake. The MHR levels exhibited by both the nondisabled group and the group with MR were also very similar to the MHR published in previous studies on subjects of similar age.

Factors other than age and motivation have also been found to affect MHR. Some investigations have found a gender effect (5,27), but others have not (2,17). In the present study, gender did not contribute to prediction of MHR for either group. Other variables such as body weight, activity level, and mode of exercise testing also contribute (17,19). In the present study, body weight was included as a significant predictor of MHR for the nondisabled group, but not in the group with MR. The contribution of body weight was negligible, as it added little to the prediction, and it is easier to predict MHR from age alone unless an additional variable significantly improves the prediction. That was clearly not the case for body weight in our study.

We did not collect information on activity level; thus, we could not evaluate the contribution of this variable. Maximal oxygen uptake is not a good substitute for activity level, because the relationship between MHR and maximal oxygen uptake is probably a reflection of the decline in both variables with age. Within age groups, fitness level has a small but significant effect on prediction of MHR (17), but will usually account for less than a 2-beats-min\(^{-1}\) difference compared with age alone. We tested all subjects using a treadmill; thus, exercise mode did not influence our results.

In summary, this study described the relationship between age and MHR in nondisabled subjects and subjects with MR. As found in previous investigations, age was related to MHR in individuals without disabilities. Our study shows that age is also related to MHR in subjects with MR, but it is not a good predictor of MHR in this population. Adding a term describing the presence or absence of DS significantly improved the prediction of MHR, to where the strength of the relationship and the accuracy of prediction were similar for subjects with and without MR. Thus, the formula provided herein can be used to predict MHR in individuals with MR, between the ages of 8 and 46 yr. The predicted MHR may help as a guide during maximal and submaximal exercise testing, and could provide a basis for exercise prescription when testing is not feasible. However, considering the large 95% confidence interval, cautious use of any predicted MHR is suggested, for individuals both with and without MR.

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