PERCEIVED EXERTION RELATIONSHIPS
IN ADULTS AND CHILDREN

Submitted by Danielle Lambrick to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Sport and Health Sciences (March, 2010)

This thesis is available for library use on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award a degree by this or any other University.
Acknowledgements

First of all I would like to express my sincere gratitude to my first supervisor, Professor Roger Eston, for his knowledge, dedication and unwavering support throughout my PhD. I am deeply grateful also to my second supervisor, Dr Ann Rowlands, for providing countless valuable suggestions and constructive advice in the course of this thesis. Both Roger and Ann have been instrumental in aiding my academic development, and it is my privilege to have worked alongside them these past few years.

I recognise that this thesis would not have been possible without the help of the volunteers who selflessly participated in each of my research studies. I am extremely grateful to each of you. I would like to thank the parents / guardians for their cooperation in this research to allow each child to participate. I would also like to extend my gratitude to Mrs Alison Turner (Headmistress of Exeter Junior School), Mr Dave Broad (Ladysmith Junior School) and Mrs Sheila Jefferies (Willowbrook Primary School) for their initial interest and support in conducting this research. Furthermore, I am also thankful to all the PhD students who kindly assisted me in data collection over the past 3 years, and to David Childs and Jamie Blackwell for their technical guidance and assistance when any problems arose.

Finally, I am forever indebted to my family and James for their endless love, patience, and understanding. Their encouragement in times of need ensured the successful completion of this thesis, and a relative level of sanity!
Abstract

The ratings of perceived exertion are commonly employed within both a clinical and exercise setting to quantify, monitor and evaluate an individual’s exercise tolerance and level of exertion. Recent advances in the area of perceived exertion have led to novel applications in the use of the ratings of perceived exertion scale as a means of predicting an individual’s maximal functional capacity (\(\dot{V}O_2\)\text{max}) for exercise (Eston, Lamb, Parfitt, & King, 2005; Eston, Faulkner, Mason, & Parfitt, 2006; Eston, Lambrick, Sheppard, & Parfitt, 2008; Faulkner, Parfitt, & Eston, 2007). Yet the utility of such procedures with low-fit individuals or children has received little or no research attention. As such, one aim of this thesis was to assess the efficacy of the ratings of perceived exertion in predicting the \(\dot{V}O_2\)\text{max} of low-fit men and women, and healthy children. It is often presumed that like adults, a child’s perception of exertion rises linearly with increases in exercise intensity, despite a limited amount research suggesting otherwise. Moreover, there is a lack of empirical evidence to suggest that children regulate their power output during a closed-loop exercise task in order to complete a given distance in the fastest time possible. Therefore, a further aim of this thesis was to explore the nature of the perceptual responses of young children across differing modes of exercise, and to examine whether children employ pacing strategies during running. In relation to this latter aim, it was of particular interest to explore pacing in relation to the ratings of perceived exertion during running, as the ratings of perceived exertion have been proposed as a key component of such a regulatory system during exercise (Tucker, 2009).

This thesis comprises a qualitative review of relevant literature, and six study chapters which were borne out of five empirical studies. The findings of studies 1 and 2 (chapters 3 & 4, respectively) support the utility of the ratings of perceived exertion to estimate \(\dot{V}O_2\)\text{max} in low-fit men and women, during cycle ergometry exercise.
Importantly, this has been shown from a single exercise test at a low-moderate exercise intensity, during either a step-incremental (study 1) or ramp-incremental (study 2) protocol. Studies 3 and 4 (chapters 5 & 6, respectively) provide evidence to suggest that a child’s perception of exertion may rise linearly or curvilinearly in relation to increasing work, during either cycle ergometry or treadmill exercise. These studies support the utility of a unique, curvilinear, paediatric ratings of perceived exertion scale in obtaining accurate exertional responses from young children, across differing modes of exercise. In contrast to studies 1 and 2, study 5 (chapter 7) suggests that the novel means of predicting maximal functional capacity from submaximal ratings of perceived exertion in adults is inaccurate with young children. This was particularly evident in the low intraclass correlation coefficients and wide limits of agreement obtained between measured- and predicted $\dot{V}O_{2\text{max}}$, for both cycle ergometry and treadmill exercise. Study 6 (chapter 8) demonstrated that young children employ pacing strategies during an 800 m run, similar to adults, and that this improves with trial familiarisation. Moreover, the presence of other competitors has a detrimental effect on performance, particularly for girls.
## Thesis Content

<table>
<thead>
<tr>
<th>Section title:</th>
<th>Page:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title page</td>
<td>1</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>2</td>
</tr>
<tr>
<td>Abstract</td>
<td>3</td>
</tr>
<tr>
<td>Thesis Contents</td>
<td>5</td>
</tr>
<tr>
<td>List of Tables</td>
<td>15</td>
</tr>
<tr>
<td>List of Figures</td>
<td>17</td>
</tr>
<tr>
<td>Abbreviations</td>
<td>21</td>
</tr>
</tbody>
</table>

### Chapter 1: Introduction
1.1 Summary of thesis

### Chapter 2: Review of Literature
2.1 Perceived Exertion
2.2 Three-effort continua
2.3 Adult Ratings of Perceived Exertion scales
   2.3.1 Borg 6-20 Scale
   2.3.2 Additional ratings scales
2.4 Paediatric Ratings of Perceived Exertion scales
   2.4.1 Children’s effort rating table (CERT)
   2.4.2 Advances in paediatric effort perception
   2.4.3 Novel curvilinear paediatric ratings scale
2.5 Physiological mediators of perceived exertion
   2.5.1 Relationship between RPE and heart rate (HR) in adults
   2.5.2 Relationship between RPE and heart rate (HR) in children
      a Estimation Procedures
      b Production Procedures
      c Evidence for a curvilinear relationship between HR and RPE in children
   2.5.3 Relationship between RPE and absolute oxygen uptake ($\bar{V}O_2$) in adults
      a Relationship between RPE and relative oxygen uptake ($\%\bar{V}O_2$) in adults
   2.5.4 Relationship between RPE and oxygen uptake ($\bar{V}O_2$ & $\%\bar{V}O_2$) in children

---

5
2.5.5 Relationship between RPE and ventilation ($\dot{V}_E$) or respiratory rate (RR) in adults

2.5.6 Relationship between RPE and ventilation ($\dot{V}_E$) or respiratory rate (RR) in children

2.5.7 Relationship between RPE and blood pH, or blood lactate (BLa) in adults

2.5.8 Influence of catecholamines on RPE

2.5.9 Influence of carbohydrate and caffeine on RPE

2.5.10 Influence of temperature on RPE

2.6 Factors affecting the RPE

2.6.1 Influence of Protocol

2.6.2 Influence of training and level of fitness

2.6.3 Influence of gender

2.6.4 Cardiorespiratory and peripheral signals of exertion

2.7 Exercise protocols

2.7.1 Estimation

2.7.2 Production

2.7.3 Estimation-Production

2.7.4 Novel application of the estimation-production procedure

2.8 Repeatability of the RPE

2.9 Perceived exertion and the regulation of performance

2.9.1 Exercise-induced fatigue

2.9.2 Teleoanticipation

2.9.3 Central Governor Model

2.9.4 Pacing strategies

2.9.5 Influence of Feedback

2.10 Thesis Rationale

Chapter 3, Study 1: Prediction of maximal oxygen uptake from the Åstrand-Ryhming nomogram and ratings of perceived exertion

3.1 Abstract

3.2 Introduction

3.2.1 The Åstrand-Ryhming (Å-R) nomogram

3.2.2 The Keele-Lifestyle RPE nomogram

3.2.3 Previous applications of estimation and perceptually-regulated exercise protocols

3.2.4 Purpose and hypotheses
3.3 Method

3.3.1 Participant
3.3.2 General procedures for cycle ergometry testing
3.3.3 Exercise tests
   a Graded exercise test to establish $\dot{V}O_2\text{max}$ (estimation)
   b Perceptually-regulated graded exercise test (production)
   c Modified Åstrand-Ryhming (Å-R) test (incorporating the Keele-Lifestyle RPE procedures)
3.3.4 Data analysis
   a Methodology to predict $\dot{V}O_2\text{max}$ using the RPE
   b Methodology to predict $\dot{V}O_2\text{max}$ using the Åstrand-Ryhming nomogram
   c Methodology to predict $\dot{V}O_2\text{max}$ using the Keele-Lifestyle RPE nomogram
3.3.5 Statistical Analyses
   a Comparison of measured- and predicted $\dot{V}O_2\text{max}$
   b Comparison of absolute and relative exercise intensities between submaximal tests
3.4 Results

3.4.1 Comparison of measured- and predicted $\dot{V}O_2\text{max}$
3.4.2 Comparison of absolute and relative exercise intensities between submaximal tests
3.5 Discussion

3.5.1 Accuracy of $\dot{V}O_2\text{max}$ predictions
3.5.2 Consistency of $\dot{V}O_2\text{max}$ predictions
3.5.3 Limitations of the Keele-Lifestyle RPE nomogram
3.5.4 Methodological considerations when using the Åstrand-Ryhming test and both estimation and production procedures
3.5.5 Extrapolation to theoretical maximal RPE cf. peak terminal RPE
3.6 Conclusion

---

Chapter 4, Study 2: Prediction of maximal oxygen uptake from submaximal ratings of perceived exertion and heart rate during a continuous exercise test: the efficacy of RPE 13

4.1 Abstract
4.2 Introduction
4.2.1 Perceptual and physiological markers of exercise intensity
4.2.2 Considerations for the practical application of the ratings of perceived exertion in predicting maximal functional capacity
4.2.3 Reliability of the RPE provided during estimation and perceptually-regulated exercise protocols
4.2.4 Practical / clinical application of the RPE
4.2.5 Purpose and hypotheses

4.3 Method
4.3.1 Participants
4.3.2 Procedures
4.3.3 Measures
4.3.4 Health assessment
4.3.5 Graded exercise test to establish $\dot{V}O_2$max
4.3.6 Determination of the gas exchange threshold (GET)
4.3.7 Data analysis
   a Prediction of $\dot{V}O_2$max from RPE 13
   b Prediction of $\dot{V}O_2$max from GET
   c Prediction of $\dot{V}O_2$max from HR at RPE 13 and GET
4.3.8 Statistical Analysis
   a Comparison of measured- and predicted $\dot{V}O_2$max
   b Measures of consistency between measured- and predicted $\dot{V}O_2$max
   c Hierarchical regression analysis

4.4 Results
4.4.1 Comparison between GET and RPE 13
4.4.2 Analysis of measured- and predicted $\dot{V}O_2$max
4.4.3 Reliability analyses of measured- and predicted $\dot{V}O_2$max
4.4.4 Hierarchical regression analysis

4.5 Discussion
4.5.1 Physiological cost of exercising at the gas exchange threshold and an RPE 13
4.5.2 Comparison of $\dot{V}O_2$max predictions using theoretical maximal- and terminal RPE
4.5.3 Evaluation of the measures of consistency in predictions of $\dot{V}O_2$max
4.5.4 Efficacy of submaximal ratings of perceived exertion, heart rate and work rate for exercise prescription

4.6 Conclusion
Chapter 5, Study 3: The perceptual response to exercise of progressively increasing intensity in children aged 7 – 8 years: validation of a pictorial curvilinear ratings of perceived exertion scale

5.1 Abstract

5.2 Introduction

5.2.1 Development of linear paediatric RPE scales

5.2.2 Validity of linear paediatric RPE scales

5.2.3 Rationale for a curvilinear paediatric RPE scale

5.2.4 The Eston-Parfitt (E-P) scale of perceived exertion

5.2.5 Purpose & hypotheses

5.3 Method

5.3.1 Participants

5.3.2 Procedures

5.3.3 E-P scale instructions

5.3.4 Graded exercise test (GXT) to $\dot{V}O_2$peak

5.3.5 Data Analysis

a Assessing the nature (curvilinear / linear) of the perceptual response

b Assessing the physiological and perceptual response to increasing exercise intensity

c Regression analysis to assess physiological responses in relation to increasing work rate

d Assessing the relationship between potential mediators of exertional responses

e Further assessment of physiological mediators using hierarchical regression analysis

f Calculation of exponents of the perceptual relationship with increasing work rate

g Select analyses to ensure consistency of the findings

5.4 Results

5.4.1 The characteristics of the perceptual response to increasing cycling work rate

5.4.2 Physiological and perceptual responses to increasing cycling work rate

5.4.3 Further analysis on the physiological responses to increasing cycling work rate

5.4.4 Physiological responses in relation to RPE during cycle ergometry

5.4.5 Physiological mediators of the perceptual response via hierarchical regression
5.4.6 RPE exponents during cycle ergometry 147
5.4.7 Supplementary analyses of consistency 147

5.5 Discussion 148
5.5.1 Changes in the RPE with increasing exercise intensity 149
5.5.2 Physiological mediators of the perceptual response 149
5.5.3 The nature of the perceptual response to cycling exercise in young children 150
5.5.4 Characteristics of the E-P scale 151
5.5.5 Curvilinear RPE responses in past literature 152
5.5.6 Terminal RPE responses of young children 153
5.5.7 Influence of age- and cognitive development 155
5.5.8 Influence of protocol 155
5.5.9 Other methodological implications 156

5.6 Conclusion 157

Chapter 6, Study 4: The perceptual response to treadmill exercise using the Eston-Parfitt Scale and marble dropping task, in children aged 7 – 8 years 159

6.1 Abstract 160

6.2 Introduction 160
6.2.1 Newly devised curvilinear RPE scale 161
6.2.2 Validation of E-P scale 161
6.2.3 Purpose & hypotheses 162

6.3 Method 162
6.3.1 Participants 162
6.3.2 Procedures 163
6.3.3 Graded exercise test (GXT) to \( \dot{V} \) \( \text{O}_2 \) max 163
6.3.4 Data Analysis 165
   a Characteristics of the RPE response 165
   b Physiological and perceptual response to increasing work 166
   c Physiological responses to increasing work rate 166
   d Relationship between physiological variables and perceived exertion 166
   e Hierarchical regression analysis to assess potential physiological mediators of the perceptual response 166
   f RPE exponents using the E-P scale and marble task 166
   g Reliability of the perceptual responses 167

6.4 Results 167
6.4.1 The nature of the perceptual response to increasing work rate 167
6.4.2 Physiological and perceptual responses to increasing work rate 168
6.4.3 Further analysis of physiological responses to increasing work rate 171
6.4.4 Comparison of physiological variables in relation to the RPE 171
6.4.5 Hierarchical regression analysis 171
6.4.6 RPE Exponents 172
6.4.7 Additional analyses 173

6.5 Discussion
6.5.1 Relationships between physiological and perceptual variables 174
6.5.2 Influence of age- and cognitive development on the perceptual response to exercise 175
6.5.3 Exponential nature of perceptual responses 175
6.5.4 Terminal ratings of perceived exertion during maximal treadmill exercise 176

6.6 Conclusion

Chapter 7, Study 5: Prediction of maximal oxygen uptake from the ratings of perceived exertion in children, aged 7 – 8 years: efficacy of the Eston-Parfitt RPE scale
7.1 Abstract
7.2 Introduction
7.2.1 Purpose & hypotheses
7.3 Method
7.3.1 Participants
7.3.2 Procedures
7.3.3 Data analysis
7.4 Results
7.4.1 Comparison between measured- and predicted \( \dot{V}O_2 \)max during cycle ergometry
7.4.2 Comparison between measured- and predicted \( \dot{V}O_2 \)max during treadmill exercise
7.4.3 Consistency of \( \dot{V}O_2 \)max predictions
7.5 Discussion
7.5.1 Appraisal of the predictions of \( \dot{V}O_2 \)max using the E-P scale
7.5.2 Implications of the limits of agreement (LoA)
Chapter 8, Study 6: Do children employ pacing strategies during field-based exercise?

8.1 Abstract

8.2 Introduction

8.2.1 Pacing in relation to the theoretical models of fatigue

8.2.2 Pacing in relation to the RPE

8.2.3 Purpose & hypotheses

8.3 Method

8.3.1 Participants

8.3.2 Procedures

8.3.3 Laboratory-based GXT to volitional exhaustion

8.3.4 Field-based exercise tests

8.3.5 Data analysis

a Physical (time), physiological (HR; % HRmax), and perceptual responses across distance

b Comparison of RPE responses at equivalent intensities across conditions (GXT cf. field-trial)

c Comparison of individual- and group responses

8.4 Results

8.4.1 Total time to complete 800 m, across three trials

8.4.2 Split times over 800 m, across three trials

8.4.3 Absolute & relative heart rate over 800 m, across three trials

8.4.4 Ratings of Perceived Exertion over 800 m, across three trials

8.4.5 Physical, physiological and perceptual differences across trials 3 and 4

8.4.6 Comparison of RPE responses across conditions (laboratory GXT cf. Field-based exercise)

8.5 Discussion

8.5.1 The ‘optimal’ pacing strategy

8.5.2 Influence of competition

8.5.3 Physiological and perceptual responses, across trials

8.5.4 Comparison of the ratings of perceived exertion between a laboratory GXT and field-based exercise

8.6 Conclusion

Chapter 9: Discussion

9.1 Main findings of the thesis
9.1.1 The accuracy of the ratings of perceived exertion in predicting maximal oxygen uptake from step-incremental or ramp-incremental exercise protocols

9.1.2 Comparison of the accuracy in predicting maximal oxygen uptake from the ratings of perceived exertion and heart rate

9.1.3 Validation of a ratings of perceived exertion scale, and the evaluation of the nature of perceptual responses during cycling and running exercise, in young children

9.1.4 Physiological mediators of the perceptual response during cycling and running, in young children

9.1.5 The employment of pacing strategies by children during track running

9.1.6 Thesis Summary

9.2 Limitations of the research studies

9.2.1 Limitations of the prediction of maximal oxygen uptake using the ratings of perceived exertion

9.2.2 Methodological concerns
   a Indirect comparison between differing protocols
   b Protocol concerns
   c Participants and sample size

9.3 Future research

9.3.1 Clinical application of the ratings of perceived exertion

9.3.2 The ratings perceived exertion in young children

9.3.3 The development of pacing strategies during exercise

Chapter 10: References

Appendices:

1a Study 1 Information Sheet
1b Study 2 Information Sheet
1c Study 3 Information Sheet (Parent / Guardian)
1d Study 3 Information Sheet (Participant)
1e Study 4 Information Sheet (Parent / Guardian)
1f Study 4 Information Sheet (Participant)
1g Study 6 Information Sheet (Parent / Guardian)
1h Study 6 Information Sheet (Participant)
2a Study 1 Consent Form
2b Study 2 Consent Form
2c Study 3 Consent Form
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2d</td>
<td>Study 3 Assent Form</td>
<td>295</td>
</tr>
<tr>
<td>2e</td>
<td>Study 4 Consent Form</td>
<td>296</td>
</tr>
<tr>
<td>2f</td>
<td>Study 4 Assent Form</td>
<td>297</td>
</tr>
<tr>
<td>2g</td>
<td>Study 6 Consent Form</td>
<td>298</td>
</tr>
<tr>
<td>2h</td>
<td>Study 6 Assent Form</td>
<td>299</td>
</tr>
<tr>
<td>3</td>
<td>General Health Questionnaire</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>Current Health Questionnaire</td>
<td>302</td>
</tr>
<tr>
<td>5</td>
<td>Keele-Lifestyle Nomogram</td>
<td>303</td>
</tr>
<tr>
<td>6</td>
<td>Transformation of $r$ to $Zr$</td>
<td>304</td>
</tr>
<tr>
<td>7</td>
<td>PAR-Q Form</td>
<td>305</td>
</tr>
<tr>
<td>8</td>
<td>ACSM Risk Stratification</td>
<td>307</td>
</tr>
<tr>
<td>9</td>
<td>Health Screening Form</td>
<td>308</td>
</tr>
<tr>
<td>10</td>
<td>Photography Consent / Assent Form</td>
<td>309</td>
</tr>
</tbody>
</table>
List of Tables

Table 3.1. Descriptive statistics, including age (y), height (cm), body mass (kg), percent body fatness (as measured by bioelectrical impedance analysis: BIA), systolic- (SBP; mmHg) and diastolic blood pressure (DBP; mmHg), for men and women. Values are mean ± SD. 86

Table 3.2. Maximal physiological (oxygen uptake: \( \dot{V}O_2 \); heart rate: HR; respiratory exchange ratio: RER), physical (work rate: WR) and perceptual (ratings of perceived exertion: RPE) responses at termination of the graded-exercise test. 94

Table 3.3. The intraclass correlation coefficients (ICC; \( R \)) and 95 % limits of agreement (LoA; ml·kg\(^{-1} \)·min\(^{-1} \)) analysis between measured- and predicted \( \dot{V}O_2\)max (ml·kg\(^{-1} \)·min\(^{-1} \)) for men (n = 11) and women (n = 13). 96

Table 3.4. Comparison between oxygen uptake (\( \dot{V}O_2 \); ml·kg\(^{-1} \)·min\(^{-1} \); % \( \dot{V}O_2 \) maximum), heart rate (HR; b·min\(^{-1} \); % HR maximum) and work rate (WR) recorded at termination of the Åstrand-Ryhming nomogram (Å-R) and at an RPE 13 during both the estimation (EST) and production (PROD) exercise protocols. Values are mean ± SD. 97

Table 4.1. Maximal physiological (oxygen uptake: \( \dot{V}O_2 \); heart rate: HR; respiratory exchange ratio: RER), physical (work rate: WR) and perceptual (ratings of perceived exertion: RPE) responses at termination of the graded-exercise test. 116

Table 4.2. The Intraclass correlations (ICC; \( R \)) and 95 % limits of agreement (LoA). The confidence intervals of the ICC are reported in parentheses. 118

Table 5.1. Coefficients of determination for the relationships (linear; curvilinear) between RPE (E-P scale; marbles) and physiological variables (\( \dot{V}O_2 \); HR; \( \dot{V}E \)) throughout the graded-exercise test. 146

Table 5.2. Total- and partial variance in the RPE response (E-P scale and marble task) that is explained by individual physiological variables (oxygen uptake, \( \dot{V}O_2 \); heart rate, HR; ventilation, \( \dot{V}E \)) using a hierarchical regression model. 148
Table 6.1. Coefficients of determination for the relationships (linear; curvilinear) between RPE (E-P scale; marbles) and physiological variables (\(\dot{V}O_2\); HR; \(\dot{V}E\)) throughout the graded-exercise test.

Table 6.2. Total- and partial variance in the RPE response (E-P scale and marble task) that is explained by individual physiological variables (oxygen uptake, \(\dot{V}O_2\); heart rate, HR; ventilation, \(\dot{V}E\)) using a hierarchical regression model.

Table 7.1. The 95 % LoA between measured- and predicted \(\dot{V}O_2\max\) from an RPE 5 and 7, using either linear (L-RPE 5; L-RPE 7) or curvilinear (C-RPE 5; C-RPE 7) extrapolation, during both cycle ergometry and treadmill exercise. Values are mean ± bias (ml·kg\(^{-1}\)·min\(^{-1}\)).
Figures

List of Figures

Figure legend:

**Figure 2.1.** Borg’s three effort continua: perceptual, physiological and performance. *Note:* Modified from Borg, G. (1998). *Borg’s Perceived Exertion and Pain Scales*, p. 6.

**Figure 2.2.** The Borg 6-20 Rating of Perceived Exertion Scale. *Note:* Modified from Borg, G. (1998). *Borg’s Perceived Exertion & Pain Scales*, p. 31.

**Figure 2.3.** Children’s Effort Rating Table (CERT). *Note:* Modified from Eston et al. (1994). Validity of a perceived exertion scale for children: a pilot study, p. 693.

**Figure 2.4.** Cart and Load Effort Rating scale (CALER). *Note:* Reprinted with permission from Eston et al. (2000). Reliability of effort perception for regulating exercise intensity in children using the Cart and Load Effort Rating (CALER) Scale, p. 390.

**Figure 2.5.** Bug and Bag Effort (BABE) scale. *Note:* Reprinted with permission from Parfitt et al. (2007). Reliability of effort perception using the children’s CALER and BABE perceived exertion scales, p. 50.

**Figure 2.6.** Pictorial Children’s Effort Rating Table (PCERT). *Note:* Reprinted with permission from Yelling et al. (2002). Validity of a pictorial perceived exertion scale for effort estimation and effort production during stepping exercise in adolescent children, p. 161.

**Figure 2.7.** Omnibus (OMNI) cycle scale. *Note:* Reprinted with permission from Robertson et al. (2000a). Children’s OMNI scale of perceived exertion: Mixed gender and race validation, p. 453.

**Figure 2.8.** Eston-Parfitt (E-P) scale. *Note:* Modified from Eston, R.G., & Parfitt, G. (2007). Perceived Exertion. In N. Armstrong (Ed.), *Paediatric Exercise Physiology*, p. 290.

**Figure 2.9.** Linear regression analysis plot demonstrating a prediction of $\dot{V}O_2max$ from an RPE 17 (RPE 9 -17) when extrapolated to the theoretical maximal RPE (20).

**Figure 2.11.** Common types of pacing strategy. Note. Modified from St Clair Gibson et al. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Medicine*, 36, 705-722.

**Figure 2.12.** Time-trial (TT) completion times for two groups; experimental and control. Note. Modified from Mauger et al. (2009a). Influence of feedback and prior experience on pacing during a 4-km cycle time trial, p.453.

**Figure 3.1.** Comparison of measured- and predicted maximal oxygen uptake ($\dot{V}O_2$max; ml·kg$^{-1}$·min$^{-1}$) for each of the six predictive methods, for men. Values are mean ± SD.

**Figure 3.2.** Comparison of measured- and predicted maximal oxygen uptake ($\dot{V}O_2$max; ml·kg$^{-1}$·min$^{-1}$) for each of the six predictive methods, for women. Values are mean ± SD.

**Figure 4.1.** Comparison of measured- and predicted maximal oxygen uptake ($\dot{V}O_2$max; ml·kg$^{-1}$·min$^{-1}$) for each of the seven predictive methods, for women (regression equation: Reg. Eq). Values are mean ± SD.

**Figure 5.1.** Timeline depicting the development of paediatric ratings scales.

**Figure 5.2.** Participant completing the discontinuous graded-exercise test to exhaustion on a cycle ergometer.

**Figure 5.3.** Participant rating his perception of exertion using the marble task, during the graded-exercise test to exhaustion on a motorised treadmill.

**Figure 5.4.** Oxygen uptake ($\dot{VO}_2$; ml·kg$^{-1}$·min$^{-1}$) at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 5.5.** Heart rate (HR; b·min$^{-1}$) at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.
**Figure 5.6.** Ventilation ($\dot{V}_E; \text{L}\cdot\text{min}^{-1}$) at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 5.7.** Ratings of perceived exertion (E-P scale) reported at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 5.8.** Number of marbles reported at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 6.1.** Participant rating his perception of exertion using the E-P scale, during the graded-exercise test to exhaustion on a motorised treadmill.

**Figure 6.2.** Oxygen uptake ($\dot{V}_O_2; \text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) at each exercise stage throughout the treadmill graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 6.3.** Heart rate (HR; b-min^{-1}) at each exercise stage throughout the treadmill graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 6.4.** Ventilation ($\dot{V}_E; \text{L}\cdot\text{min}^{-1}$) at each exercise stage throughout the treadmill graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 6.5.** Ratings of perceived exertion (E-P scale) reported at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 6.6.** Number of marbles reported at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

**Figure 7.1.** Measured- and predicted $\dot{V}_O_2\text{max}$ from an RPE of 5 and 7, using both linear (L-RPE 5; L-RPE 7) and curvilinear (C-RPE 5; C-RPE 7) extrapolation during cycle ergometry. Values are mean ± SD.

**Figure 7.2.** Measured- and predicted $\dot{V}_O_2\text{max}$ from an RPE of 5 and 7, using both linear (L-RPE 5; L-RPE 7) and curvilinear (C-RPE 5; C-RPE 7) extrapolation during treadmill exercise. Values are mean ± SD.

**Figure 8.1.** Participant performing the 800 m run during an individual field trial.

**Figure 8.2.** Participants performing the 800 m run during the group field trial.

**Figure 8.3.** Split times (s) of each 200 m distance, across all field trials (1 to 4). Values are mean ± SD.
FIGURES

Figure 8.4. Total time (s) to complete each 800 m distance, across all field trials (1 to 4). Values are mean ± SD. 201

Figure 8.5. Average heart rate (b·min⁻¹) during each 200 m distance, across all field trials (1 to 4). Values are mean ± SD. 202

Figure 8.6. Average ratings of perceived exertion (RPE; E-P scale) reported for each 200 m distance, across all field trials (1 to 4). Values are mean ± SD. 203
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACSM</td>
<td>American College of Sports Medicine</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>b·min⁻¹</td>
<td>Beats per minute</td>
</tr>
<tr>
<td>BABE</td>
<td>Bug And Bag Effort scale</td>
</tr>
<tr>
<td>BIA</td>
<td>Bioelectrical Impedance Analysis</td>
</tr>
<tr>
<td>CALER</td>
<td>Cart And Load Effort Rating scale</td>
</tr>
<tr>
<td>CERT</td>
<td>Children’s Effort Rating Table</td>
</tr>
<tr>
<td>CR-10</td>
<td>Category Ratio-10 scale</td>
</tr>
<tr>
<td>DBP</td>
<td>Diastolic Blood Pressure</td>
</tr>
<tr>
<td>E-P scale</td>
<td>Eston-Parfitt RPE scale</td>
</tr>
<tr>
<td>GET</td>
<td>Gaseous Exchange Threshold</td>
</tr>
<tr>
<td>GXT</td>
<td>Graded-exercise Test</td>
</tr>
<tr>
<td>HR</td>
<td>Heart Rate</td>
</tr>
<tr>
<td>% HRmax</td>
<td>Heart rate expressed as a percentage of maximal heart rate</td>
</tr>
<tr>
<td>ICC</td>
<td>Intraclass Correlation Coefficients</td>
</tr>
<tr>
<td>L·min⁻¹</td>
<td>Litres per minute</td>
</tr>
<tr>
<td>LoA</td>
<td>Limits of Agreement</td>
</tr>
<tr>
<td>m</td>
<td>Meters</td>
</tr>
<tr>
<td>min</td>
<td>Minutes</td>
</tr>
<tr>
<td>ml·kg⁻¹·min⁻¹</td>
<td>Millilitres per kilogram per minute</td>
</tr>
<tr>
<td>mmHg</td>
<td>Millimeters of mercury</td>
</tr>
</tbody>
</table>
n Sample size

OMNI Omnibus RPE scale

PCERT Pictorial Children’s Effort Rating Table

\( r \) Pearson’s correlation coefficient

\( R \) Intraclass correlation coefficient

\( R^2 \) Coefficient of determination

\( \text{rev} \cdot \text{min}^{-1} \) Revolutions per minute

RPE Ratings of Perceived Exertion

RR Respiratory Rate

s Seconds

SBP Systolic Blood Pressure

SD Standard Deviation

\( \dot{V} \text{CO}_2 \) Volume of Carbon Dioxide

\( \dot{V}_E \) Ventilation

\( \dot{V} \text{O}_2 \) Volume of Oxygen Uptake

\( \dot{V} \text{O}_2\text{max} \) Maximal Oxygen Uptake

\( \dot{V} \text{O}_2\text{peak} \) Peak Oxygen Uptake

\( \% \dot{V} \text{O}_2\text{max} \) Oxygen uptake expressed as a percentage of maximal oxygen uptake

VT Ventilatory Threshold

W Watts

WR Work Rate