The 220-age equation does not predict maximum heart rate in children and adolescents

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Our primary purpose was to provide maximum heart rate (HR_{max}) values for ambulatory children with cerebral palsy (CP). The secondary purpose was to determine the effects of age, sex, ambulatory ability, height, and weight on HR_{max}. In 362 ambulatory children and adolescents with CP (213 males and 149 females; age range 6–19y; 195 spastic unilateral, 162 spastic bilateral, and five ataxic CP), HR_{max} was measured during a 10-m (Gross Motor Function Classification System [GMFCS] levels I and II) or 7.5 m (GMFCS level III) shuttle run test. The mean HR_{max} was 194 (SD 9.9) beats per minute (bpm), with a 95% prediction interval between 174 and 214 bpm. No associations were found in HR_{max} related to age, sex, ambulatory ability, height, and weight. Since the HR_{max} did not vary with age, equations such as 220-age are not appropriate. When direct evaluation of HR_{max} with exercise testing is not feasible, we suggest the mean value of 194 bpm be considered as an estimate of HR_{max} at the individual level.

Children with cerebral palsy (CP) often have poor cardiorespiratory fitness which may compromise their physical functioning.[1] Since their cardiorespiratory fitness improves with aerobic training,[2–4] such training can be an important component of their rehabilitation. To design an effective exercise prescription, an understanding of the exercise heart rate is important because it is used as an indicator of exercise intensity because of its link with oxygen uptake (energy expenditure) during exercise.[5] The American College of Sports Medicine's latest recommendation for developing and maintaining cardiorespiratory fitness, for example, suggests aerobic exercise be performed at 50 to 85% of an individual's maximum oxygen uptake. Based on recently published data in healthy children, this translates to 72 to 93% of their maximum heart rate (HR_{max}).[5]

Although it has been criticized,[6] the most common method to estimate HR_{max} is the 220-age formula. Even accepting a certain amount of error, it is likely that this method is not valid for predicting HR_{max} for children with CP because the relationship between HR_{max} and age is different for children compared with adults.[6] Since, as noted above, exercise intensity is an essential part of the exercise training recommendations for cardiovascular fitness for children with CP, it is important for clinicians and researchers to have a valid determination of HR_{max}. Therefore, the primary purpose of this study was to provide a range of possible HR_{max} values for ambulatory children with CP. Our secondary purpose was to determine the possible effects of age, sex, ambulatory ability (Gross Motor Function Classification System,[7] [GMFCS] level), height, and weight on HR_{max}.

METHOD

Participants

The dataset (children and adolescents with CP aged 6–19y) consisted of 362 participants (213 males and 149 females; 195 spastic unilateral, 162 spastic bilateral, and five ataxic CP) who took part in an international study on aerobic fitness reference values[8] as well as new data from Quebec City (*n*=47), Canada and the Netherlands (*n*=13). All children were attending a rehabilitation centre or a special school during their time in the study. As per the regulations of the local institutional review boards in each location where data were collected, informed consent was not obtained where this evaluation was part of the standard of care or usual clinical assessments that the child was already receiving. Where this was not the case, that is for the Quebec data, the project was approved by the local institutional review board and informed consent was obtained from the parent and assent from the participant.

Anthropometry

Body mass and height were measured using standardized procedures.[7] The body mass index (BMI) was calculated as body mass in kilograms divided by height in meters.[2] Physical characteristics are summarized in Table I.

Maximum heart rate

HR_{max} was determined using a progressive exercise test. All participants wore a portable heart rate monitor and performed a 10-m shuttle run test (SRT-I and SRT-II) if they were classified at GMFCS level I and II or a 7.5m SRT (SRT-III) if they were classified at GMFCS level III. Both tests are reliable and valid for these children.[9,10] The tests require participants to walk or run at increasingly faster speeds[9,10] between two markers delineating a 7.5 or 10 m course. Pace is set by an auditory signal from a pre-recorded compact disk. All children were instructed to walk or run until exhaustion. The test was considered maximal if heart rate at the end was ≥180 beats/min and if the children showed either an unsteady running pattern, sweating, facial flushing, or clear unwillingness to continue running in spite of repeated strong verbal encouragement. The HR_{max} was read from the wrist monitor immediately at the end of the test and recorded on a score form.

Data analyses

The data were analysed using SAS 9.2 software (SAS OnlineDoc 9.2; SAS Institute Inc. 2009, Cary, NC, USA). Descriptive statistics (mean, range and standard deviation) summarized the data. To determine the association of HR_{max} with age, sex, height, weight, and GMFCS level, linear regression models were used. All possible sub-models were fit. The best model was selected according to Mallows' C_p statistic.[11] This method, which takes into consideration the number of possible predictor variables, allows one to select the model that best fits the data. Approximate residual normality and homoscedasticity were also checked. Prediction intervals from this model were compared with the obtained HR_{max} with the formula 220-age. Results with $p<0.05$ were considered significant.

RESULTS

HR_{max} varied from 164 to 221 beats per minute (bpm), with an mean (SD) of 194 (SD 9.9). The best model had no predictor variables. The prediction equation 220-age is inside the 95% prediction interval (174–214bpm) 99% of the time. However, its value is always higher than the mean prediction given by the selected model (Fig. 1).

What this paper adds

- This paper provides clinicians and researchers with a range of possible HR_{max} values for ambulatory children with CP.

DISCUSSION

Our primary purpose was to provide a range of HR_{max} values for ambulatory children with CP. Using a large sample of children classified at GMFCS levels I, II, and III (n=362) we found that the mean HR_{max} was 194 (SD 9.9) bpm with a 95% prediction interval of 174 to 214 bpm.

The theoretical upper limit of a healthy heart rate is 220 bpm, since the main limit of HR_{max} is the electrical impulse conduction time through the atrioventricular node (maximum conduction of 220 action potentials per minute).[12] We found no differences in HR_{max} related to sex, height, weight, GMFCS level, or age. Our HR_{max} values are comparable with those recently reported in typically developing children during treadmill testing (197bpm [SD 8]).[13]

Three children had HR_{max} values of <180 bpm at their measurement. As discussed by Verschuren et al.[10] some children can show a significantly higher HR_{max} and above 180 bpm during a second measurement. Clearly, more information is needed on the effect of a habituation session before the actual test.

The data used in the present study were collected in rehabilitation centers or schools for special education. This situation may have led to selection bias towards children who require rehabilitation services. Thus it is possible that our HR_{max} results are an underestimation of the results for children with CP with very minor physical impairment. Assuming these children closely resemble typically developing children, however, the conclusion that the equation 220-age does not predict their HR_{max} may very likely apply to them, as this finding is already known for typically developing children.[6]

Table I: Participant characteristics

	Ambulatory ability														
	GMFCS level I					GMFCS level II					GMFCS level III				
	Mean	SD	Min	Max	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max	n
Males															
Maximum heart rate	194.5	10.0	172.0	219.0	150	192.6	10.2	181.0	216.0	52	192.4	5.3	184.0	200.0	11
Age (y)	11.8	2.8	6.0	18.8	150	12.3	3.5	6.7	19.0	52	11.5	2.9	7.0	16.0	11
Height (cm)	149.4	16.5	114.0	187.0	150	149.1	20.0	122.0	190.0	52	145.0	11.8	129.0	168.0	11
Weight (kg)	42.7	15.1	18.0	92.0	150	42.0	15.9	22.0	88.0	52	40.7	12.8	24.5	61.0	11
BMI (kg/m^2)	18.6	3.7	12.7	30.8	150	18.2	3.3	13.6	26.5	52	19.1	4.9	13.9	31.1	11
Females															
Maximum heart rate	194.3	10.3	180.0	221.0	96	193.6	9.3	164.0	214.0	51	193.5	19.1	180.0	207.0	2
Age (y)	12.1	3.2	6.0	18.9	96	12.0	2.7	6.4	17.2	51	15.0	1.4	14.0	16.0	2
Height (cm)	148.4	17.7	107.0	181.0	96	140.3	13.7	115.0	178.0	51	161.0	1.4	160.0	162.0	2
Weight (kg)	43.5	16.8	16.0	85.0	96	37.5	12.9	20.0	90.0	51	69.7	21.7	54.3	85.0	2
BMI (kg/m^2)	19.0	4.0	12.2	30.5	96	18.7	4.2	13.0	30.5	51	26.9	8.8	20.7	33.2	2

GMFCS, Gross Motor Function Classification System; BMI, body mass index; SD, standard deviation; Min, minimum; Max, maximum.

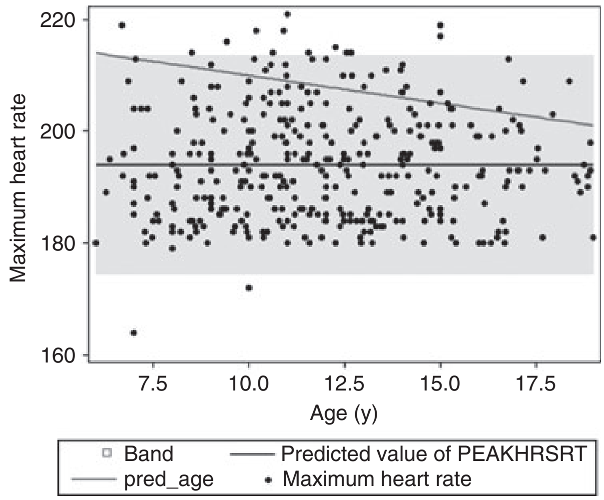

Figure 1: Scatterplot of maximum heart rate in relation to age in children and adolescents with CP. The red line represents the 220-age formula.

According to our findings, if HR_{max} is estimated from the 220-age equation and not determined directly from a progressive exercise test, it is possible that a training intensity too high for the child to maintain might be chosen, especially in younger children. For example, the predicted HR_{max} for a 6-year-old female with CP, based on the 220-age equation, would be 214 bpm. While this value could be possible, based on our data, it is more likely that her HR_{max} would be lower. Assuming a conservative HR_{max} estimate of our mean value of 194 bpm, a training intensity of 85% HR_{max} (an intense but acceptable level) based on a HR_{max} of 214 bpm would result in a training heart rate of 182 bpm, which would, 'in reality' for her, be a training intensity of 94% HR_{max}. Such an error could result in the child being unable to maintain the exercise for a sufficiently long period of time to obtain a training effect or unnecessary discouragement, on the part of the child, parent, or therapist, since the exercise task would appear to be more difficult than what one would expect given the exercise intensity. Although the error could be less at lower intensities (with the above example, a target heart rate of 60% HR_{max} would result in an actual overestimation of only 6%), it could again be a problem even at lower training intensities if the child had HR_{max} lower than our average. For example, if the female in the above example had a HR_{max} of 180 bpm, the error at 60% HR_{max} would be 11%. That is, she could actually be training at a target training heart rate of 71% when the goal was a target of 60% HR_{max}.

While the risk of overtraining is probably greater than the risk of under-training using the 220-age equation, use of our values could result in either an under- or overestimation of the training intensity, since we can provide, at best, only a range of values. For example, a 14-year-old male with CP might really have a HR_{max} of 212 bpm (1SD above the mean) rather than 194 bpm. If one used our mean value of 194 bpm to determine a training intensity for him of 90% HR_{max}, it would be 165 bpm, which would only be 78% of his 'real' HR_{max}. Thus one might not see the gains expected from the training. Given these potential errors, we therefore recommend that, before beginning an exercise training program, the HR_{max} of children with CP be measured directly, with a heart rate monitor, using a progressive exercise test that fits the type of training to be done (e.g. walking/running tests if that is the type of training that will be done). Since exercise training is time-consuming, it is imperative, we believe, that training be as efficacious as possible. Thus if one assumes the child, family, and therapist (or researcher) are investing a minimum of 15 hours in a training program (30min, three times weekly for 10wks), the addition of 30 minutes to perform a progressive exercise test represents only 3% of the total training time. Moreover, tests such as the adapted shuttle run tests for children with CP do not require specialized equipment nor extensive expertise.[9,10]

CONCLUSION

Estimations of HR_{max}, either using an equation such as 220-age or using a large data base such as presented here, may be not precise enough for determining effective aerobic exercise training intensities for individual children with CP. The use of a heart rate monitor to determine the child's HR_{max} during a graded exercise test to exhaustion is optimal when designing exercise programs. When individual heart rate monitoring or exercise testing is not possible for the child with CP, we would suggest using the mean of 194 bpm as an estimate of HR_{max} rather than calculating it using the equation 220-age, as the latter is based on directly measured HR_{max} data for children with CP and the error will likely be less.

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