

**CONCURRENT AND CONSTRUCT VALIDITY OF THREE ALTERNATIVE
VERSIONS OF THE STANDARD OMNI CYCLE SCALE OF PERCEIVED
EXERTION IN YOUNG ADULT MALES**

by

George Louis Panzak

BSN University of Pittsburgh, 1977

MS University of Pittsburgh, 1989

Submitted to the Graduate Faculty of
School of Education in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

University of Pittsburgh

2012

UNIVERSITY OF PITTSBURGH

SCHOOL OF EDUCATION

This dissertation was presented

by

George Louis Panzak

It was defended on

December 12, 2012

and approved by

Fredrick L. Goss, Associate Professor, Health and Physical Activity

Elizabeth F. Nagle, Associate Professor Health and Physical Activity

Elaine N. Rubinstein, Assistant Professor, Measurement and Evaluation of Teaching

Dissertation Advisor: Robert J. Robertson, Professor Emeritus, Health and Physical Activity

Copyright © by George L. Panzak

2012

CONCURRENT AND CONSTRUCT VALIDITY OF THREE ALTERNATIVE VERSIONS OF THE STANDARD OMNI CYCLE SCALE OF PERCEIVED EXERTION IN YOUNG ADULT MALES

George L. Panzak, PhD

University of Pittsburgh, 2012

Purpose: To examine, (a) both the concurrent and construct validity of three Alternative Adult OMNI-Cycle Scale formats that eliminate the zero category as an exercise response and (b) to determine if the alternative formats identify perceptual signal dominance integration.

Methods: Sixteen young adult males performed four load incremented cycle ergometer tests. Concurrent validity was established by correlating RPE from the three alternative scales with corresponding VO_2 and HR responses. Construct validity was established by correlating RPE from the three alternative scales with RPE from the original scale. Perceptual signal dominance and signal integration were examined by a within subjects three factor ANOVA. All perceptual and physiological data were measured at 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$.

Results: Correlations between RPE (Alt I, II, III) and both VO_2 and HR ranged from $r = 0.81$ to 0.94 ($P < 0.001$). Correlations between RPE (Alt I, II, III) and RPE (Original Scale) ranged from $r = 0.93$ to 0.98 ($P < 0.001$). RPE-Legs were higher ($P < 0.05$) than RPE-Chest for all three Alternative Scales. RPE-Overall did not differ from the mean of RPE-Legs & RPE-Chest.

Conclusion: Findings supported concurrent and construct validity of the three Alternative Adult OMNI-Cycle Scale formats where the zero category was eliminated or represented a resting state and not an exercise response. Both perceptual signal dominance and integration were supported for all three Alternative Scales.

TABLE OF CONTENTS

PREFACE.....	XV
1.0 INTRODUCTION.....	20
1.1 RATIONALE	23
1.2 STATEMENT OF THE PROBLEM.....	26
1.2.1 Research Aims:	26
1.2.2 Research Hypotheses	27
2.0 LITERATURE REVIEW.....	29
2.1 INTRODUCTION	29
2.2 PSYCHOPHYSICS	30
2.3 PERCEIVED EXERTION	32
2.3.1 Effort Continua.....	32
2.3.2 Range Model	34
2.3.3 Peripheral and respiratory-metabolic factors	35
2.3.3.1 Historical development of the two factor model of perceptual mediators	35
2.3.3.2 Physiological mediators	36
2.3.3.3 Final Common Neuro-physiological Pathway.....	38
2.3.3.4 Psychosocial mediators.....	39

2.3.3.5	Exertional symptoms	40
2.3.3.6	Differentiated Perceived Exertion Model	44
2.4	BORG'S DEVELOPMENTAL WORK	47
2.4.1	Borg's RPE Scale	47
2.4.2	Quantitative Semantics	48
2.5	DEVELOPMENT AND VALIDATION OF THE OMNI SCALES	50
2.5.1	Aerobic.....	54
2.5.1.1	Cycle	54
2.5.1.2	Walk/Run.....	55
2.5.1.3	Step	58
2.5.1.4	Resistance Exercise	59
2.6	APPLICATION OF THE OMNI SCALES	61
2.7	INDICES INVOLVING THE OMNI SCALES.....	63
2.8	EXAMPLES OF EXERCISE RELATED PSYCHOPHYSICAL INDICES INVOLVING MEASURES OF PERCEIVED EXERTION.....	64
2.9	SUMMARY	68
3.0	METHODS	70
3.1	SUBJECTS.....	70
3.1.1	Recruitment procedures.....	71
3.1.2	Exclusion criteria.....	71
3.2	POWER ANALYSIS	72
3.3	ADULT OMNI CYCLE SCALES	73
3.4	EXPERIMENTAL DESIGN	76

3.4.1	Orientation Session.....	77
3.4.1.1	Orientation Protocol	78
3.4.1.2	Assessments During Orientation	79
3.4.2	Experimental Trials.....	83
3.4.2.1	Description.....	83
3.4.2.2	Experimental Protocol	84
3.4.2.3	Experimental Variables	86
3.5	DATA ANALYSIS.....	88
4.0	RESULTS	91
4.1	SUBJECT'S DESCRIPTIVE CHARACTERISTICS.....	92
4.2	DESCRIPTIVE RESPONSES.....	92
4.3	AIM 1 - CONCURRENT VALIDITY: THREE ALTERNATIVE ADULT OMNI-CYCLE SCALES.....	96
4.4	AIM 2 - CONSTRUCT VALIDITY: ALTERNATIVES I, II, AND III ADULT OMNI-CYCLE SCALES.....	98
4.5	PERCEPTUAL SIGNAL DOMINANCE: THREE ALTERNATIVE ADULT OMNI-CYCLE SCALES AND ORIGINAL ADULT OMNI-CYCLE SCALE	100
4.5.1	Aim 3 - Signal Dominance.....	100
4.5.2	ANOVA to determine perceptual signal dominance for the Alternative and Original Adult OMNI-Cycle Scales	101
4.6	PERCEPTUAL SIGNAL INTEGRATION	103
4.6.1	Aim 4 - Signal Integration.....	103

4.6.2	ANOVA to determine perceptual signal integration for the Alternative and Original Adult OMNI-Cycle Scales	104
4.7	SUMMARY	106
4.7.1	Aim 1 - Concurrent Validity	106
4.7.2	Aim 2 - Construct Validity.....	106
4.7.3	Aim 3 - Perceptual Signal Dominance: Alternative OMNI-Cycle Scales and Original Adult OMNI-Cycle Scale.	107
4.7.4	Aim 4 - Perceptual Signal Integration: Alternative Adult OMNI-Cycle Scales and Original Adult OMNI-Cycle Scale.....	108
5.0	DISCUSSION	110
5.1	INTRODUCTION	110
5.2	CONCURRENT VALIDITY OF THE THREE ALTERNATIVE VERSIONS OF THE ADULT OMNI-CYCLE SCALE OF PERCEIVED EXERTION	114
5.2.1	Conceptual Background.....	114
5.2.2	Purpose and Hypothesis.....	115
5.2.3	Summary of Research Findings	116
5.2.4	Comparisons with Previous Research	118
5.2.5	Explanatory Mechanisms.....	119
5.2.6	Summary of Findings	120
5.3	CONSTRUCT VALIDITY OF THE THREE ALTERNATIVE ADULT OMNI-CYCLE SCALES OF PERCEIVED EXERTION	121
5.3.1	Conceptual Background.....	121

5.3.2	Purpose and Hypothesis.....	123
5.3.3	Summary of Research Findings	123
5.3.4	Comparison with Previous Research.....	124
5.3.5	Explanatory Mechanisms.....	125
5.3.6	Summary of Findings	127
5.4	DIFFERENTIATED PERCEPTUAL-SIGNAL DOMINANCE:.....	128
5.4.1	Conceptual Background.....	128
5.4.2	Purpose and Hypothesis.....	129
5.4.3	Summary of Research Findings	129
5.4.4	Comparisons with Previous Research	130
5.4.5	Explanatory Mechanisms.....	133
5.4.6	Summary of Findings	135
5.5	DIFFERENTIATED PERCEPTUAL-SIGNAL INTEGRATION:.....	136
5.5.1	Conceptual Background.....	136
5.5.2	Purpose and Hypothesis.....	137
5.5.3	Summary of Research Findings	138
5.5.4	Comparison with Previous Research.....	139
5.5.5	Explanatory Mechanisms.....	140
5.5.6	Summary of Findings	142
6.0	CONCLUSIONS	143
6.1	SUMMARY OF FINDINGS.....	143
6.2	TRANSLATION/APPLICATION:.....	144
6.2.1	Derived perceptual index	144

6.2.2	RPE conversions	146
6.2.3	RPE equivalent to %VO _{2peak} : Methodological advantage	148
6.2.4	Selection of the Alternative Scale Format:.....	149
6.3	LIMITATIONS OF RESEARCH:.....	152
6.4	FUTURE RESEARCH LIST:	153
APPENDIX A		154
APPENDIX B		156
APPENDIX C		168
APPENDIX D		181
APPENDIX E		183
BIBLIOGRAPHY		184

LIST OF TABLES

Table 2-1 Psychosocial Mediators of Perceived Exertion	39
Table 3-1 Random assignment of scale format for the orientation session.	78
Table 3-2 Counterbalanced RPE measurement sequence for the orientation session.	81
Table 3-3 Counterbalanced sequence for scale presentation during experimental trials.....	84
Table 3-4 Counterbalanced RPE measurement sequence for the experimental trials.	87
Table 4-1 Descriptive characteristics for adult males (N = 16)	92
Table 4-2 Physiological and perceptual responses during cycle exercise for the three Alternative Adult OMNI-Cycle RPE Scales and the Original Adult OMNI-Cycle RPE Scale.	93
Table 4-3 Alternative I Adult OMNI-Cycle Scale: Regression analyses of RPE expressed as a	96
Table 4-4 Alternative II Adult OMNI-Cycle Scale: Regression analyses of RPE expressed as a	97
Table 4-5 Alternative III Adult OMNI-Cycle Scale: Regression analyses of RPE expressed as a	97
Table 4-6 Original Adult OMNI-Cycle Scale: Regression analyses of RPE expressed as a function of	98
Table 4-7 Regression analyses: RPE from Alternative I Adult OMNI-Cycle Scale expressed ..	99
Table 4-8 Regression analyses: RPE from Alternative II Adult OMNI-Cycle Scale expressed .	99
Table 4-9 Regression analyses: RPE from Alternative III Adult OMNI-Cycle Scale expressed	99

Table 4-10 Ratings of perceived exertion (RPE-Legs and RPE-Chest) during cycle exercise at 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale (N=16).	101
Table 4-11 Results of the three-factor ANOVA to determine perceptual signal.....	102
Table 4-12 RPE-Overall and the Avg RPE(L,C) at 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ for the three Alternative Adult OMNI-Cycle RPE Scales and the Original Adult OMNI-Cycle Scale (N=16).	103
Table 4-13 Results of the three factor ANOVA to determine perceptual signal	105
Table 5-1 Numerical categories and verbal descriptors for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale.	113
Table A-1 Ratings of perceived exertion (RPE-Legs and RPE-Chest) for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale used to determine signal dominance (RPE-Legs >RPE-Chest) (N=16). Data are marginal means derived from the three-factor ANOVA.....	183
Table A-2 Ratings of perceived exertion (RPE-Legs and RPE-Chest) for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale used to determine signal integration (RPE-Overall=Avg RPE(L,C) (N=16). Data are marginal means from the three-factor ANOVA.....	183

LIST OF FIGURES

Figure 2-1 Robertson's adaptation of Borg's Effort Continua Model (89).	33
Figure 2-2 Robertson's conceptualization of.....	35
Figure 2-3 Physiological Mediators of perceived exertion (89).	37
Figure 2-4 Revised model of perceived exertion by Robertson (76).	43
Figure 2-5 Montage of picture cues for the OMNI perceived exertion scale (89).	51
Figure 2-6 RPE conversions between the OMNI, Borg 6-20 and Borg CR-10 scales (89).	52
Figure 2-7 OMNI-Cycle Scale of perceived exertion for children (88).	53
Figure 2-8 OMNI-Cycle Scale of perceived exertion for adults (84).	55
Figure 2-9 OMNI-Walk/Run Scale of perceived exertion for children (102).	56
Figure 2-10 OMNI-Walk/Run Scale of perceived exertion for adults (101).	57
Figure 2-11 OMNI-Step Scale of perceived exertion for children: (A) Female, (B) Male (81)..	58
Figure 2-12 OMNI-Resistance Scale of perceived exertion for adults (74).	59
Figure 2-13 OMNI Resistance scale of perceived exertion for children (80).	60
Figure 3-1 Original Adult OMNI-Cycle Scale (84).	73
Figure 3-2 Adult OMNI-Cycle Scale Alternative I	74
Figure 3-3 Adult OMNI-Cycle Scale Alternative II	75
Figure 3-4 Adult OMNI-Cycle Scale Alternative III.	76

Figure 4-1 Alternative I Adult OMNI-Cycle Scale: Ratings of perceived exertion (RPE) for the overall body, (RPE-Overall), legs, (RPE-Legs), and chest (RPE-Chest). N: Number of subjects for whom means (\pm SD) were calculated at that power output exercise stage. Data are mean \pm SD.	94
Figure 4-2 Alternative II Adult OMNI-Cycle Scale: Ratings of perceived exertion (RPE) for the overall body, (RPE-Overall), legs, (RPE-Legs), and chest (RPE-Chest). N: Number of subjects for whom means (\pm SD) were calculated at that power output exercise stage. Data are mean \pm SD.	94
Figure 4-3 Alternative III Adult OMNI-Cycle Scale: Ratings of perceived exertion (RPE) for the overall body, (RPE-Overall), legs, (RPE-Legs), and chest (RPE-Chest). N: Number of subjects for whom means (\pm SD) were calculated at that power output exercise stage. Data are mean \pm SD.	95
Figure 4-4 Original Adult OMNI-Cycle Scale: Ratings of perceived exertion (RPE) for the overall body, (RPE-Overall), legs, (RPE-Legs), and chest (RPE-Chest). N: Number of subjects for whom means (\pm SD) were calculated at that power output exercise stage. Data are mean \pm SD.	95
Figure 6-1 Original RPE Conversion Chart (89).	146
Figure 6-2 Revised RPE Conversion Chart for all three Alternative Adult OMNI-Cycle Scales.	147
Figure 6-3 Revised RPE Conversion Chart for Alternative Adult OMNI-Cycle Scale II.	151

PREFACE

To my advisor Dr. Robert J. Robertson, Professor Emeritus of Health and Physical Activity University of Pittsburgh, thank you for providing your unwavering support and generously imparting your renowned expertise to me and throughout this project. To appreciate your professionalism and commitment to furthering the knowledge base and the writing of exercise science, one has to become a student of yours. Thank you for challenging and preparing me for the future as an exercise scientist, as I have truly become a beneficiary of your wisdom.

To the outstanding faculty members of my doctoral committee that include Dr. Fredrick L. Goss, Associate Professor, Health and Physical Activity, Dr. Elizabeth F. Nagle, Assistant Professor FACSM, Health and Physical Activity, and Dr. Elaine N. Rubinstein, Assistant Professor, Measurement and Evaluation of Teaching, University of Pittsburgh. Thank you for offering your invaluable recommendations, expertise, support, and kindness to me and throughout this project.

To Donna Farrell Administrative Assistant, thank you for all your helpful assistance and patience extended to me and throughout this project.

To Alfred Cecchetti, PhD, MSc, MSc IS, eResearchPro, Director Information Management and Business Intelligence, thank you for your invaluable expertise, friendship, and words of support offered to me over the years and throughout this project.

To Dr. Govindasamy Balasekaran, Associate Professor, Physical Education and Sports Science, National Institute of Education, Singapore, thank you for your words of encouragement and support and invaluable expertise extended to me and throughout this project.

To my following friends, thank you for your words of support and encouragement that you extended to me and throughout this project:

To Dr. Nathan T. Davis, Professor and Director of Jazz studies at the University of Pittsburgh, thank you for your inspiration as a world-renowned jazz saxophone artist, but also as a true friend, mentor, and music scholar throughout my student-life at the University of Pittsburgh.

To Dr. James Anthony “Buster” Alston, faculty, University of Pittsburgh, thank you for your enthusiastic friendship and inspiration as an accomplished jazz saxophonist and jazz director throughout my student-life at the University of Pittsburgh.

To Master Curtis Smith, Martial Arts and Self-Defense faculty, University of Pittsburgh, thank you for your words of wisdom and sharing you philosophy of life, as you have been my Sensei and “Mr. Miyagi” throughout my student-life at the University of Pittsburgh.

To William Acheson, Keynote Speaker and former communication faculty member, University of Pittsburgh, thank you for sharing your passion and conviction for the art of public speaking and your encouragement throughout my student-life at the University of Pittsburgh.

To Dr. Lisa Bernardo, faculty, Carlow University, thank you for believing in me and offering your inspiration for giving back to others through a healthy mind, body, and spirit.

To Coach Joseph B. Natoli, former Head Football Coach Morningside Bulldogs, thank you for your guidance and instilling the importance of academics with athletics during my youth as a Morningside Bulldog football player.

To Mr. E. Alex Howson, Assistant Director of Admissions, Carnegie Mellon University and Faculty Emeriti Shady Side Academy, thank you for believing in me and encouraging me to become a doctor during my student-athlete years at Shady Side Academy.

To Dr. Frank Morgan, Superintendent Kershaw County School District, Camden South Carolina, thank you for your loyal friendship and your inspiration of leadership since our student-athlete days at Shady Side Academy.

To Coach Jerry Page, former Head Football Coach, Laurel Valley High School, thank you for believing in me and instilling the meaning of “discipline” and integrity.

To Dr. William J. Kraemer, FACSM, CSCN, FNCSA Professor of Kinesiology, Physiology, and Neurobiology University of Connecticut, Professor of Medicine University of Connecticut School of Medicine, thank you for believing in me and your inspiration of renowned teaching and scientific research in health, medicine, fitness, and sports performance.

To Boyd Epley MEd, CSCS,*D, FNCSA, RSCC*E, Sr. Director Coaching and Special Projects, National Strength and Conditioning Association (NSCA), thank you for believing in me and your inspiration of “Unity” and implementing sports science while winning five National NCAA Division I football championships at the University of Nebraska.

To Richard “Smithy” Smith, Olympic Weightlifting Coach, 1976 Montreal Olympics, thank you for believing in me and the true meaning of a “CHAMPION”.

To Lee Haney, eight-time Mr. Olympia Bodybuilding Champion, thank you for realizing the importance of balancing faith and family with professional bodybuilding while giving back to others.

To Dorian Yates, six-time Mr. Olympia Bodybuilding Champion, thank you for symbolizing the meaning of self-regulating intensity and commitment during exercise.

To Tommy Kono, two-time Gold Medal Olympic Weightlifting Champion, six-time World Olympic Weightlifting Champion, and Mr. World Bodybuilding Champion, thank you for the power of self-coaching and documentation during exercise.

To the late great Gregory Hines, actor, singer, dancer, and choreographer, thank you for your amazing tap dancing talents that will forever inspire others and me across the world. Thank you for graciously offering your gifts of improvisation and rhythm to the world of dance, fitness and sports.

To Buddy Lee, 1992 Olympian and 20-time National Wrestling Champion, thank you for your amazing rope jumping talents that continue to inspire others and me across the world. Thank you for the inspiration of achieving your best and giving back to others through the “flow”- mind, body, and spirit.

To Tom Webster, President Webster’s Fitness Products, Inc., thank you for your valued friendship and humbling support extended to me over the years and throughout this project. Thank you for your inspiration revealed through your passion and commitment in helping young and old to become strong and physically fit.

To Robert Buckanavage, Executive Director, Pennsylvania State Athletic Directors Association (PSADA), thank you for the inspiration drawn from your leadership, passion, and commitment to the profession of Athletic Directors. Thank you for teaching the invaluable life-lessons learned from athletics to your colleagues and the youth of our country.

To Al Borowski, MEd., CSP, Certified Speaking Professional, National Speakers Association (NSA), thank you for your gift of inspiring others to believe in themselves and making a positive difference in their lives through your speaking, communication skills, and commitment in serving others.

To Roberta Rollings, Association Administrator, National Speakers Association (NSA) Pittsburgh, thank you for your genuine interest, acts of kindness, and appreciation for education.

Finally, to my loving family members:

To my loving brother, James Panzak, thank you for being my life-long friend, devoted brother, and providing your words of encouragement and support to me over the years and throughout this project. Thank you for your inspiration as a talented pianist and professional.

To my loving mother, Philomena Margaret Panzak and late father, Kenneth Panzak, thank you for all your sacrifices while working long hours and shifts to pay for my education. Thank you for exposing and teaching the wisdom and benefits of an education, the joy and excitement of sports, and the beauty and grace of music and the performing arts to me. Thank you for raising me with all your love and devotion and realizing the importance of commitment to faith, family, helping others, and chosen profession. Mom and Dad, this one is for you.

To my loving sister-in-laws, Janet Kocan and Mary Jo Kocan, and my loving mother-in-law, Sophie Kocan and late father-in-law, Joseph Kocan, thank you for extending your overwhelming support to me over the years and throughout this project. Thank you for your sense of kindness, generosity, and being my loving extended family. You are all an inspiration to me.

To my loving wife Michaelene, thank you for all your sacrifices and hardships that you endured to help me throughout this project. Thank you for your faith, support, and kindness that you have willingly provided me over the years. Thank you for believing in me, sharing my vision, and realizing the strength of a team effort in achieving goals. Thank you for being my life-long friend, partner, and loving devoted wife. How truly blessed and fortunate I am to have you in my life. Simply stated, without you, this accomplishment would not be possible.

1.0 INTRODUCTION

The purpose of this investigation was to determine the concurrent and construct validity of three alternative versions of the Adult OMNI-Cycle Scale of Perceived Exertion (see Figure 3-1). The rationale underlying this investigation recognizes that certain applications of the original OMNI Scale may present measurement difficulties owing to the presence of a zero perceptual category in the response range. This category acts as an integer in statistical and mathematical calculations. An example of this limitation can be seen in the computation of the Physical Activity Index (PAI) (73,103). The PAI is computed as the product of a rating of perceived exertion (RPE) and a pedometer step count. Using the OMNI Scale, an RPE of zero is expected at extremely low exercise intensities. When an RPE of zero is multiplied by the corresponding pedometer step count, the calculated PAI is zero. According to mathematical principles, any integer multiplied by a zero will produce a zero. This presents obvious statistical limitations when using the OMNI Scale to compute an exertional measure such as the PAI. Weary et al. using the original version of the OMNI Scale, identified this limitation when computing a linear regression equation derived from the PAI that included an RPE of zero (73,103). To the extent that a zero RPE is reported, the utility of the original OMNI Scale to compute a perceptual index may be inappropriate for certain applications.

Another such calculation where the zero category on the OMNI Scale presents computation difficulties is the Exercise Discomfort Index (EDI) (39,89). The EDI is calculated as the product of RPE and a rating of muscle hurt/pain (RMP). Both the OMNI perceived exertion scale and the OMNI muscle hurt/pain scale have a zero category. As such, the derived index will yield a zero if either an RPE or RMP is reported as zero. Other derived indices involving RPE include those used to evaluate training load, training monotony, training strain, and thermal strain (30,31,100). Calculation of these indices could be complicated when a zero rating response from the OMNI Scale is involved.

Thus, there exists a need to modify the standard OMNI Scale format by either eliminating the zero category as a possible exercise response or to specifically link the zero category to a resting (i.e., non-exercise) state. Such a modification would facilitate research and clinical applications of the OMNI Scale where derived indices are computed from perceptual physiological, sensory, psychobehavioral, and/or physical activity variables.

The present investigation examined both the concurrent validity and the construct validity of three alternative Adult OMNI-Cycle Scale formats. The investigation assessed RPE for the overall body (RPE-Overall), legs (RPE-Legs), and chest/breathing (RPE-Chest) using three Alternative Adult OMNI-Cycle Scale formats and the Original Adult OMNI-Cycle Scale. The RPE responses were determined for young adult males performing a load incremented cycle ergometer protocol terminating at peak intensity.

Concurrent validity of the alternative scales was determined by statistically regressing the criterion variables of submaximal oxygen uptake (VO_2), and heart rate (HR) against the concurrent variables of RPE-Overall, RPE-Legs, and RPE-Chest. The RPE used to assess concurrent validity were derived from the three Alternative versions of the Adult OMNI-Cycle

Scale of Perceived Exertion. It was expected that the concurrent variables (i.e., OMNI Scale RPE) would distribute as a positive function of the criterion physiological variables (VO_2 , and HR).

Construct validity was examined by statistically regressing the construct variables of RPE-Overall, RPE-Legs, and RPE-Chest derived from the three conditional (i.e. alternative) Adult OMNI-Cycle Scale formats against RPE (Overall, Legs, Chest) derived from the criterion (Original) Adult OMNI-Cycle Scale. It was expected that the RPE derived from the three conditional (alternative) Adult OMNI-Cycle Scales would distribute as a positive function of RPE derived from the criterion (Original) Adult OMNI-Cycle Scale. Finally, it was expected that RPE would not differ between the Original Adult OMNI-Cycle Scale and the three Alternative Adult OMNI-Cycle Scale formats. Such correlational and factorial findings would establish construct scale validity indicating that the criterion and conditional scales measure the same perceptual construct, i.e. exertional perceptions.

In addition, it would be determined if the differentiated RPE-Legs and RPE-Chest derived from the three alternative Adult OMNI- Cycle Scales were consistent with the two components of the Differentiated Perceived Exertion Model i.e., signal dominance and signal integration. The Differentiated Perceived Exertion Model examines both perceptual signal dominance and signal integration during aerobic exercise (62,76). When applying this model to cycle ergometer responses, it was expected that (1) RPE-Legs would be more intense than RPE-Chest (i.e. signal dominance) and (2) that RPE-Overall would be an average of RPE-Legs and RPE-Chest (i.e. signal integration). The Differentiated Perceived Exertion Model describes rating scale precision where anatomically regionalized perceptual signals (i.e., RPE-Legs, RPE-Chest) can be distinguished from the total body signal (i.e., RPE-Overall).

1.1 RATIONALE

A large body of literature reports that ratings of perceived exertion are valid and reliable subjective measures during exercise (24,25,26,28,61,63). In 1958, Borg, an experimental psychologist working at the University of Stockholm, developed the first rating of perceived exertion (RPE) scale. The Borg RPE Scale consists of 15-response categories ranging from 6 (no exertion) at all to 20 (maximal exertion) and is one of the most commonly used perceived exertion metrics. Subsequent scales developed by Borg include the Category-Ratio (CR-10) Scale, the CR-100 Scale, and the Marks-Borg CR-13 Scale (16,18).

Robertson et al. recognized potential methodical and semantic limitations of the Borg 6-20 and CR-10 RPE scales when applied to children. Consequently, Robertson et al. developed the OMNI pictorial-verbal category scale to assess exertional perceptions of female and male children performing both aerobic and resistance exercise (80,88). Subsequent OMNI RPE Scales were developed for adults. The pictorial descriptors for the child and adult OMNI formats are exercise mode, age, and sex specific (89). A unique property of the OMNI RPE scale is its use of pictorial descriptors that are generally consonant with the activity being performed. While the pictorial descriptors vary among the OMNI scale formats, all formats employ 11 numerical categories (i.e. 0 to 10) (89). A uniform set of verbal descriptors is employed with all adult scale formats and a different uniform set of verbal descriptors is employed with all child formats. Research in multimedia instruction and cognitive load theory supports the rationale for including pictorial descriptors with verbal descriptors and numerical categories in metrics that scale sensory functions (99).

Robertson et al. developed the first OMNI picture system to measure RPE for children and adolescents. These initial studies established concurrent validity of the OMNI RPE Scale for use with male and female children performing cycle ergometer exercise and graded treadmill exercise (83,88,102). In addition, a concurrent and construct research paradigm was employed to validate the Children's OMNI-Step Scale (81). Subsequent investigations by Robertson et al. involving adult subjects demonstrated concurrent and construct validity of various formats of the OMNI RPE Scale for resistance and aerobic exercise (74,84).

Of particular importance to the rationale underlying the present investigation is the study by Robertson et al. (84) to determine the concurrent and construct validity of the Adult OMNI-Cycle Scale of perceived exertion for use by adult women and men performing cycle ergometer exercise. Concurrent validity was established using a correlation/regression analysis that indicated RPE-Overall, RPE-Legs, and RPE-Chest distributed as a positive linear function of both VO_2 and HR ($r = 0.81$ to 0.95 ; $P < 0.01$). A regression analysis was also used to establish construct scale validity. Results of this analysis determined that for both female and male subjects, RPE-Overall, RPE-Legs and RPE-Chest derived from the Adult OMNI-Cycle Scale were positively and linearly related to Borg Scale RPE over a wide range of submaximal power outputs. These findings established construct validity for the Adult OMNI-Cycle Scale ($r = 0.92$ to 0.97 ; $P < 0.01$). In addition, the RPE-Legs was higher ($P < 0.01$) than RPE-Chest at each exercise stage for both genders. This finding was consistent with the Differentiated Perceived Exertion Model. The model predicts that the perceptual signal arising from the legs will be more intense than that arising from the chest, demonstrating signal dominance during cycle ergometer exercise. As a result, the Adult OMNI-Cycle Scale provides precision in distinguishing between anatomically regionalized perceptual signals.

In summary, substantial evidence reported in previous investigations supports the concurrent validity and construct validity of the various mode specific formats of the OMNI RPE Scale for use during cycling, walking/running, stepping and resistance exercise. Validity evidence supports the use of the OMNI Scale by female and male children and adults performing weight bearing and non-weight bearing aerobic exercise and upper and lower body resistance exercise. In addition, the OMNI Scale demonstrates precision in distinguishing between an anatomically regionalized perceptual signal (i.e., RPE-Legs, RPE-Chest) and a total body perceptual signal (i.e., RPE-Overall) when both assessments are made at approximately the same time during aerobic and resistance exercise.

The above described psychometric of the OMNI scale advantages notwithstanding, under selected applications the original scale format may present measurement difficulties owing to the presence of a zero category in the perceptual response range. In some cases the zero category acts as an integer and presents statistical and mathematical limitations when calculating derived indices such as the Physical Activity Index (PAI), and conditioning related indices that measure training load, training monotony, and training strain (31,73,94,103). Thus, there appears to be a need to modify the original Adult OMNI Scale format by either eliminating the zero category as a possible exercise response or to specifically link the 0 category to a resting (i.e., pre- or post-exercise) state.

1.2 STATEMENT OF THE PROBLEM

The purpose of this investigation was to determine both concurrent validity and construct validity of three alternative versions of the Original Adult OMNI-Cycle Perceived Exertion Scale. The investigation also examined perceptual signal dominance and mode of perceptual signal integration using RPE-Overall, RPE-Legs, and RPE-Chest derived from the three alternative Adult OMNI-Cycle Scales of Perceived Exertion.

1.2.1 Research Aims:

1. The first aim of this investigation was to determine concurrent validity of three alternative versions of the Adult OMNI-Cycle Scale of perceived exertion for young males performing load incremented cycle ergometer exercise. This paradigm used RPE-Overall, RPE-Legs, and RPE-Chest responses derived from the three alternative formats of the Adult OMNI-Cycle Scale as the concurrent variables. Oxygen uptake and HR were used as criterion variables. The concurrent validity was examined separately for each alternative OMNI-Cycle Scale.
2. The second aim of this investigation was to determine the construct validity of three alternative versions of the Adult OMNI-Cycle Scale of Perceived Exertion for young adult males performing load incremented cycle ergometer exercise. This paradigm employed the three Alternative Adult OMNI-Cycle Scale formats as the conditional metrics and the Original Adult OMNI-Cycle Scale as the

criterion metric. The RPE-Overall, RPE-Legs, and RPE-Chest served as the construct variables. Construct validity was examined separately for each alternative OMNI Scale.

3. The third aim of this investigation was to determine if the differentiated RPE-Legs and the RPE-Chest derived from the three Alternative Adult OMNI-Cycle Scales (i.e., I, II, III) demonstrated signal dominance ($\text{RPE-Legs} > \text{RPE-Chest}$) as predicted by the Differentiated Perceived Exertion Model.
4. The fourth aim of this investigation was to determine if the undifferentiated RPE-Overall represents an average of the differentiated RPE-Legs and the RPE-Chest determined separately for the three Alternative Adult OMNI- Cycle Scales (i.e., I, II, III) demonstrate signal integration as predicted by the Differentiated Perceived Exertion Model.

1.2.2 Research Hypotheses

It was hypothesized that during load incremented cycle ergometry:

1. a) Oxygen uptake would be positively correlated with RPE-Overall, RPE-Legs, and RPE-Chest when data are derived separately from Alternative Adult OMNI-Cycle Scales I, II, and III.
- b) Heart rate would be positively correlated with RPE-Overall, RPE-Legs, and RPE-Chest when data are derived separately from Alternative Adult OMNI-Cycle Scales I, II, and III.

These responses would establish concurrent measurement validity for the three Alternative Adult OMNI-Cycle Scales for young adult males performing load incremented cycle ergometer exercise.

2. There would be a positive correlation between RPE (Overall, Legs, and Chest) derived separately from the Alternative Adult OMNI-Cycle Scales I, II, and III and the Original Adult OMNI-Cycle Scale.

These responses would establish the construct measurement validity for the three Alternative Adult OMNI-Cycle Scales for young adults performing load incremented cycle ergometer exercise.

3. For the data derived from the Alternative Adult OMNI-Cycle Scales I, II, and III, RPE-Legs would be greater than RPE Chest. These findings would indicate that the three alternative scales identify perceptual signal dominance consistent with the predictions of the Differentiated Perceived Exertion Model.
4. For the data derived from the Alternative Adult OMNI-Cycle Scales I, II, and III, RPE-Overall would not differ from the mean of RPE-Legs and RPE-Chest. These findings would indicate that the three alternative scales identify perceptual signal integration consistent with the prediction of the Differentiated Perceived Exertion Model.

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this investigation was to determine the concurrent and construct validity of three alternative versions of the Adult OMNI-Cycle Scale of Perceived Exertion. The investigation would also examine perceptual signal dominance and mode of perceptual signal integration using RPE-Overall, RPE-Legs, and RPE-Chest derived from the three alternative Adult OMNI-Cycle Scales of Perceived Exertion. The rationale underlying this investigation recognizes that certain applications of the original OMNI Scale may present difficulties owing to the presence of a “0” category in the perceptual response range. This literature review includes the following content: 1) Psychophysics, 2) Perceived exertion, 3) Peripheral (Local) and Respiratory Metabolic (Central) Mediators, 4) Differentiated Perceived Exertion Model, 5) Borg’s Range Model and Borg’s RPE Scale, 6) Quantitative semantics, 7) Development and validation of the OMNI Scales, 8) Application of the OMNI Scales, 9) Indices involving the OMNI Scales, 10) Examples of exercise related psychophysical indices involving measures of perceived exertion, and 11) Summary.

2.2 PSYCHOPHYSICS

The conceptual framework of perceived exertion is embedded in the discipline of psychophysics. Various extrinsic and intrinsic factors such as environmental conditions and muscular skeletal work are known to influence the human sensory experience (62). Human sensory mechanisms involve physiological end organs that determine the intensity of external stimuli. These sensory mechanisms have a unique biological ability to detect subtle changes in our environment. The measurement of the sensory responses to various external stimuli evolved from the study of psychophysics. History credits Aristotle for the classification of the conventional five senses: taste, smell, touch, hearing, and sight (23,47,71,93). Other non-basic senses include the body movement or kinesthetic sense that is mediated through the nervous system. Unlike the basic and non-basic senses, physical effort or exertion is a complex sensory experience that at present cannot be directly linked to a specific cell membrane receptor or nervous system component. The existence or identification of the effort sense continues to interest scientists who study the field of psychophysics. Thus, psychophysics can be used to define and measure the orderly relation between exercise stimuli and effort sensation (62).

In 1860, Gustav T. Fechner founded the area of *classical* psychophysics with his publication of *Elemente der Psychophysik* (62). Fechner and E.H. Weber, another classical psychophysicist, were interested in measuring an individual's ability to identify the presence of a sensory stimulus or a change in that stimulus. They employed indirect experimental methods, recognizing that it was impossible to develop a direct method for measuring human sensation. However, *modern* psychophysics traces its roots to the work of S.S. Stevens in 1930 and focuses on the identification of sensory power functions and scale development (62,96,97). Stevens

would later develop the ratio method of sensory scaling known as magnitude estimation. The fundamental view of modern psychophysics is that humans can describe the magnitude of sensations experienced during presentation of a physical stimulus (15,16,17,62). Modern psychophysics examines the sensory response of an individual as opposed to the stimulus or the change in the stimulus that was the view of classical psychophysics. As a result, the methods of modern psychophysicists lead to the development of scales for measuring the perceptual responses associated with the sensory link between extrinsic factors and physical exercise (15,16,62).

In 1962, Borg defined the perception of exertion as an interactive response that consists of sensory signals from the muscles, skin, and joints together with signals related to fatigue, strain, pressure, and pain (11,13,15). An assumption that evolved from these psychophysical studies regarding the origin of sensory signals of exertion is that these processes are shared in common among all individuals (15,16,62,76). The observed variability of these shared sensory signals lead to the psychometric assumption that humans can function as “measuring instruments” (15,17,18,62). According to Borg, the unique ability of our senses to identify subtle changes of a stimulus through a sensory-perceptual process such as those that occur during physical exercise permits us to scale the sensory response (15,16,17,18,62). Borg later theorized that any observed variation from the general sensory-perceptual process describes an innate limitation for that particular individual. Such individual differences in sensory responses were observed during the development of exponents in the psychophysical power function and are reflected in scales to measure sensation (7,13,16,18,42,62).

The evolution of perceptual scaling that followed these initial psychophysical studies provided methods that mathematically quantify the relation between a physical stimulus (i.e. exercise) and an associated sensory response (i.e. exertion).

2.3 PERCEIVED EXERTION

The perception of physical exertion involves the feelings of effort, strain, discomfort, and fatigue that a person experiences during exercise (16,62,76,89). Since the early collaborative work of Borg, Noble, and Morgan, a number of scales for quantifying the perception of physical exertion have been developed and validated (16,18,62). The scales typically display numerical categories that correspond to the intensity of exertion that is experienced during exercise. This numerical category is termed a rating of perceived exertion, or RPE. The RPE is used by exercise practitioners to quantify an individual's perception of physical exertion during aerobic and resistance exercise (89).

2.3.1 Effort Continua

The theoretical framework that has guided the development of perceived exertion rating scales is based on the functional interdependence of complex sensory and physiological processes during exercise. This rationale led Borg to develop the Effort Continua Model. The model consists of three main effort continua: physiological, perceptual, and performance (8,16). The Effort

Continua Model describes a relation between the exercise performance and both physiological and perceived exertion responses to an exercise forcing function.

The Effort Continua Model was later re-conceptualized by Robertson as illustrated in Figure 2-1. Robertson's version of the Effort Continua Model describes the relation between the physiological demands of exercise performance and the perception of exertion that is associated with the corresponding exercise performance (89). The model predicts that as the intensity

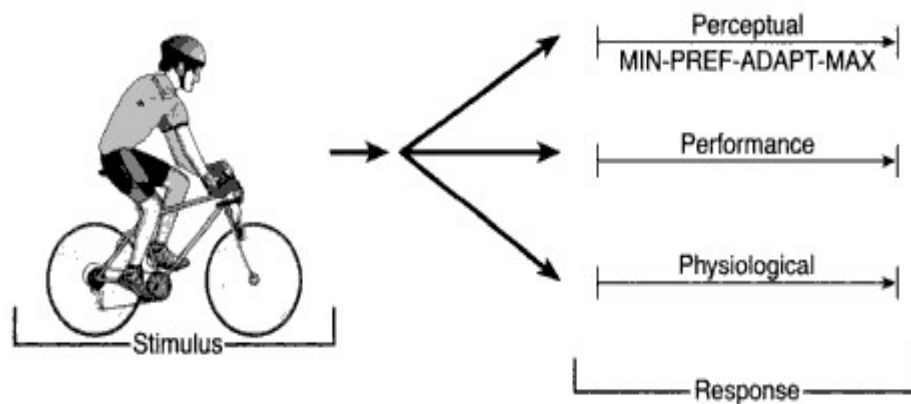


Figure 2-1 Robertson's adaptation of Borg's Effort Continua Model (89).

of exercise performance increases there are corresponding and functionally interdependent changes that occur in both the perceptual and physiological response continua. The interdependence between the three effort continua shows that a perceptual response provides the equivalent information regarding exercise performance as do selected physiological responses (16,89).

2.3.2 Range Model

In an attempt to measure individual differences in perceptual responses, various psychophysical scales have been developed. In addition to category scales, these sensory measurement systems include absolute magnitude estimation, joint scaling, magnitude matching, master scaling, and constrained scaling (16,18,62,95,97). In particular, Borg proposed a method to measure individual differences in perceptual responses based on the Range Model. This model is known as the cornerstone of perceive exertion measurement using category scales. The Range Model provides the basis for individual comparisons of RPE derived from category scales as measured in various exercise settings (11,13,16,18,19,62,75,89).

The model describes a range of intensity changes from a very low to a very high effort. Borg's Range Model employs two important assumptions. First, it is expected that for any given exercise range between rest and maximum, there is a corresponding and equal perceived exertion range. The second assumption maintains that both the RPE range and the intensity of perceptions at low and high exercise levels are equal between individuals regardless of their fitness status. According to Borg's Range Model, comparisons of an individual's exertional perceptions will depend upon their position within the entire dynamic range from minimal to maximal or near maximal intensity. The dynamic range is the same for most individuals. As a result, any RPE can be evaluated in relation to its position in the individual's range and provides the opportunity to compare responses across individuals regardless of changes that may occur within the dynamic range (16,18,62,76,89). These two psychometric assumptions predict that as exercise increases from minimal to maximal intensity, a corresponding and equal increase will occur in perceived exertion response from minimal to maximal levels. As a result, two

individuals determined to be clinically normal will be able to estimate their exertion at 50% of their perceptual response range independent of their aerobic fitness level (Figure 2-2) (62,76,89).

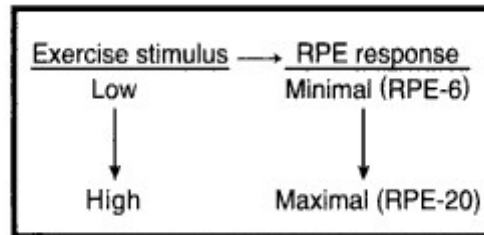


Figure 2-2 Robertson's conceptualization of Borg's Range Model for category Scaling of perceived exertion (89).

2.3.3 Peripheral and respiratory-metabolic factors

2.3.3.1 Historical development of the two factor model of perceptual mediators

For practitioners to effectively apply RPE in various health-fitness and clinical settings it is necessary to understand the underlying physiological, psychological, and symptomatic processes that mediate an individual's exertional perceptions.

Early investigators described two categories of physiological factors that influence RPE i.e. local and central factors. Contemporary terminology has replaced the term local factors with "peripheral mediators". Peripheral mediators are specific to perceptual signals arising from muscles/joints in active limbs and the trunk. The term central factor has been replaced with "respiratory-metabolic mediators". Respiratory-metabolic mediators refer to perceptual signals that arise from the chest and reflect aerobic metabolic and ventilatory functions.

Initial studies by Borg proposed two categories of factors that mediate the perception of exertion during exercise (8,14). These include local and central perceptual signals that arise from peripheral muscles and the circulatory system, respectively. Ekblom and Goldbarg (27,62) refined Borg's concept proposing that the perception of exertion was the result of two broad categories of responses that included local factor arising from muscles/joints and central factors that arise from the cardiopulmonary system. Pandolf (66,68) latter examined the comparative importance of peripheral and respiratory-metabolic responses that mediate the intensity of the perception of exertion during aerobic exercise.

2.3.3.2 Physiological mediators

Robertson et al. subsequently replaced the terms local and central factors with peripheral and respiratory-metabolic mediators, respectively (62,76,89). Robertson classified the physiological factors that mediate perceived intensity of exertion as: 1) peripheral, 2) respiratory-metabolic, and 3) nonspecific (62,76,89). Peripheral physiological mediators are regionalized to the limbs and trunk. Respiratory-metabolic mediators are physiological signals that are linked to ventilatory drive during exercise. Nonspecific mediators are generalized or systemic physiological signals that occur during exercise (62,76,89). The physiological mediators that are linked to the three perceptual signal classes are listed in the Figure 2-3.

In particular, the peripheral physiological mediators are recognized to arise from exercising muscles that are located in the limbs, trunk, and upper torso (76,89). The physiological mechanisms that are considered to influence the peripheral physiological mediators include 1) metabolic acidosis (pH, lactic acid), 2) blood-borne energy substrates (i.e., blood

glucose, free fatty acids, muscle glycogen), 3) blood flow to muscle, and 4) muscle fiber type (i.e., Type I, Type II) are listed in the Figure 2-3 (89).

The second group of mediators are respiratory-metabolic factors that consist of physiological responses known to influence ventilatory drive during dynamic exercise. These physiological responses are 1) pulmonary ventilation, 2) oxygen uptake, 3) carbon dioxide production, 4) heart rate, and 5) blood pressure as listed in Figure 2-3 (89).

The third and final group of physiological factors that mediate the intensity of exertional perception occur during exercise are general or systematic responses identified as non-specific. These physiological responses include 1) hormonal regulation (catecholamines, β -endorphins), 2) temperature regulation (core and skin), 3) pain, 4) cortisol and serotonin, 5) cerebral blood flow and oxygen as listed in Figure 2-3 (89).

Respiratory-Metabolic	Peripheral	Nonspecific
Pulmonary ventilation	Metabolic acidosis (pH, lactic acid)	Hormonal regulation (catecholamines, β -endorphins)
Oxygen uptake	Blood glucose	Temperature regulation (core and skin)
Carbon dioxide production	Blood flow to muscle	Pain
Heart rate	Muscle fiber type	Cortisol and serotonin
Blood pressure	Free fatty acids	Cerebral blood flow and oxygen
	Muscle glycogen	

Figure 2-3 Physiological Mediators of perceived exertion (89).

2.3.3.3 Final Common Neuro-physiological Pathway

The perception of physical exertion experienced during dynamic exercise is a conscious interpretation of neurophysiological signals received by the sensory cortex (89). To meet the demands of increasing exercise intensity, the number of central motor feed-forward commands to peripheral and respiratory skeletal muscles need to increase. Corollary signals branch from these descending motor commands and travel to the sensory cortex. These signals received in the sensory cortex are consciously interpreted and described as the effort sensation. The increase in signal strength of perceived exertion is the result of an increase in these corollary signals secondary to an increase in central motor commands to skeletal muscle. To assist in the refinement of these central motor commands, muscles and joints transmit afferent feedback signals to the sensory cortex (53,76,89). Thus, exertional signals arising from peripheral skeletal muscle in active limbs and trunk as well as respiratory muscles share a common neurophysiological pathway. The previously discussed physiological factors are thought to play a role in regulating the contractile properties of skeletal muscle during dynamic exercise. These physiological factors mediate the intensity of the perceptual signals in direct correspondence to the number of descending motor commands required to activate skeletal muscle (89). Thus, the combination of feed-forward and feedback commands regulates the intensity of exertional perceptions experienced during exercise. These feed-forward and feedback pathways are illustrated in models developed by Cafarelli (21,89) and Gandeivia (34,35,36).

2.3.3.4 Psychosocial mediators

Borg described the contribution of psychological factors in setting the intensity of exertional perceptions. These factors include information processing, learning, and motivation to perform muscular exercise (10,15,62). Morgan (57,58) supported this assumption in initial studies that described the significance of various psychological states and traits on the perception of exertion. In studies using hypnosis, Morgan (55,56) further supported the effect of psychological factors on the perception of physical exertion. The RPE of subjects increased when hypnotic suggestion indicated that they were pedaling up a steep hill during a constant load cycle ergometer test (55,56,76). However, a subsequent study by Kraemer using hypnotic suggestion failed to confirm this finding (43,76). Reports by Morgan et al. (54), Noble and Robertson (76,89) suggest that certain psychological and sociological factors influence exertional perceptions. Table 2-1 lists four broad classifications of psychosocial mediators of exertional perceptions.

Table 2-1 Psychosocial Mediators of Perceived Exertion

Classification	Factor
Emotion or mood	Anxiety Depression Extroversion Neuroticism
Cognitive function	Dissociation Self-efficacy Type A personality
Perceptual process	Pain tolerance Sensory augmentation or reduction Somatic perception
Social or situational	Music Sex of counselor Social setting

Adapted from Morgan (89).

Reports by Morgan (57) and Noble (62) determined that various physiological responses accounted for approximately two thirds of the variance in RPE. Morgan (57) further proposes that the remaining unexplained variance is possibly attributed to various psychological factors. A report by Rejeski (72) demonstrated the influence of psychosocial factors on performance measured in various field environments. These factors attenuated the effect of physiological signals known to intensify the effort sense (72,76,89). As a result, these investigations suggest that psychological factors can contribute significantly to the explained variance in RPE (2,57,62,72,76,89).

Previous research has determined that interindividual differences in RPE can be the result of the aforementioned psychosocial factors (89). The existence of one or more of these psychological mediators, nevertheless, does not provide evidence of a consistent pattern of change in RPE. A specific psychological mediator may result in different RPE from one individual to another. Additional research is necessary to determine the effects of these psychological factors on exertional perception during exercise (89).

2.3.3.5 Exertional symptoms

Exertional symptoms are an expression of a “perceptual reality” during dynamic exercise (76). Underlying the expression of perception is a complex psychophysical process comprised of various exertional symptoms described previously as the effort sense (57). For example, a report by Weiser et al. (76,104) identified subsets of fatigue during cycle ergometer exercise by using key cluster analysis. The subsets of fatigue included 1) leg fatigue, 2) general fatigue, and 3) cardiopulmonary fatigue. The results of the key cluster analysis demonstrated a modest to significant interrelation ($r = 0.26-0.82$) (76,104). This classification of exertional symptoms was

later validated by Horstman et al. (37,76) who demonstrated that fatigue in the legs and cardiorespiratory system are predictors of submaximal endurance during a cycle ergometer exercise. Thus, fatigue was determined to be a common exertional symptom experienced during high intensity exercise (76).

The identification of fatigue as a common exertion symptom lead to the development of a format to categorize exertional symptoms into an ascending vertical sensory pathway. Weiser and Stamper (62,76,105) developed the first generation model describing the sensory link between subjective symptoms and physiological responses to exercise. Their model displayed exertional symptom clusters as a vertical sensory pathway in a pyramid configuration. The figure illustrated the sensory link of physiological clusters in a hierarchal order that leads to an overall body rating of exertion experienced by an individual. Thus, the model suggests that exertional symptoms such as fatigue are linked directly with their respective physiological clusters (62,76,105). The Weiser and Stamper model includes five ascending levels of psychophysiological responsiveness: 1) physiological clusters-located at the base of the pyramid 2) discrete symptoms, (i.e., shortness of breath, muscle aches, and weariness, 3) subordinate level-combines the discrete symptoms into three fatigue subclusters (i.e., cardiopulmonary, leg, and general fatigue, 4) ordinate level-three subordinate subclusters combine to form a primary symptom cluster termed bicycling fatigue, and 5) superordinate level-positioned at the top of the pyramid. The superordinate level describes the assimilation of the primary symptom clusters that convey an overall body rating of fatigue. Thus, the overall body rating for fatigue is the result of the vertical communication of signals that influence subjective reports of exertion experienced during exercise (62,76,105). It is proposed that these primary symptom clusters are

mediated by mechanisms within the sensory cortex (76). However, the neurophysiologic mechanisms that monitor this integration process are poorly understood.

Exertional symptoms that influence the subclusters positioned at the superordinate level can be differentiated by their corresponding physiological mediators specific to local muscle or cardiorespiratory systems. Reports by Robertson (62,76,78,79,85,89) and Pandolf (66,67) suggest that differentiated perceptual signals provide a more accurate measure of the physiological mediators that influence their “perceptual reality” during dynamic exercise. Pandolf et al. (65) theorized that the undifferentiated RPE is linked to the superordinate level as opposed to the subordinate level of subjective reports. Pandolf et al. (65) revised the previously described Weiser and Stamper model and proposed that differentiated RPE are closely linked to two symptom clusters that includes a local factor (leg fatigue) and a central factor (cardiopulmonary fatigue). Thus, the revision of the Weiser and Stamper model by Pandolf et al. (65) inserted muscular exertion and cardiopulmonary exertion as two differentiated clusters at the subordinate level.

A subsequent third generation model (Figure 2-4) developed by Robertson (62,76) replaced the terms local factors and central factors with peripheral (i.e., muscles, joints of active limbs) and respiratory-metabolic (i.e., respiration) differentiated perceptual signals respectively. This new terminology replaced the previous terms at the ordinate level (Figure 2-4).

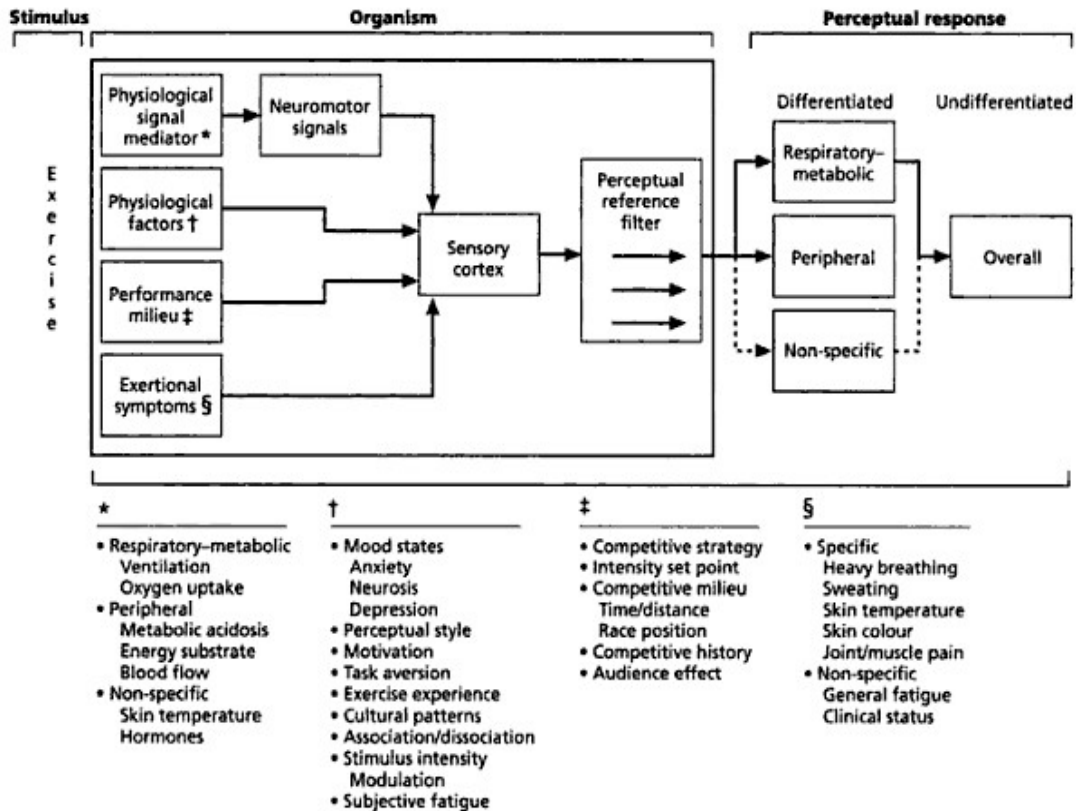


Figure 2-4 Revised model of perceived exertion by Robertson (76).

The Weiser and Stamper (62,76,105) model also includes nonspecific exertional symptom clusters to describe psychological characteristics. These nonspecific clusters include task aversion and motivation and are located at the ordinate level. Robertson (76) proposed that these clusters of exertional symptoms interact to form an individual's "perceptual style" that influences their subjective reporting of exertional perceptions experienced during dynamic exercise. Robertson (62,76,89) further theorized that by combining these two nonspecific symptom clusters, a "perceptual-cognitive reference filter" emerges as a single construct that is positioned at the subordinate level. This filter includes psychological and cognitive factors that evolve from various sensory information and experiences which shape the individual's perceptual style

(62,76,89). These factors may operate interpedently or may be linked with physiological factors in setting the intensity of the exertional signals (62,76,89). Thus, the contents of the “perceptual-cognitive reference filter” modulate the intensity of perceptual signals as they ascend from the physiological base of the pyramid, ultimately being expressed as the differentiated and undifferentiated RPE (62,76,89).

2.3.3.6 Differentiated Perceived Exertion Model

Differentiated RPE are localized or regionalized to anatomical areas include the arms (RPE-Arms), legs (RPE-Legs), and/or chest (RPE-Chest) (89). The undifferentiated RPE is defined as the RPE for the overall body (RPE-Overall) (89). A report by Robertson (76) identified two overarching questions regarding differentiated perceptual signals 1) Which differentiated signal dominates the “perceptual integration” process during a specific exercise activity and 2) What is the mode of “integration” of the differentiated signals as they form the undifferentiated perceptual signals?

Robertson explains that the usual expression of the undifferentiated RPE is determined by a neurological interrelation of sensory dominance and signal integration. Typically, a specific intensity weighting corresponds to an individual differentiated rating of perceived exertion. For example, the highest intensity weighting is assigned to the perceptual signals arising from specific limbs and body regions that are involved in exercise or work related activities (64,67,78,84). The first, second, and third generation models developed by Kinsman and Weiser (42,62,76), Pandolf (64,65,66), and Robertson (Figure 2-4) (62,76) respectively, illustrate the flow of neurological signals that ascend from the physiological base of the pyramid model through the ordinate and superordinate levels to conscious expression of the differentiated and

undifferentiated RPE. The differentiated perceptual signals arise from the limbs and body regions that are associated with the physiological base and appear at the ordinate level. The total integration of the various differentiated RPE responses forms the undifferentiated RPE response for the overall body and appears at the superordinate level. Thus, signals arising from both the ordinate and superordinate levels express conscious perceptual responses during dynamic exercise (62,76).

Measurement of differentiated RPE allows the determination of the mode of integration and dominance of perceptual signals (62). For example, the differentiated signals arising from the legs during cycle ergometer exercise were more intense than those from the chest. This indicated perceptual dominance of the leg signal (62,64,78). Robertson (76,78) found that the RPE-Overall to be the weighted average of the differentiated RPE-Legs and RPE-Chest when varying the pedal rate and maintaining a constant power output (PO) during cycle exercise. However, when multiple limbs were involved in activities such as pushing a wheelbarrow, the RPE-Overall was greater than the RPE for the differentiated signals (33,38,76). The RPE-Overall was also found to be equal or greater than the differentiated signals during maximal treadmill running (33,38,76). Thus, the differentiated signals are integrated to form the RPE-Overall and are dependent upon the mode of exercise, the active limbs involved, and the exercise setting (i.e., land, water) (76).

Earlier studies comparing cycle ergometer, arm ergometer, and arm-leg ergometer exercise demonstrated that the mode of exercise determines the origins of differentiated perceptual signals arising from specific limbs (40,64,76,88). In an investigation involving a cycle ergometer protocol it was found that RPE-Legs appeared as the dominant perceptual signal (78). However, perceptual signals that arose from the arms were dominant during arm

ergometry or permutations of arm-leg ergometry (78). In each of these studies, the RPE-Overall was equivalent to the weighted average of the differentiated ratings (78)

During an investigation involving intermittent cycle ergometer exercise, the RPE-Legs was found to be greater than the RPE-Chest whereas the RPE-Chest equaled the RPE-Overall (76,82). Studies comparing arm and leg ergometry in air and water frequently demonstrated RPE-Arms was greater than the RPE-Legs when varying pedal rate and PO (75,76). Research using bench stepping with hand weights at 70% $\text{VO}_{2\text{peak}}$ produced comparable results (76,82).

Other reports examined the effects of carrying loads held either at the waist, and head, or using a frontal yolk and transverse yolk while walking on a treadmill (6,76,77). These findings suggested that the RPE-Legs were the dominate perceptual signal. In addition, the RPE-Overall was found to be a weighted average of the undifferentiated RPE-Legs and RPE-Chest when the loads were carried at the waist level (6,76,77).

Robertson et al. (76,86) found that the external signal arising from the legs continued its dominance during a 12-minute exercise recovery period. The evidence also demonstrated that the weighted average of the undifferentiated perceptual signals was similar to the RPE-Overall (76,86).

An investigation by Pandolf et al. (65,76) and Pimental and Pandolf (70,76) examined perceived response while of transporting light and heavy external payloads at slow and moderate walking speeds. The results determined that the RPE-Legs and RPE-Chest did not differ and equaled the RPE-Overall when carrying lighter loads at slow and moderate speeds. However, the RPE-Chest was greater than the RPE-Legs when carrying heavy loads (65,70,76). The findings further suggest that the RPE-Chest significantly influenced the RPE-Overall at faster walking speeds and suggested an existence of a differentiated threshold (DT) (65,70,76).

Robertson et al. examined the presence of a differentiated threshold (DT) for young adult women while transporting payloads based on percentage of individuals' body weight (76,77). The results indicated that a DT was found when subjects walked at 6.44 km/hr carrying a load equal to 7.5% of bodyweight and when they walked at 4.83 km/hr carrying a load equal to 15% of bodyweight. When subjects walked at speeds below the DT, the RPE-Legs, RPE-Chest, and RPE-Overall were similar (76,77). At treadmill speeds greater than DT, the RPE-Legs was greater than the RPE-Overall and the RPE-Chest less than the RPE-Overall (76,77).

The findings suggested that mode of integration of perceptual signals and the appearance of a dominate signal is associated with combinations of speed and external loads once the exercising intensity exceeded the DT (76). Thus, these previous investigations suggest that the mode of integration and dominance of sensory signals arising from the differentiated signals is dependent upon the type of exercise, intensity, and active limb involvement during dynamic exercise (76).

2.4 BORG'S DEVELOPMENTAL WORK

2.4.1 Borg's RPE Scale

In 1958, psychologist Gunnar Borg from the University of Stockholm developed the first RPE scales. These scales were validated with the assistance of Nobel and others and continue to be used by various exercise practitioners to describe an individual's perception of exertion during aerobic and resistance exercise. The most commonly employed metric developed by Borg is the

6-20 Scale often referred to as the RPE Scale. This scale contains 15-numerical categories ranging from 6 (no exertion) at all to 20 (maximal exertion). The scale was initially developed for use during a cycle ergometer exercise protocol where power output was increased progressively every 4-6 minutes. Thus, the Borg 6-20 Scale, due to its linearity, provides interval exertional responses to load incremented protocols. The range in response categories from 6 to 20 was initially thought to correspond to the HR range of 60 to 200 beats min⁻¹ for healthy young individuals. Subsequent research has demonstrated that this RPE:HR does not hold under most exercise conditions and as such should not be employed. Due to the simplicity and popularity of the Borg 6-20 Scale, it is used in various medical, exercise, and research settings (16,62,89). However, the Borg 6-20 Scale presents semantic and numerical limitations when used with children. Another limitation of the Borg 6-20 scale is its inability to provide power functions that agree with ratio scaling where the “0” response category defines a period of rest (16,62,89).

2.4.2 Quantitative Semantics

Subsequently, a second generation of perceptual scales were developed using the “level-anchored ratio scale” process (18). This process resulted in a ratio scale containing verbal cues that was presented in a category format. Prior investigations using quantitative semantics demonstrated that it was possible to place adjectives and adverbs on a category scale that had ratio properties (9,13,18,38). Placing verbal cues in juxtaposition to numerical categories strengthen the measurement properties of the metric category-ratio scales (17,18,89).

The challenge in developing category-ratio scales is the placement of the verbal descriptors and numerical categories that represent an accurate expression of the perceptual sensory experience known as a stimulus-response (S-R) function (18). Initial psychophysical studies by Stevens (18,96,97) identified sensory power functions using magnitude estimation. These studies provided the foundation for establishing the validity of ratio scaling methodology. A study by Stevens and Galanter (18,95) demonstrated that when merging magnitude estimation (i.e., ratio scaling) with responses from category scales, the scale responses increased linearly. This finding resulted in the repositioning of the verbal descriptors from the category scale to identify the corresponding psychophysical sensory experience (18). For example, a verbal descriptor of “strong” obtained from the converted category rating scale will approximate the median of the “maximal” effort sensation from the original category rating scale (18). The transformation equation to establish this relation between magnitude estimation and a category rating scale was developed by Borg and Borg (18). The resulting category scale takes form of a semi-log metric. According to Borg and Borg (18), as the physical intensities increase, the perceptual responses will result in a positively skewed distribution (i.e., log normal). Borg and Borg (18) theorized that the transformation equation that repositioned the verbal anchors from the category scale should approximate a numerical value of the distribution from the ratio scale. Thus, as the relation of data derived from a symmetrical category scale (rating scale) grows linearly as a psychophysical power function of the ratio scale (stimulus), the placement of verbal descriptors is possible (18).

Studies have confirmed the relation between the symmetrical category rating scale and the ratio scale (18). The “level-anchored ratio scale” process resulted in the first category-ratio

scale. Known as the Borg CR-10 scale this metric yields data that parallel the same psychophysical function as determined with magnitude estimation (18).

The Borg CR-10 scale ranges from “0”, nothing at all, to 10, very, very strong, with the first verbal cue positioned at the numerical category 0.5, i.e. very, very weak. The upper numerical category is a 10 and is linked to the verbal descriptor “Extremely strong, maximal” (18).

Other perceived exertion metrics that have been developed using the “level-anchored ratio scale” process are variants of the original CR-10 scale and include the Borg CR-12, CR-20, CR-60, and CR-100 (centiMax) scales (18). However, the CR-10 scale, unlike the Borg 6-20 RPE scale, includes a numerical rating of “0” that allows individuals to determine a true period of no exertion. This observation in part provides support for the rationale underlying the present investigation.

2.5 DEVELOPMENT AND VALIDATION OF THE OMNI SCALES

Recognizing the methodological and semantic limitations of the Borg RPE and CR scales, the OMNI picture system of perceived exertion was developed Robertson (89). The term OMNI is condensed from the Latin word *omnibus*, indicating a metric having a wide range of exercise applications. A major difference between the OMNI RPE scale and previous RPE scales is the use of pictorial descriptors that are generally consonant with the performance activity. These pictorial descriptors are placed in juxtaposition to verbal descriptors and numerical ratings in a category scale format. The inclusion of pictorial descriptors to represent intensity and mode of

exercise for use by male and female adults and children is an essential feature of the OMNI RPE scale (Figure 2-5). Research in multimedia learning and cognitive load theory offers a supporting rationale for positioning pictorial cues in conjunction with verbal cues and numerical ratings in a category metric (99).

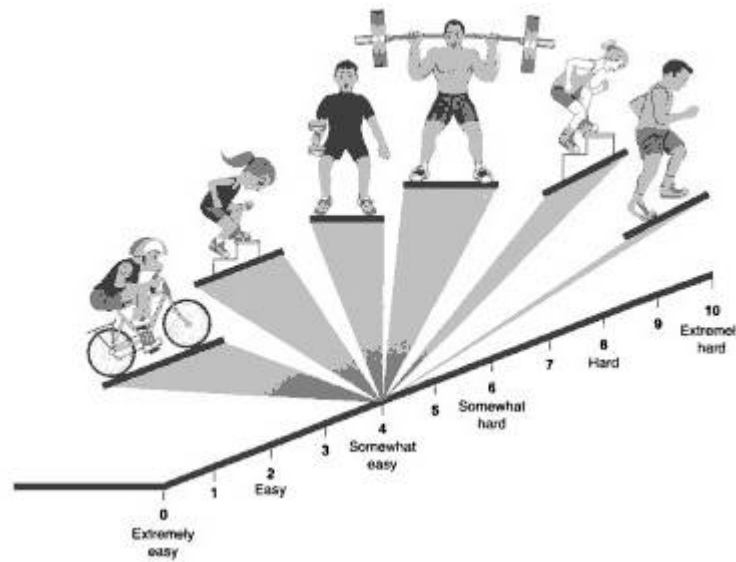


Figure 2-5 Montage of picture cues for the OMNI perceived exertion scale (89).

The numerical categories on the OMNI scale range from 0 (extremely easy) to 10 (extremely hard) and are easily inter-converted between the Borg 6-20 and Borg CR-10 scales (Figure 2-6). The OMNI and Borg CR-10 scales are equivalent in total number of response categories.

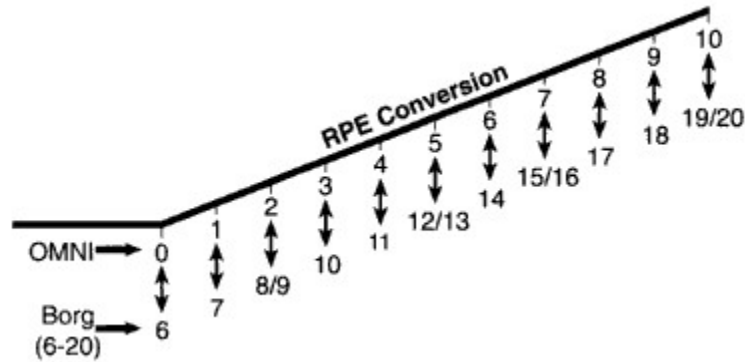


Figure 2-6 RPE conversions between the OMNI, Borg 6-20 and Borg CR-10 scales (89).

Robertson et al., developed the first OMNI picture system to measure RPE for children and adolescents (Figure 2-7) (88). Subsequent scales have been developed for use with adults (76). In the adult formats the OMNI numerical categories range from “0” (i.e., extremely easy) to 10 (i.e., extremely hard). Subsequent research established concurrent and construct validity of various formats of the child and adult OMNI Scales for aerobic and resistance exercise (74,80,81,83,84,88). A number of these studies also demonstrated construct validity of the OMNI Scale to assess RPE. These investigations of construct validity used the Borg Scale 6-20 Scale as the criterion metric (84,101). Several studies have demonstrated the reliability of the OMNI picture system noting that measurement reproducibility was comparable to the Borg Scale (84,101).

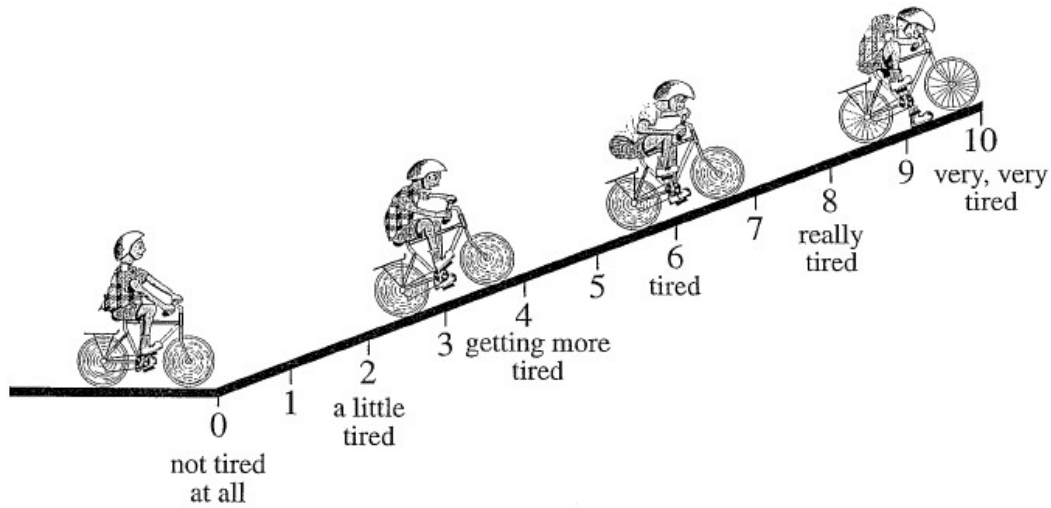


Figure 2-7 OMNI-Cycle Scale of perceived exertion for children (88).

To establish measurement validity of the OMNI-Scale, Robertson et al. employed concurrent and construct experimental paradigms in a series of investigations involving aerobic and resistance exercises. A concurrent validation paradigm employs a two variable scheme. The criterion variables consisting of oxygen uptake (VO_2 , $\text{ml} \cdot \text{min}^{-1}$) and HR responses are correlated with the concurrent variables RPE-Overall, RPE-Legs and RPE-Chest.

Construct validity was determined by correlating the RPE derived from the OMNI Scale with the RPE measured by the Borg Scale. The OMNI Scale was designated the conditional metric and the Borg Scale designated the criterion metric. The RPE for this paradigm served as the construct variable.

2.5.1 Aerobic

2.5.1.1 Cycle

Initial validation of the Children's OMNI-Cycle Scale employed a cross-sectional, perceptual estimation paradigm using a single multi-stage cycle ergometer protocol involving clinically normal African-American and Caucasian children (Figure 2-7) (88). The criterion variables consisted of VO_2 and HR. The concurrent variables consisted of the undifferentiated RPE-Overall, and the differentiated RPE-Legs, and RPE-Chest. RPE were determined at the end of each continuously administered 3-min PO test stage. The results demonstrated that RPE-Overall, RPE-Legs, and RPE-Chest distributed as a positive linear function of both VO_2 and HR; ($r = 0.85$ to 0.94 ; $P < 0.01$). These results provided evidence for concurrent validity of the OMNI-Cycle Scale for use with female and male African American and white American children eight to twelve years of age.

A concurrent and construct paradigm was employed to validate the Adult OMNI-Cycle Scale of perceived exertion. This study employed young adult women and men performing cycle ergometer exercise (Figure 2-8) (84). Correlation/regression analysis indicated that RPE-Overall, RPE-Legs, and RPE-Chest distributed as a positive linear function of both VO_2 and HR ($r = 0.81$ to 0.95 , $P < 0.01$) establishing concurrent validity. Regression analysis also determined that for both female and male subjects, RPE-Overall, RPE-Legs, and RPE-Chest derived from the Adult OMNI-Cycle Scale were positively and linearly related to the Borg (6-20) Scale over a wide range of submaximal power outputs ($r = 0.92$ to 0.97 , $P < 0.01$). These findings established construct validity for the Adult OMNI-Cycle Scale. An ANOVA indicated that the RPE-Legs

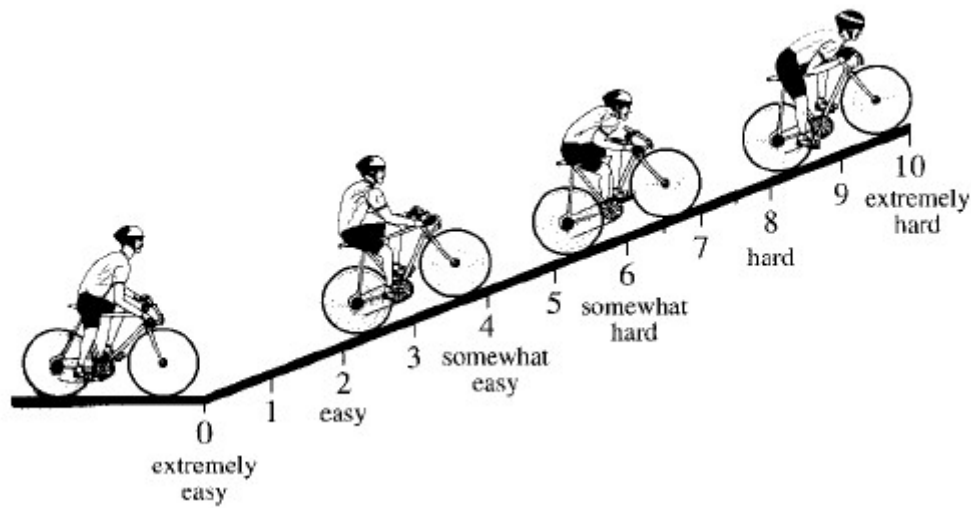


Figure 2-8 OMNI-Cycle Scale of perceived exertion for adults (84).

derived from the Adult OMNI-Cycle Scale was higher ($P < 0.01$) than RPE-Chest at each exercise stage for both sex groups. This finding is consistent with the Differentiated Perceived Exertion Model that predicts the perceptual signal arising from the legs will be more intense than that arising from the chest (i.e. signal dominance) during cycling exercise. As a result, the Adult OMNI-Cycle Scale provides precision in distinguishing between anatomically regionalized perceptual signals (76).

2.5.1.2 Walk/Run

A subsequent study by Utter et al. (102) examined validity of the Children's OMNI-Walk/Run Scale. Subjects were female and male children who performed a graded treadmill exercise test (Figure 2-9) (102). The criterion variables included (VO_2 , $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), relative oxygen uptake ($\%\text{VO}_2$ max), pulmonary ventilation (V_E , $\text{L}\cdot\text{min}^{-1}$), respiratory rate (RR, $\text{breaths}\cdot\text{min}^{-1}$), respiratory exchange ratio (RER), and $\text{V}_E\cdot\text{VO}_2$. The RPE-Overall body served

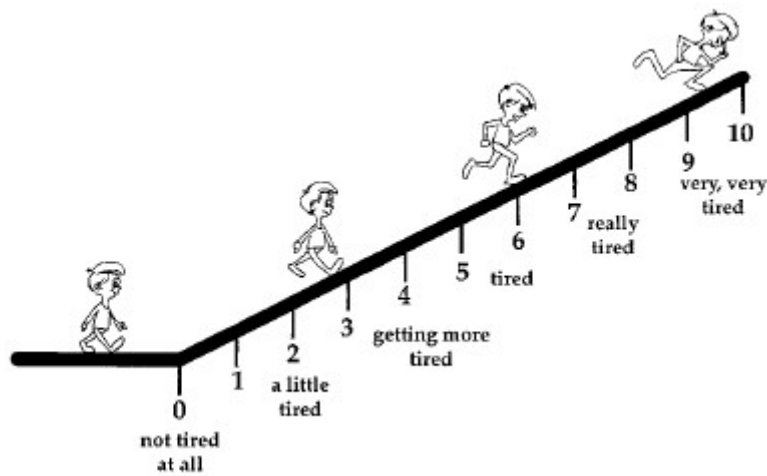


Figure 2-9 OMNI-Walk/Run Scale of perceived exertion for children (102).

as the concurrent variable. The results demonstrated significant correlations between RPE-Overall (Omni Scale) and VO_2 , $\% \text{VO}_2\text{max}$, HR, $\text{V}_E:\text{VO}_2$, and RR throughout the treadmill exercise test. The strongest correlations were found between RPE Overall and $\% \text{VO}_2 \text{ max}$ ($r = 0.41$ to 0.60 , $P < 0.001$) and HR ($r = 0.26$ to 0.52 , $P < 0.01$), thus establishing concurrent validity of the Children's OMNI-Walk/Run Scale for use with female and male children performing a graded treadmill exercise test.

Utter et al. (101) employed concurrent and construct experimental paradigm to establish validity of the Adult OMNI-Walk/Run Scale (Figure 2-10). Perceived exertion estimates were obtained during a graded treadmill exercise test (101). The criterion

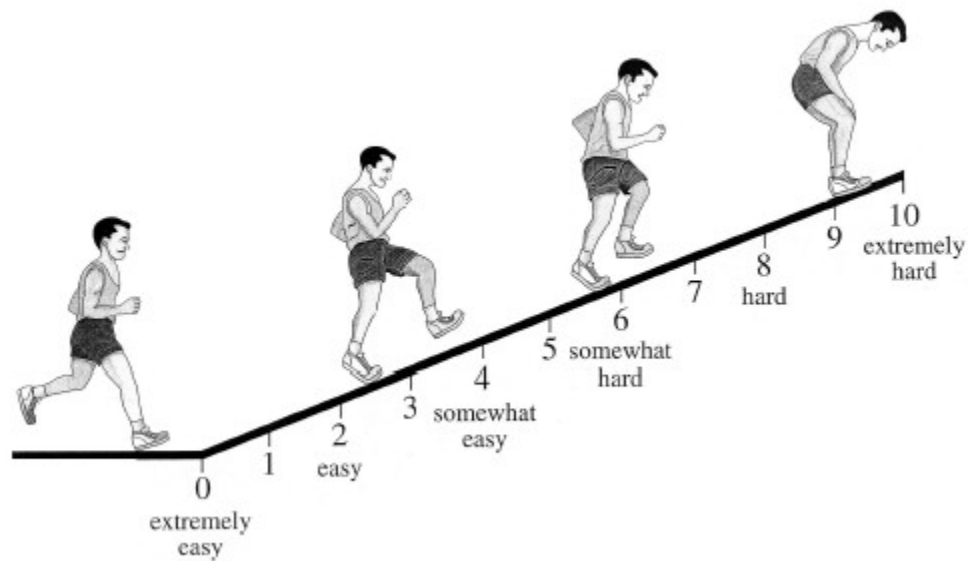


Figure 2-10 OMNI-Walk/Run Scale of perceived exertion for adults (101).

variables were VO_2 , HR, $\% \text{VO}_{2 \text{ max}}$, V_E , RR, and the RER. The undifferentiated RPE-Overall body served as the concurrent variable. Correlation/regression analyses resulted in the RPE-Overall distributing as a positive linear function of all the criterion physiological variables for both males and females ($r = 0.67$ to 0.88 ; $P < 0.05$). This investigation also established construct validity using the Borg Scale (6-20) as the criterion metric and the OMNI-Walk/Run Scale as the conditional metric. Regression analysis determined that RPE-Overall distributed as a positive linear function of Borg Scale RPE responses for both males and females ($r = 0.96$; $P < 0.01$). Utter et al., concluded that the Adult OMNI-Walk/Run Scale format could be used during treadmill exercise by adult females and males to estimate RPE for the overall body.

2.5.1.3 Step

A concurrent and construct research paradigm was employed to validate the Children's OMNI-Step Scale (Figure 2-11) (81). To establish concurrent validity, the criterion variables were VO_2 ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and HR ($\text{beats}\cdot\text{min}^{-1}$).

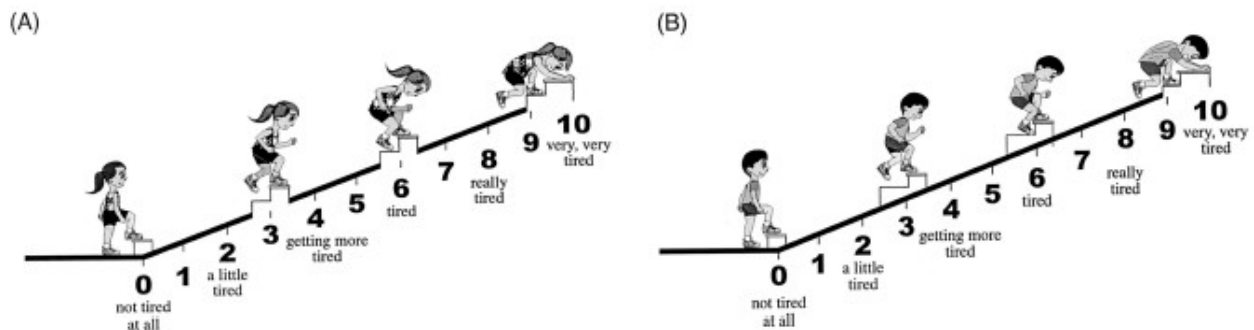


Figure 2-11 OMNI-Step Scale of perceived exertion for children: (A) Female, (B) Male (81).

The undifferentiated RPE-Overall and the differentiated RPE-Legs and RPE-Chest were the concurrent variables. Regression analyses indicated that the concurrent variables distributed as a positive linear function of both criterion variables ($r = 0.81$ to 0.94 $P < 0.05$). Evidence of construct validity was provided by a regression analysis where RPE-Overall, RPE-Legs, and RPE-Chest derived from the Children's OMNI-Step Scale distributed as a positive function of RPE-Overall, RPE-Legs, and RPE-Chest derived from the Children's OMNI-Cycle Scale across a range of submaximal intensities ($r = 0.93$ to 0.95 ; $P < 0.01$). This evidence of construct validity is consistent with that found in previous investigations involving the Adult OMNI-Cycle Scale format (84). These findings support the administration of the Children's OMNI-Step Scale to female and male children.

2.5.1.4 Resistance Exercise

The first validation study involving the OMNI Resistance Exercise Scale (OMNI-RES) of perceived exertion employed recreationally trained young adult females and males (Figure 2-12) (74). The concurrent validation paradigm called for subjects to perform biceps curl and knee extension isotonic resistance exercise using a volume loading protocol (74). In this study, measures of total weight lifted and blood lactic acid concentration [Hla], served as the criterion variables. The undifferentiated RPE-Overall and differentiated RPE for the active muscles

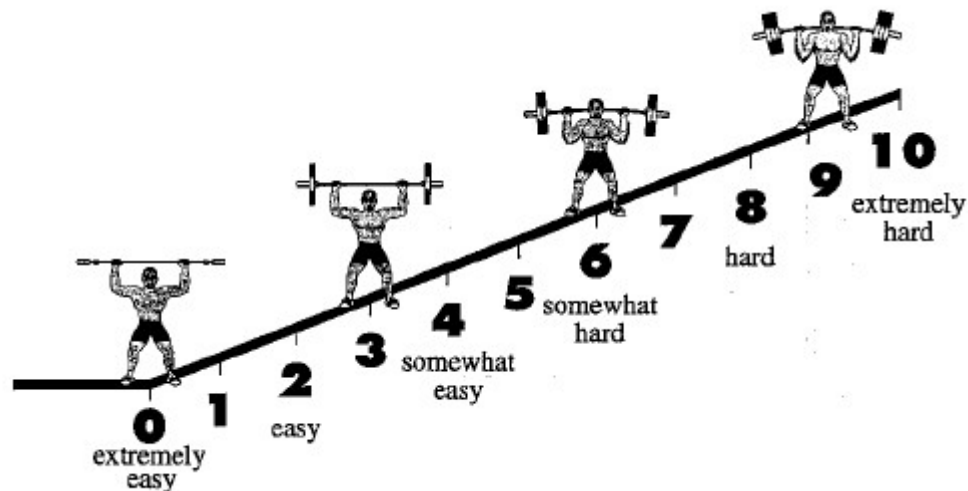


Figure 2-12 OMNI-Resistance Scale of perceived exertion for adults (74).

(RPE-AM) were the concurrent variables. The RPE-Overall and RPE-AM were assessed at the mid- and final repetition of each set. For both male and female groups the RPE-AM ranged from 3.6 to 8.2 for biceps curl and 5.1 to 9.6 for knee extension exercises. The RPE-Overall ranged from 2.4 to 6.7 for biceps curl and 4.2 to 7.6 for knee extension exercises. Positive linear regressions ranging from ($r = 0.79$ to 0.91 , $P < 0.01$) for both females and males were found between total weight lifted and RPE-Overall, RPE-AM (mid-repetition), and RPE-AM (final

repetition) during the biceps curl and knee extension exercises. Moreover, blood [Hla] was found to have a positive relation with RPE-AM (final) ($r = 0.87$, $P < 0.01$) during biceps curl exercise for both sex groups. The RPE-AM was greater than the RPE-Overall across all three sets for biceps curl and knee extension exercises ($P < 0.01$). Thus, the study provided evidence for concurrent validity of the OMNI-RES to measure undifferentiated RPE-Overall and differentiated RPE-AM in young adults performing upper and lower body isotonic resistance exercise (74).

The second validation study using the OMNI-RES employed male and female children (Figure 2-13) (80).

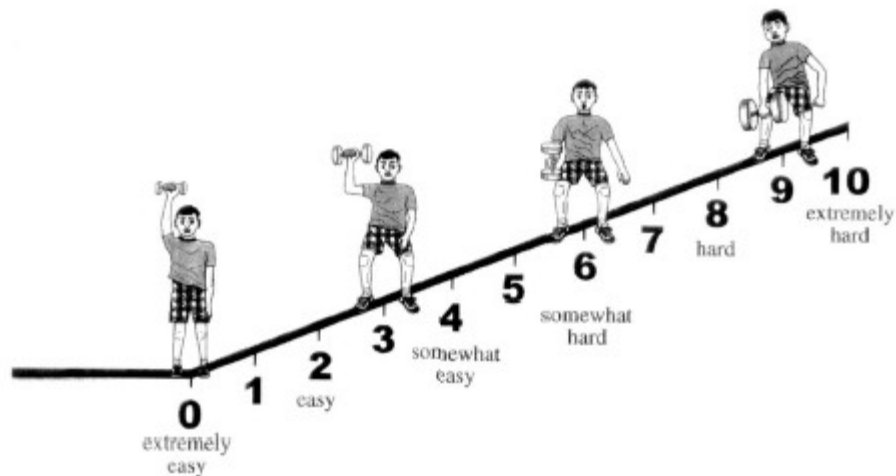


Figure 2-13 OMNI Resistance scale of perceived exertion for children (80).

The experimental design of this investigation replicated a cross-sectional, perceptual estimation design used previously to establish the concurrent validity of the Adult OMNI-RES. The concurrent validation paradigm called for subjects to perform biceps curl and knee extension isotonic resistance exercise using a volume loading protocol. Subjects were clinically normal male and female children. In this study, measures of total weight lifted served as the criterion

variables. The undifferentiated RPE-Overall and differentiated RPE-AM were the concurrent variables. The RPE-Overall and RPE-AM were assessed at the mid- and final repetition of each exercise set. For both male and female groups the RPE-AM ranged from 2.9 to 8.3 for biceps curl and 4.5 to 9.6 for knee extension exercises. The RPE-Overall ranged from 1.9 to 7.0 for biceps curl and 3.6 to 7.7 for knee extension exercises. Positive linear regressions ranging from ($r = 0.72$ to 0.88 $P < 0.01$) were found between total weight lifted and RPE-Overall, RPE-AM (mid), and RPE-AM (final) during the biceps curl and knee extension exercises in both sex groups. The RPE-AM was greater ($P < 0.01$) than the RPE-Overall across all three sets for biceps curl and knee extension exercises ($P < 0.01$). Thus, the study provided evidence for concurrent validity of the OMNI-RES to measure undifferentiated RPE-Overall and differentiated RPE-AM in children performing upper and lower body isotonic resistance exercises (80).

2.6 APPLICATION OF THE OMNI SCALES

Practitioners have applied the various formats of the OMNI RPE scales to assess aerobic fitness, evaluate strength training outcomes, and monitor conditioning progress. A multi-modal prescriptive application uses a target RPE training zone that includes exercise intensities that will improve cardiovascular fitness, decrease percent body weight, and increase muscle strength. One advantage of the RPE training zone is that it does not require extensive preparticipation practice to achieve the individual's prescribed target training intensity. Practitioners can easily convert the RPE training zones determined using the OMNI scale formats to the Borg 6-20 scale

and the CR-10 scale formats as needed. As a result, the RPE zone system provides individuals the ability to “slide up” or “slide down” to determine the optimal and appropriate training stimulus to improvement in aerobic fitness, muscular strength and/or weight loss (89).

Practitioners can apply the sliding OMNI RPE zone system to individuals who participate in variety of land and aquatic exercise programs. For example, the OMNI-RES sliding zone system provides an effective method to enhance muscular endurance, muscular hypertrophy, and muscular strength. It is proposed that the RPE zone system will help to prevent injuries, and greatly assist competitive athletes in avoiding overtraining and overreaching. Land based applications include cross-training, children and youth exercise programs, resistance training for wheelchair individuals, indoor group cycling, marathon training, body weight loss, activities of daily living, home exercises, stability ball exercises, stretch band/cord exercises, mind-body programs (i.e. Pilates, yoga), perceptual preference zones, and energy efficient zones (89).

Other successful applications allow practitioners to use the OMNI-RPE sliding zone system to meet the challenges of prescribing exercise for special populations. This includes strength training for women, aquatic exercise for pregnant women, physical activity therapy for osteoporosis, exercise therapy for arthritis patients and cancer survivors, aerobic and resistance exercise for older clients, exercise prescription for children using the anaerobic threshold as a metabolic marker, environmental adaptations (i.e. hot and cold ambient temperatures and high altitude exercise) and in the workplace for various occupational conditions. Clinical applications include the use of the OMNI-RPE sliding zone system to regulate exercise therapy for inpatient and outpatient cardiac and pulmonary rehabilitation, and for cardiac transplant patients (89).

2.7 INDICES INVOLVING THE OMNI SCALES

Several studies have noted that the OMNI picture system of perceived exertion presents statistical difficulties owing to the presence of a “0” category that acts as an integer (39,103). For example, when computing the Physical Activity Index (PAI), a “0” category rating results in a “0” index value when the RPE is multiplied by the corresponding step count. In mathematical terms, any integer multiplied by a “0” will yield a “0”. This presents challenges when performing statistical computations using values derived from RPE based indices that evaluate training load, training monotony, and training strain (30,31).

Resler et al. and Weary et al. developed the Physical Activity Index (PAI) as a measure of the total activity load during exercise (73,94,103). The PAI is a derived index that accounts for volume (number of steps) and intensity (RPE) of exercise. The computed PAI (i.e., volume x intensity) during an exercise session was then used to estimate energy expenditure for the entire exercise session. The initial investigation by Resler et al. demonstrated a positive relation ($r=0.69$) between the energy expenditure estimated by the PAI and actually measured energy expenditure during aerobic exercise (73). A follow-up investigation by Weary validated a statistical model to predict energy expenditure from the PAI score i.e., **Predicted kcal = $28.056 + 0.006(\text{PAI score})$** $P < 0.05$, SEE 17.34, $r = -0.80$, $r^2 = 0.64$ (103). The statistical model was found to explain the most variance in estimating kcal expenditure for moderate walking intensities. It explained slightly less variance for low and high walking intensities.

Another calculation where the “0” category on the OMNI Scale can potentially present computation difficulties is the Exercise Discomfort Index (EDI). The EDI is calculated as the product of RPE and a rating of muscle hurt/pain (RMP) (39,89). Both the OMNI perceived

exertion scale and the OMNI muscle hurt/pain scale have a “0” category. As such, the derived index will yield a “0” if either an RPE or RMP is reported as “0” category.

Thus, there exists a need to modify the standard OMNI Scale format by either eliminating the “0” category as a possible exercise response or to specifically link the “0” category to a resting (i.e., non-exercise) state. Therefore, the present investigation will examine the validity of alternative Adult OMNI RPE Scale formats that omit the “0” category as its lowest anchoring point or link a “0” category to a true rest period.

2.8 EXAMPLES OF EXERCISE RELATED PSYCHOPHYSICAL INDICES INVOLVING MEASURES OF PERCEIVED EXERTION

The overtraining syndrome has been observed in athletes who frequently maintain a high intensity and high volume conditioning load that may be compounded by additional life stressors. Kreider et al. defined overtraining as a profound long-term performance decrement typically accompanied by signs and symptoms of excessive exercise strain (45,89). Conversely, overreaching is a short-term performance decrement that occurs despite a continued increase in the training overload. The overtraining complex appeared in racehorses when training loads were increased on easy days and the day-to day training variability was decreased (20,31). Based on these observations using an animal model, it has been suggested that other indices of training variability involving measures of total training load and perceived exertion may signal the onset of the overtraining syndrome in human competitors.

Derived indices that include RPE values have been shown to be useful in identifying banal illness and the overtraining syndrome in competitive athletes. The indices quantify training load, training monotony, and training strain. Previous studies by Foster, et al., defined the index of training variability as the daily mean load (total time of training from warm-up until cool-down) divided by the standard deviation of the load calculated over a training week (30). This index provides a measure of training monotony (30). In a subsequent investigation, Foster et al. demonstrated that high training load and high training monotony are variables that relate to negative training adaptations (31). Because of this relation, the investigators calculated the training strain as the product of the training load and training monotony. It was proposed that this strain may predispose negative adaptations to training such as the overtraining syndrome. The following equations are used to calculate the index of training variability and training strain (31).

- 1. Daily load= duration of session (min) x RPE session= load for each training day.**
- 2. Daily mean load (calculated as the mean of the daily loads performed during each week).**
- 3. Daily standard deviation (calculated as the standard deviation of the daily loads during each week).**
- 4. Training Monotony (index of training variability): daily mean load ÷ daily standard deviation**
- 5. Weekly load (daily mean load x the number of weekly training sessions)**
- 6. Training Strain (Weekly load x Training Monotony)**

A study examining the overtraining syndrome reported that a spike in training load, training monotony, and especially training strain above an individual's threshold resulted in a high percentage of illnesses and/or performance decrements (31). The index of training variability can be used when conditioning involves very high exercise loads. Therefore, by controlling for training strain, competitors can reduce the risk of the overtraining syndrome.

Synder et al. used the ratio of lactic acid to RPE to monitor signs and symptoms of overtraining (31,98). Using this procedure, lactic acid and RPE are measured for a standard training pace. The ratio is calculated by dividing lactic acid concentration by the RPE and multiplying that value by 100. If the ratio consistently decreases over several measurement periods at the same standard training pace, the exerciser should be monitored for all signs and symptoms of overtraining.

Another derived index to monitor overtraining is the Perceptual-Mood Index of Overtraining developed by Morgan et al. (54,89). The equation to compute this index is as follows:

$$\text{Perceptual-Mood Index (PMI)} = [(\text{RPE-O} + \text{Fatigue})/\text{Vigor}] \times 100 \quad (54,89)$$

In the above equation, RPE-O is the overall body exertional rating measured using the Borg 6-20 scale. The fatigue and vigor values are determined from the Profile of Mood States. If the PMI increases over the training period, signs and symptoms of overtraining should be monitored.

A study by Pandolf et al. (69,89) demonstrated that RPE of individuals exercising at a normal training pace is significantly greater in high ambient temperature especially when the relative humidity is high. When the air temperature is greater than 88° F, the RPE is 1.5 to 2.5 categories on the Borg scale and 1 to 2 on the OMNI scale above that recorded for the normal

training zone (69,89). When individuals report an elevated RPE during hot ambient conditions, practitioners should instruct their clients to exercise at a lower intensity to avoid heat strain. This practice will in most conditioning sessions also require the individual to exercise at a lower intensity when the relative humidity is above 70%. In addition, Pandolf demonstrated that RPE is related in part to an individual's sensation of body temperature or how hot they feel. In this context, the OMNI Temperature Sensation Scale has numerical ratings and verbal descriptors that range from 1 (neutral) to 5 (very hot). It can be used in conjunction with the standard OMNI perceived exertion scale formats to simultaneously measure temperature sensation and RPE. Under hot or humid conditions, the individual should be instructed to decrease the training pace when the upper-limit rating of 8 is estimated for the OMNI Temperature Sensation Scale and 4 is estimated on the OMNI Perceived Exertion Scale (69,89).

The Perceptual Heat-Strain Index (P_{eSI}) developed by Tikuisis et al. (89,100) is derived by simultaneously measuring RPE and thermal sensations during exercise in a thermally stressful condition. This index is accurate for untrained individuals. However, the P_{eSI} underestimates heat strain for athletes. Thus, the P_{eSI} should be used in conjunction with physiological measures that include core temperature to assess heat strain in competitive athletes.

The OMNI and Borg perceived exertion scales can be used to assess dyspnea in patients with chronic obstructive pulmonary disease (COPD). Mahler and Horowitz (49,89) developed the severity index for COPD patients. When using this index the severity of dyspnea is rated using the Borg CR-10 Scale. The numerical ratings on the CR-10 Scale range from "0" indicating no breathing difficulty to 10 or maximum breathing difficulty. The dyspnea rating is measured for each PO stage during a load incremented cycle ergometer exercise test. Subsequently, the severity index is computed as the ratio of the dyspnea rating to PO (w); i.e.

$(\text{CR-10 rating} \div w) \times 100$ (49,89). Thus, at any stage of the exercise test a higher dyspnea index will indicate a comparatively greater severity of obstructive pulmonary disease (49,89). For example, patients with severe COPD ($\text{FEV}_1 < 50\%$ predicted) who exercise at a moderate cycle ergometer power output of 75W could have a severity index of 8, while patients with mild to moderate COPD (FEV_1 50% to 70% predicted) could have a severity index of 6. In addition, the severity index can be used to track the training progress of COPD patients who are participating in a pulmonary exercise rehabilitation program. Thus, at a given submaximal PO, a decrease in the severity index with exercise training will indicate an improvement in the patient's obstructive pulmonary condition (49,89).

Another index that can assist pulmonary patients to regulate exercise intensity is the RPE-Respiratory Rate Index developed by Linderholm (48,89). During a load incremented cycle ergometer exercise test, both the RPE and the respiratory rate (RR) are assessed each minute. Subsequently, the RR is plotted as a function of the corresponding RPE. This plot is done for each exercise test throughout the exercise program. Using the plotted data, a decrease in RPE at any given RR will indicate an improvement in the patient's pulmonary status and functional aerobic power (48,89).

2.9 SUMMARY

An important assumption of psychometric scaling methods is that humans can function as “measuring instruments.” Borg defined the perception of exertion as an interactive response involving psychological and physiological factors. This concept lead to the development of the

Borg Perceived Exertion Scales and the Effort Continua Model. In attempt to characterize individual differences in perceptual responses, Borg developed the Range Model for category scaling. In addition, early studies by Borg proposed that exertional perceptions are mediated by peripheral and respiratory metabolic signals. This concept lead to the development of the Differentiated Perceived Exertion Model that describes both mode of perceptual signal integration and signal dominance. However, the numerical format and verbal descriptors of the various Borg scales can present limitations especially when applied to children. Recognizing the methodical and semantic limitations of the Borg RPE and Borg CR scales, Robertson developed the OMNI picture system of perceived exertion. A major difference between the Borg RPE scales and OMNI RPE scale is the use of pictorial descriptors specific to the exercise activity in the latter metric. These pictorial descriptors are placed in juxtaposition to the verbal descriptors and numerical ratings in a category scale format. However, recent studies employing the OMNI perceived exertion picture system demonstrate statistical difficulties when a “0” rating is used in the computation of an exertional index such as the PAI. When using this index if a “0” rating is multiplied by the corresponding step count a “0” value is derived. This presents obvious statistical challenges especially when attempting to use the OMNI RPE scales to compute exercise related indices. Thus, there exists a need to modify the standard OMNI Scale format by either eliminating the “0” category as a possible exercise response or to specifically link the “0” category to a resting (i.e., non-exercise) state. Such a modification would facilitate research and clinical applications of the OMNI Scale where derived indices are computed from perceptual, physiological, sensory, psychobehavioral, and/or physical activity variables. The present investigation will examine both the concurrent validity and the construct validity of three alternative Adult OMNI-Cycle Scale formats that meet the above modification.

3.0 METHODS

The purpose of this investigation was to determine the concurrent and construct validity of three alternative versions of the OMNI-Cycle Scale of Perceived Exertion. All procedures were approved by the Institutional Review Board (IRB) of the University of Pittsburgh. Subjects provided their written consent to participate before undertaking the research study.

Cycle ergometry was chosen for this investigation because the original Adult OMNI Scale was validated using a load incremental cycle ergometer protocol terminating at peak exercise intensity (84). At present, no published studies have examined the validity of an Adult OMNI Perceived Exertion Scale that (a) does not employ a zero category as a possible exercise response or (b) specificity links the zero category to a resting (i.e. non-exercise) state.

3.1 SUBJECTS

Males ranging in age from 18-30 years old were recruited as subjects for this investigation. All subjects were recreationally active and healthy. Recreationally active individuals are those who currently perform aerobic exercise a minimum of 2 days/week for 60 min with a weekly total of no more than 150 min, and who are not participating in collegiate or professional sports. Resistance training did not count toward the weekly physical activity total.

3.1.1 Recruitment procedures

Potential research subjects were recruited by advertisements (Appendix A) distributed through the University of Pittsburgh media and posted in various University newspapers and at selected campus sites. All potential subjects were pre-screened during a phone interview to determine recent physical activity levels and any previous exposure to RPE scales. Using an IRB waiver, the phone interview was performed prior to signing the consent form to participate and scheduling the orientation session (Appendix B). All potential subjects read an informed consent document that explains the nature of the research, its risks, and benefits, and their rights as research subjects. At the time a potential research subject agreed by signed consent to participate in the study and meets inclusion criteria, he was scheduled for an orientation trial.

3.1.2 Exclusion criteria

All subjects were screened for pre-existing clinical conditions that indicate they are at risk for non-physician supervised exercise testing according to the American College of Sports Medicine (ACSM) Guidelines (1). Subjects were excluded from the study based on the following criteria:

1. Regular aerobic exercise training more than 150 min per week during the previous six months.
2. Previous experience with perceived exertion scales.
3. Body mass index (BMI) $> 30 \text{ kg} \cdot \text{m}^{-2}$.
4. Female sex.

Clinical exclusion criteria are listed in Appendix C. If a disease or clinically significant condition was identified during the screening procedures, the subject was told to contact his primary care physician as soon as possible. That subject was excluded from participation in the investigation. All subjects completed the Physical Activity Readiness Questionnaire (PAR-Q) (Appendix B) and the Medical History Form (Appendix B) prior to participating in the study. If the medical history indicated any contraindications to exercise testing or if the subject answered YES to any of the PAR-Q questions, the subject was excluded from participating in the study. The only exception to this exclusion was that the subject obtains written permission from his physician to participate.

3.2 POWER ANALYSIS

A sample of 16 participants were used based on power analyses related to the 4 (scale format) by 3 (body site) by 4 (exercise stage) ANOVA. Power analyses were carried out for the main effects of site and exercise stage, and for the site by stage interaction. The alpha level was set at .05 for all analyses. Based on previous research a large effect of 0.9 was posited for body site (84). Given a large effect (Cohen's $f = .4$) and a moderate correlation between RPE ratings at the three sites ($r = .50$) a sample size of 16 would achieve power of 80%. Given a medium effect size (Cohen's $f = .25$) for the site by stage interaction, a sample size of 16 would achieve power slightly greater 80%. Power calculations were determined by the Sample Power Release 1.20.

3.3 ADULT OMNI CYCLE SCALES

The original version of the Adult OMNI-Cycle Scale and the three Alternative Adult OMNI-Cycle Scale formats are presented in Figures 3-1 to 3-4. The Original Adult OMNI-Cycle Scale format includes a zero category as the lowest numerical rating of exertion. The exertional scale categories range from a number 0 (i.e., extremely easy) to number 10 (i.e., extremely hard). The original scale positions verbal descriptors next to the numerical categories of 0, 2, 4, 6, 8, and 10. Pictorial descriptors are placed in juxtaposition to the 0, 3, 6, and 9 numerical categories. Figure 3-1 displays the Original Adult OMNI-Cycle Scale.

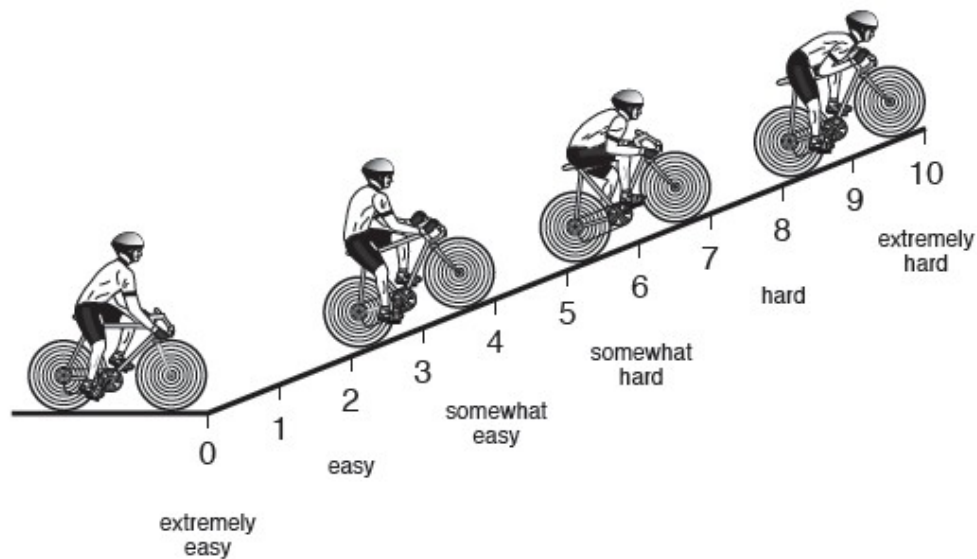


Figure 3-1 Original Adult OMNI-Cycle Scale (84)

The Alternative I Adult OMNI-Cycle Scale employs numerical categories ranging from 1 (i.e., extremely easy) to 11 (i.e., extremely hard) with pictorial descriptors positioned next to the

numerical categories of 1, 4, 7, and 10. Verbal descriptors are positioned at the numerical categories 1, 3, 5, 7, 9, and 11. Figure 3-2 presents the Alternative I Adult OMNI-Cycle Scale.

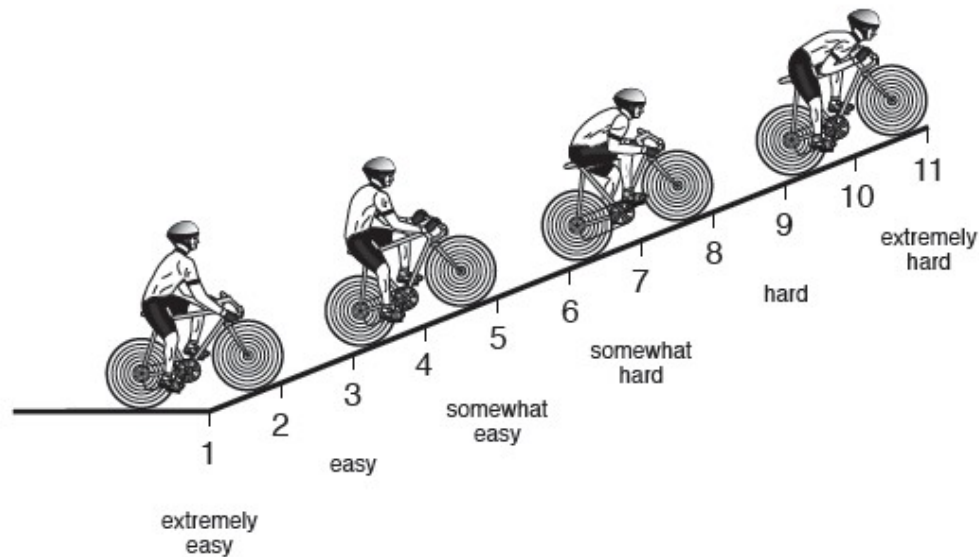


Figure 3-2 Adult OMNI-Cycle Scale Alternative I

The Alternative II Adult OMNI-Cycle Scale eliminates the “extremely easy” verbal descriptor and adds a “rest” verbal descriptor. This scale uses numerical categories ranging from 0 (i.e., rest) to 10 (i.e., extremely hard) with pictorial descriptors placed next to the numerical categories of 1, 4, 7, and 10. The Alternative II Adult OMNI-Cycle Scale positions verbal descriptors next to the numerical categories of 0, 2, 4, 6, 8, and 10. Figure 3-3 presents the Alternative II Adult OMNI-Cycle Scale.

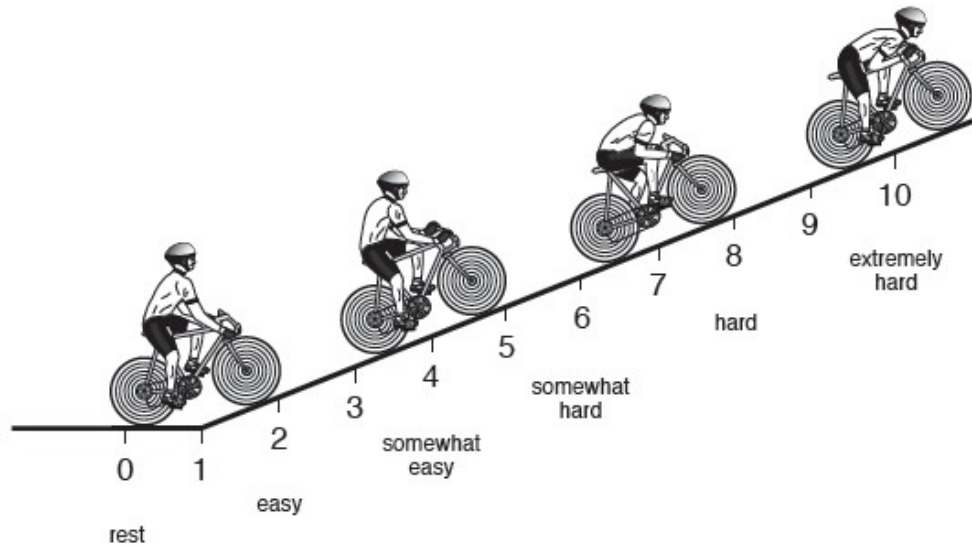


Figure 3-3 Adult OMNI-Cycle Scale Alternative II

The Alternative III Adult OMNI-Cycle Scale is identical to the Alternative II Scale except that it eliminates the 0 (i.e., rest) category. This scale presents numerical categories ranging from 1 (i.e., no verbal descriptor) to 10 (i.e., extremely hard) with pictorial descriptors placed next to the numerical categories 1, 4, 7, and 10. The Alternative III Adult OMNI-Cycle Scale positions verbal descriptors next to the numerical categories 2, 4, 6, 8, and 10. The pictorial descriptors used in the three Alternative Adult OMNI-Cycle Scales are identical to the pictorial descriptors used in the Original Adult OMNI-Cycle Scale. Figure 3-4 presents the Alternative III Adult OMNI-Cycle Scale.

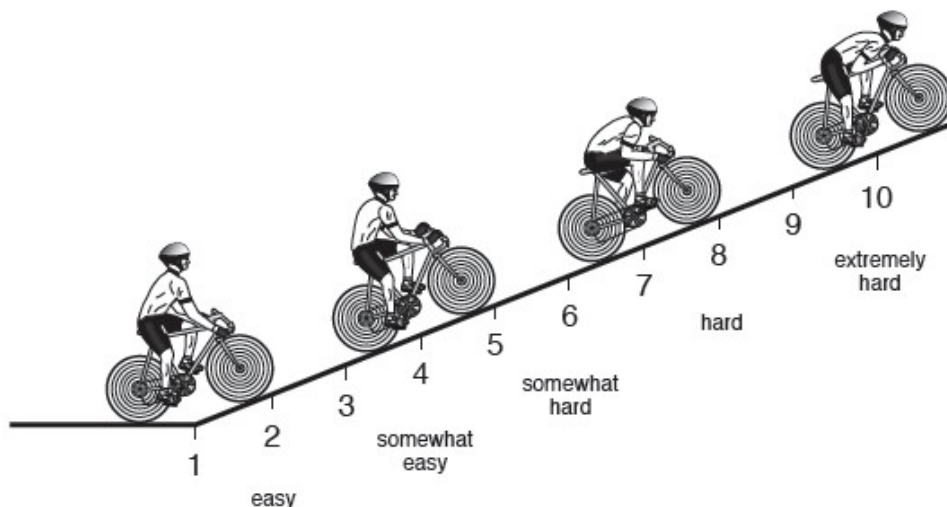


Figure 3-4 Adult OMNI-Cycle Scale Alternative III

3.4 EXPERIMENTAL DESIGN

A within subject multiple observation design consisting of one orientation session followed by four counterbalanced experimental trials was used. The purpose of the orientation was to familiarize subjects with cycle ergometer testing and use of either the Original Adult OMNI-Cycle Scale format or one of the three Alternative Adult OMNI-Cycle Scale formats (i.e. I, II, III). During each of the four counterbalanced experimental trials either the Original Adult OMNI-Cycle Scale format or one of the three Alternative Adult OMNI-Cycle Scale formats (i.e. I, II, III) was presented. All subjects performed the four experimental trials which involved a load incremented cycle ergometer exercise protocol.

3.4.1 Orientation Session

Subjects initially participated in an orientation session. Age, height, weight, and body composition (i.e. % lean body mass, % body fat) were recorded for each subject. Next, rating instructions and memory anchoring procedures, either for the Original Adult OMNI-Cycle Scale of Perceived Exertion or for one of the three Alternative Adult OMNI-Cycle Scale formats, were read to the subjects according to counterbalanced assignment (Appendix C). All subjects received standard instructions regarding the use of their assigned scale format immediately before undertaking the orientation cycle ergometer exercise protocol. This would allow the subject to practice estimating their RPE-Overall, RPE-Legs, and RPE-Chest during each power output stage of the orientation test.

The scale format used during the orientation session was assigned by a counterbalanced sequence (without replacement). Each subject used only one of the four formats. The counterbalanced assignment sequence for scale orientation was intended to insure that an equal number of subjects practiced scaling with the Original Adult OMNI-Cycle Scale format and Alternative Adult OMNI-Cycle Scale formats I, II, III. Therefore, clusters of four subjects used one of the four OMNI Scales for the perceptual orientation procedures and were not exposed to the remaining three OMNI Scales. The counterbalanced assignment sequence was intended to insure that the pre-experimental exposure to a given scale format during the orientation session was equally distributed between subjects. This would equalize multiple exposure to a given scale when that scale was presented during both the orientation and the experimental trials (84). Table 3-1 lists the counterbalanced assignment sequences for the orientation session.

Table 3-1 Random assignment of scale format for the orientation session.

<u>Scale Format</u>	<u>Subjects ID Code</u>			
Original OMNI Scale Format	1	6	11	16
Alternative OMNI Scale Format Version 1	2	8	9	15
Alternative OMNI Scale Format Version 2	3	5	12	14
Alternative OMNI Scale Format Version 3	4	7	10	13

All subjects were instructed to maintain their current level of physical activity during the experiment.

3.4.1.1 Orientation Protocol

The orientation test would allow each subject to practice a load incremented cycle exercise protocol. An electronically braked Lode Corival Cycle Ergometer (Model 844, Groningen, Netherlands) was employed for the orientation test. The load incremented continuous test protocol included three, three-minute power output stages as follows: Stage 1, 75 W; Stage 2, 125 W; and Stage 3, 175 W. Following completion of Stage 3, the load was increased by 25 W each minute until peak intensity was achieved. All subjects were instructed to maintain a pedal cadence of $50 \text{ rev} \cdot \text{min}^{-1}$ during each of the three-power output stages. An electronic metronome (Franz Mfg. Co. Inc., Model XB 100 New Haven, CO) with visual and audio signals was used to cue pedal rate (i.e. $50 \text{ rev} \cdot \text{min}^{-1}$). A respiratory valve/mouth-piece, nose clip, and Polar heart rate monitor were positioned on each subject.

Immediately following test termination, subjects completed a two-minute active cool-down consisting of pedaling at $50 \text{ rev} \cdot \text{min}^{-1}$ with zero W brake resistance.

3.4.1.2 Assessments During Orientation

Height: Height (cm) was measured using a Detect-Medic Balance Scale and attached stadiometer (Detecto Scales, Inc., Brooklyn, NY). Height was recorded to the nearest 0.25cm.

Weight: Body weight (kg) was measured using a Tanita bioelectrical impedance analyzer (BIA) (TBF-310GS Tanita Corporation of America, Arlington Heights, Illinois). Subjects were instructed to wear light-weight exercise clothes consisting of shorts and a T-shirt. The subjects did not wear shoes or socks during weight measurement. Weight was recorded to the nearest 0.5kg.

Body Composition: % lean body mass (kg) and % body fat (kg) was measured using BIA procedures (TBF-310GS the Tanita Corporation of America, Arlington Heights, Illinois). Subjects were instructed to wear light-weight exercise clothes consisting of shorts and a T-shirt. The subjects did not wear shoes or socks during the BIA procedures. Body fat was recorded to the nearest 0.1% and 0.5kg using the standard setting.

Oxygen Consumption: An open circuit respiratory-metabolic system (Parvo Medics, Salt Lake City, Utah) was used to measure the following: VO_2 , ($\text{L}\cdot\text{min}^{-1}$ and $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), V_E , ($\text{L}\cdot\text{min}^{-1}$ STPD), and RER. Measurements were made every 30 s during each three-min PO stage. A standard respiratory valve (Rudolph, Model 2700, Kansas City, Mo) with mouthpiece and nose clip were used for all respiratory-metabolic measurements. The respiratory-metabolic system was calibrated using gases of known concentrations before each exercise protocol.

Heart Rate: Heart rate ($\text{beats}\cdot\text{min}^{-1}$) was measured during the last 30 s of each minute of exercise using a wireless Polar Monitoring System (Woodbury, NJ). A Polar transmitter belt was fitted to the subject's chest, just below the pectoralis major muscles. A Polar monitor was attached to the cycle to record the HR responses.

Ratings of perceived exertion: Ratings of perceived exertion were assessed during the load incremented cycle ergometer exercise test using the Adult OMNI-Cycle Scale format assigned to the subject according to the counterbalanced sequence. The undifferentiated RPE-Overall, and differentiated RPE-Legs, and RPE-Chest were measured for each subject using either the Original Adult OMNI-Cycle Scale or one of the three Alternative Adult OMN-Cycle Scale formats. The RPE-Overall, RPE-Legs, and RPE-Chest were measured in counterbalanced order from 30 s to 60 s of each minute of the entire cycle ergometer orientation test. Subjects were randomly assigned to one of the counterbalanced RPE measurement sequences listed in Table 3-2.

Table 3-2 Counterbalanced RPE measurement sequence for the orientation session.

<u>Number of subjects</u>		<u>RPE Sequence</u>		
Cluster 1	3	A	B	C
Cluster 2	3	B	A	C
Cluster 3	3	C	B	A
Cluster 4	3	B	C	A
Cluster 5	2	C	A	B
Cluster 6	2	A	C	B
RPE Sequence Legend:				
Overall=A				
Legs=B				
Chest=C				

The orientation trial would familiarize subjects with cycle ergometer testing and use of a perceived exertion category rating scale. A set of standardized rating instructions and cognitive anchoring procedures for either the Original Adult OMNI-Cycle Scale or for one of the three Alternative Adult OMNI-Cycle Scale formats (Appendix C) were read to each subject immediately before the orientation ergometer exercise test. Instructions and anchoring procedures were specific to the scale assigned to the subject as described in Table 3-1. These instructions included: a) a definition of perceived exertion, and b) an explanation of the procedures to set the low and high OMNI scale anchor points (84,89). For all four scales, perceived exertion was defined as the *subjective intensity of effort, strain, discomfort, and/or*

fatigue that is felt during exercise. The undifferentiated rating was used to estimate the overall body exertion (RPE-Overall), and the differentiated ratings estimated peripheral perceptions of exertion arising from the legs (RPE-Legs) and respiratory perceptions in the chest (RPE-Chest).

The low and high perceptual anchors for the Adult OMNI-Cycle Scale were established using a visually interfaced cognitive procedure. In addition, perception of physical exertion at peak exercise was used to reinforce the high scale anchor. For the Original Adult OMNI-Cycle Scale this anchoring procedure required the subject to cognitively establish a perceived intensity of exertion that is consonant with the numerical rating and verbal descriptor at the bottom (i.e. low anchor, rating 0, extremely easy) and at the top (i.e. high anchor, rating 10, extremely hard) of the perceptual response gradient (Figure 3-1).

For the Adult OMNI-Cycle Scale Alternative I, the anchoring procedure required the subject to cognitively establish a perceived intensity of exertion that is consonant with (a) the low numerical rating (i.e. 1), verbal descriptor (i.e. extremely easy), and the cyclist depicted at the bottom of the scale, and (b) the high numerical rating (i.e. 11), verbal descriptor (i.e. extremely hard), and the cyclist depicted at the top of the perceptual response gradient (Figure 3-2).

For the Adult OMNI-Cycle Scale Alternative II, the anchoring procedure required the subject to cognitively establish a pre-exercise resting state that is consonant with (a) the low numerical rating (i.e. 0), verbal descriptor at the bottom (i.e. rest) of the scale, and (b) the high numerical rating (i.e. 10), verbal descriptor (i.e. extremely hard) and the cyclist depicted at the top of the perceptual response gradient (Fig. 3-3).

Finally, for Adult OMNI-Cycle Scale Alternative III, the anchoring procedure also required the subject to cognitively establish a perceived intensity of exertion that is consonant

with (a) the low numerical rating (i.e. 1), and the cyclist depicted at the bottom of the scale, and (b) the high numerical rating (i.e. 10), verbal descriptor (i.e. extremely hard) and the cyclist depicted at the top of the perceptual response gradient (Figure 3-4).

The standardized rating instructions and cognitive anchoring procedures for the Original Adult OMNI-Cycle Scale and for each of the three Alternative Adult OMNI-Cycle Scale formats are presented in Appendix C.

The position of an attached respiratory valve and nose clip prohibited a verbal RPE response. Therefore, subjects were instructed to point to the number on the OMNI scale that indicates their RPE. The subject pointed to a numerical rating that tells how the whole body exertion feels, a number that tells how the legs exertion feels and a number that tells how the breathing exertion feels in the chest. The rating was verbally repeated to the subject by the investigator to confirm its accuracy. The OMNI Scale designated for that trial was in full view of the subject at all times during each test.

3.4.2 Experimental Trials

3.4.2.1 Description

Each subject undertook four experimental trials. During each trial either the Original Adult OMNI-Cycle Scale format or one of the three Alternative Adult OMNI-Cycle Scale formats (i.e. I, II, III) was presented. The scale format used for a given experimental trial was determined by a counterbalanced sequence. A given sequence was randomly assigned to each subject without replacement. Table 3-3 lists the counterbalanced sequences for the experimental trials.

Table 3-3 Counterbalanced sequence for scale presentation during experimental trials.

<u>Number of subjects</u>		<u>Scale Assignment</u>			
Cluster 1	4	A	B	C	D
Cluster 2	4	B	D	A	C
Cluster 3	4	C	A	D	B
<u>Cluster 4</u>	<u>4</u>	<u>D</u>	<u>C</u>	<u>B</u>	<u>A</u>
Assignment Legend:					
A= Original OMNI Scale Format					
B= Alternative OMNI Scale Format Version I					
C=Alternative OMNI Scale Format Version II					
D=Alternative OMNI Scale Format Version III					

As indicated in Table 3-3, an equal number of subjects were randomly assigned to the four scale sequences containing the Original Adult OMNI-Cycle Scale format and Alternative Adult OMNI-Cycle Scale formats I, II, III. The counterbalanced sequence was intended to control for a rating demand bias that could occur if the same four-scale sequence was presented to each subject during the experimental trials.

3.4.2.2 Experimental Protocol

A load incremented exercise protocol was performed during the experimental trials using an electronically braked Lode Corival Cycle Ergometer (Model 844, Groningen, Netherlands). The test protocol consisted of three-minute power output stages with the initial stage set at 75 W

and subsequent stages incremented by 50 W continuing until termination. All subjects were instructed to maintain a pedal cadence of 50 rev·min⁻¹ throughout the exercise protocol. The cycle exercise test was terminated by the subject due to exhaustion or when the investigator determined that the subject could not maintain the designated pedal rate of 50 rev·min⁻¹ for 10 consecutive seconds or at the subject's request for any other reason. An electronic metronome (Franz Mfg. Co. Inc., Model XB 100 New Haven, CO) with visual and audio cues was used to signal pedal rate (i.e. 50 rev·min⁻¹). A respiratory valve/mouth-piece, nose clip, and Polar heart rate monitor were positioned on each subject. Peak oxygen consumption (VO_{2peak}) was determined when oxygen consumption at the highest exercise intensities remained at steady state despite an increase in cycle power output. To ensure a physiologically valid VO_{2peak} had been obtained, two of the following criteria were met:

1. change in VO₂ of $\leq 150 \text{ ml}\cdot\text{min}^{-1}$ between contiguous stages at peak exercise intensity;
2. inability to maintain pedal frequency of 50 rev·min⁻¹ for 10 consecutive seconds,
3. attainment of $\pm 5 \text{ beats}\cdot\text{min}^{-1}$ of the age-predicted maximal/peak heart rate;
4. respiratory exchange ratio (RER) ≥ 1.1 ;
5. volitional termination due to exhaustion,
6. VO_{2peak} was not statistically different between all four experimental trials.

Immediately following test termination, subjects completed a two-minute active cool-down period consisting of free-wheeling with no brake resistance.

A minimum of 72 h and a maximum of 96 h separated the orientation session from the first experimental trial. Subsequent experimental trials were separated by a 72 to 96 h period. All subjects were tested in a three-hour postprandial state and were instructed to abstain from

alcohol consumption or participating in vigorous physical activity during the 24 h period preceding each trial. All subjects were evaluated for Delayed Onset Muscle Soreness (DOMS) prior to each experimental trial. All subjects were instructed to maintain their current level of physical activity during the experimental period.

3.4.2.3 Experimental Variables

Oxygen Consumption: An open circuit respiratory-metabolic system (Parvo Medics, Salt Lake City, Utah) will be used to measure the following: $\dot{V}O_2$, ($L \cdot \text{min}^{-1}$ and $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), \dot{V}_E , ($L \cdot \text{min}^{-1}$ STPD), and RER. Measurements were made every 30 s during each three-minute PO stage. A standard respiratory valve (Rudolph, Model 2700, Kansas City, Mo) with attached mouthpiece and a nose clip were used for all respiratory-metabolic measurements. The respiratory-metabolic system was calibrated using gases of standard concentrations before each exercise protocol.

Heart Rate: Heart rate ($\text{beats} \cdot \text{min}^{-1}$) was measured during the last 30 s of each minute of the exercise trial using a wireless Polar Monitoring System (Woodbury, NJ). A Polar transmitter belt was fitted to the subject's chest, just below the pectoralis major muscles. A Polar wrist monitor was attached to the cycle to record the HR responses

Ratings of perceived exertion: Ratings of perceived exertion were assessed during the load incremented cycle ergometer exercise test using the Adult OMNI-Cycle Scale format assigned to the subject for that particular trial. The RPE-Overall, RPE-Legs, and RPE-Chest were measured in counterbalanced order from 30 s to 60 s of each minute of each PO stage. Subjects were randomly assigned to one of the counterbalanced RPE measurement sequences listed in Table 3-4.

Table 3-4 Counterbalanced RPE measurement sequence for the experimental trials.

<u>Number of subjects</u>		<u>RPE Sequence</u>		
Cluster 1	3	A	B	C
Cluster 2	3	B	A	C
Cluster 3	3	C	B	A
Cluster 4	3	B	C	A
Cluster 5	2	C	A	B
<u>Cluster 6</u>	<u>2</u>	<u>A</u>	<u>C</u>	<u>B</u>
RPE Sequence:				
Overall=A				
Legs=B				
Chest=C				

Prior to the cycle ergometer exercise test, format specific scaling instructions and cognitive anchoring procedures specific to the designated format for that trial were read to the subject i.e. either the Original Adult OMNI-Cycle Perceived Exertion Scale or one of the three Alternative Adult OMNI-Cycle Scale formats (Appendix C). Each of these procedures were identical to that employed in the orientation trial. For all four scales, perceived exertion was defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that is felt during exercise. The undifferentiated rating was used to estimate the overall body exertion (RPE-Overall), and the differentiated ratings estimated peripheral perceptions of exertion arising from the legs (RPE-Legs) and respiratory perceptions in the chest (RPE-Chest). The low and high perceptual

anchors for the Adult OMNI-Cycle Scale were established using a visually interfaced cognitive procedure (84,89). At the conclusion of the four experimental trials, all subjects were asked to identify the scale format(s) that they prefer.

3.5 DATA ANALYSIS

Initial data analysis computed (\pm) standard deviations for all perceptual and physiological variables.

Due to inter-subject variation in total number of completed exercise test stages two conceptually similar strategies were employed to derive RPE, VO_2 , and HR responses. These derived responses were used in all subsequent statistical analyses. In the first strategy, the absolute VO_2 ($\text{L}\cdot\text{min}^{-1}$) equivalent to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ was calculated for each subject using data from each experimental trial. In this procedure, the separate $\text{VO}_{2\text{peak}}$ ($\text{L}\cdot\text{min}^{-1}$) obtained for each individual for each experimental trial was multiplied by the *a priori* selected percentages i.e., 40%, 65%, and 90%. Regression models were then generated for each subject that separately expressed the derived VO_2 ($\text{L}\cdot\text{min}^{-1}$) values as a function of RPE-Overall, RPE-Legs, and RPE-Chest. The regression models used RPE (Overall, Legs, Chest) and VO_2 ($\text{L}\cdot\text{min}^{-1}$) responses for all completed exercise stages. The slopes and intercepts of the individual regression models were then used to *predict* RPE-Overall, RPE-Legs, and RPE-Chest corresponding to the VO_2 ($\text{L}\cdot\text{min}^{-1}$) equivalent to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$. These calculations were performed separately for each subject for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale. This statistical procedure (a) ensured

that concurrent and construct scale validity were determined using RPE (Overall, Legs, Chest) that were equivalent to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ for each subject and (b) allowed RPE comparisons to be made at the same relative aerobic metabolic rate when examining perceptual signal dominance and integration separately for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale.

In the second statistical strategy, regression equations were generated for each subject by expressing VO_2 ($\text{L}\cdot\text{min}^{-1}$) as a function of HR ($\text{beats}\cdot\text{min}^{-1}$). These models used HR ($\text{beats}\cdot\text{min}^{-1}$) and VO_2 ($\text{L}\cdot\text{min}^{-1}$) responses for all completed exercise stages with calculations performed separately for each experimental trial. The slopes and intercepts of the individual regression models were then used to *predict* HR ($\text{beats}\cdot\text{min}^{-1}$) corresponding to the VO_2 ($\text{L}\cdot\text{min}^{-1}$) previously determined to be equivalent to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$. The regression models were generated for each subject for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale. This statistical procedure ensured that concurrent scale validity was determined using RPE (Overall, Legs, Chest) corresponding to the HR ($\text{beats}\cdot\text{min}^{-1}$) equivalent to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ for each subject.

To test concurrent validity, statistical analysis separately regressed the criterion variables VO_2 ($\text{L}\cdot\text{min}^{-1}$) and HR ($\text{beats}\cdot\text{min}^{-1}$) against the concurrent variables RPE-Overall, RPE-Legs, and RPE-Chest. The concurrent and criterion variables used to generate the regression models corresponded to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$. All variables were derived separately for each subject. Separate regression coefficients were calculated for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale.

To test construct validity, the analysis separately regressed the RPE obtained from the Original Adult OMNI-Cycle Scale against RPE obtained from each of the three Alternative

Adult OMNI-Cycle Scales. Separate regression coefficients were calculated for the RPE-Overall, RPE-Legs, and RPE-Chest equivalent to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$.

To test signal dominance and signal integration, a within subjects three-factor (Rating Site X % $\text{VO}_{2\text{peak}}$ X Scale Format) analysis of variance (ANOVA) was used. The analysis compared 1) RPE-Legs to RPE-Chest, and 2) RPE-Overall to the mean of RPE-Legs and RPE-Chest (Avg RPE(L,C)). The Avg RPE(L,C) equivalent to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ was calculated separately for each subject. A Simple Main Effects *post hoc* analysis decomposed significant main and *a priori* selected interaction effects (i.e., Site x % $\text{VO}_{2\text{peak}}$). Data analysis used Statistical Package for the Social Sciences (SPSS) 17.0 (SPSS, Inc. Chicago, IL). For all analyses statistical significance was set at an alpha level of $P \leq 0.05$.

4.0 RESULTS

This investigation determined the concurrent and construct validity of three alternative versions of the OMNI-Cycle Scale of Perceived Exertion. In contrast to the Original Adult OMNI-Cycle Scale, the formats of the three Alternative Scales (a) did not employ a zero category as a possible exercise response or (b) specifically linked the zero category to a resting (i.e. non-exercise) state. Males ranging from 18-30 years old were recruited as subjects for this investigation. All subjects were recreationally active and healthy. A within subject multiple observation design consisting of one orientation session followed by four counterbalanced experimental trials was used. The purpose of the orientation was to familiarize subjects with cycle ergometer testing and use of either one of the three Alternative Adult OMNI-Cycle Scale formats (i.e. I, II, III) or the Original Adult OMNI-Cycle Scale format. During each of the four counterbalanced experimental trials either one of the three Alternative Adult OMNI-Cycle Scale formats (i.e. I, II, III) or the Original Adult OMNI-Cycle Scale format was presented. Each subject performed all four experimental trials. The trials involved a load incremented cycle ergometer exercise protocol consisting of three-minute power output stages terminating at peak intensity. The scale format to be used for a given experimental trial was determined by a counterbalanced sequence. Ratings of perceived exertion were assessed during the load incremented cycle ergometer exercise test using the Adult OMNI-Cycle Scale format assigned to the subject for that particular trial. The RPE-Overall,

RPE-Legs, and RPE-Chest were measured in counterbalanced order from 30 s to 60 s of each minute of the load incremented cycle protocol.

4.1 SUBJECT'S DESCRIPTIVE CHARACTERISTICS

Listed in Table 4-1 are the means (\pm SD) of the subject's descriptive characteristics for age (yrs), height (Ht), weight (Wt), percent body fat (%), body mass index (BMI), and $\text{VO}_{2\text{peak}}$ ($\text{L}\cdot\text{min}^{-1}$; $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).

Table 4-1 Descriptive characteristics for adult males (N = 16)	
	Mean \pm (SD)
Age (yrs)	23.50 \pm 3.06
Height (cm)	176.19 \pm 7.74
Weight (kg)	75.90 \pm 8.02
Fat (%)	10.83 \pm 3.11
BMI ($\text{kg}\cdot\text{m}^{-2}$)	24.40 \pm 1.67
$\text{VO}_{2\text{peak}}$ ($\text{L}\cdot\text{min}^{-1}$)	2.98 \pm 0.34
$\text{VO}_{2\text{peak}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	39.05 \pm 4.60
Ht, height; Wt, weight; BMI, body mass index ($\text{kg}\cdot\text{m}^{-2}$);	
$\text{VO}_{2\text{peak}}$, peak oxygen consumption ($\text{L}\cdot\text{min}^{-1}$; $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).	

4.2 DESCRIPTIVE RESPONSES

For descriptive purposes the means (\pm SD) of physiological and perceptual responses for the three Alternative Adult OMNI-Cycle Scales (i.e. I, II, & III) and the Original Adult OMNI-Cycle Scale are presented in Table 4-2. The means (\pm SD) of the RPE responses are presented in

Figures 4-1, 4-2, 4-3, and 4-4. These physiological and perceptual data were used to determine concurrent and construct validity of the three Alternative Adult OMNI-Cycle Scales and in the factorial analyses to examine perceptual signal dominance and integration as predicted by the Differentiated Perceived Exertion Model.

Table 4-2 Physiological and perceptual responses during cycle exercise for the three Alternative Adult OMNI-Cycle RPE Scales and the Original Adult OMNI-Cycle RPE Scale.

	Stage	Power Output	Test time*	(N)**	VO ₂ (L·min ⁻¹)	VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	HR (beats·min ⁻¹)	RPE-Legs	RPE-Chest	RPE-Overall
		(W)	(min)		Mean (±SD)	Mean (±SD)	Mean (±SD)	Mean (±SD)	Mean (±SD)	Mean (±SD)
Alternative I	I	75	3	16	1.29 (.07)	17.29 (2.31)	113.94 (14.74)	2.50 (1.21)	2.00 (0.82)	2.06 (1.00)
	II	125	6	16	1.85 (.10)	24.73 (3.29)	139.13 (17.07)	6.00 (1.60)	5.06 (1.77)	5.38 (1.82)
	III	175	9	15	2.57 (.23)	33.61 (4.24)	168.07 (13.54)	9.47 (1.19)	8.40 (1.60)	9.00 (1.36)
	IV	225	12	3	2.97 (.47)	34.87 (6.37)	178.33 (16.92)	10.67 (0.58)	10.00 (1.73)	10.33 (1.16)
	V	275	13	1	3.35 (.00)	38.40 (0.00)	181.00 (0.00)	11.00 (0.00)	10.00 (0.00)	10.00 (0.00)
Alternative II	I	75	3	16	1.27 (.07)	16.62 (1.63)	114.25 (10.49)	2.00 (1.10)	1.81 (0.98)	1.75 (1.00)
	II	125	6	16	1.81 (.08)	24.17 (2.81)	139.44 (12.40)	5.19 (1.76)	4.69 (1.30)	4.94 (1.57)
	III	175	9	14	2.59 (.11)	33.84 (3.71)	165.50 (9.73)	8.36 (1.50)	8.07 (1.33)	8.07 (1.27)
	IV	225	12	5	3.29 (.23)	39.48 (3.13)	180.20 (8.67)	9.60 (0.55)	9.60 (0.89)	9.60 (0.55)
	V	275	13	2	3.39 (.29)	39.35 (3.32)	179.50 (12.02)	10.00 (0.00)	9.50 (0.71)	9.50 (0.71)
Alternative III	I	75	3	16	1.25 (.08)	16.71 (2.24)	112.50 (13.84)	2.63 (1.09)	2.06 (0.77)	2.00 (0.82)
	II	125	6	16	1.84 (.11)	24.66 (3.40)	138.94 (17.23)	6.06 (1.57)	5.00 (1.63)	5.31 (1.58)
	III	175	9	14	2.56 (.15)	33.41 (3.44)	164.50 (11.75)	9.00 (1.04)	8.14 (1.41)	8.14 (1.29)
	IV	225	12	2	3.51 (.41)	40.90 (5.52)	170.50 (10.61)	9.50 (0.71)	9.00 (0.00)	9.50 (0.71)
	V	275	13	2	3.37 (.56)	39.20 (7.21)	177.00 (8.49)	10.00 (0.00)	9.50 (0.71)	10.00 (0.00)
Original	I	75	3	16	1.30 (.07)	17.28 (1.83)	115.44 (10.20)	1.63 (1.41)	1.31 (0.95)	1.63 (1.46)
	II	125	6	16	1.86 (.09)	24.77 (2.95)	141.25 (14.11)	4.94 (2.08)	4.31 (1.58)	4.44 (2.10)
	III	175	9	14	2.57 (.10)	33.34 (2.58)	168.07 (13.49)	8.36 (1.65)	7.36 (1.39)	7.64 (1.60)
	IV	225	12	3	3.51 (.20)	42.40 (4.84)	177.33 (8.62)	9.33 (0.58)	9.33 (0.58)	9.33 (0.58)
	V	275	13	2	3.35 (.38)	39.05 (4.60)	179.50 (7.79)	10.00 (0.00)	10.00 (0.00)	10.00 (0.00)

VO₂, oxygen consumption (L·min⁻¹; ml·kg⁻¹·min⁻¹); HR, heart rate (beats·min⁻¹); RPE, Ratings of Perceived Exertion.

*Test time: Cumulative minutes of exercise completed to a given test stage.

**N: Number of subjects for whom means (±SD) were calculated at the cumulative test time.

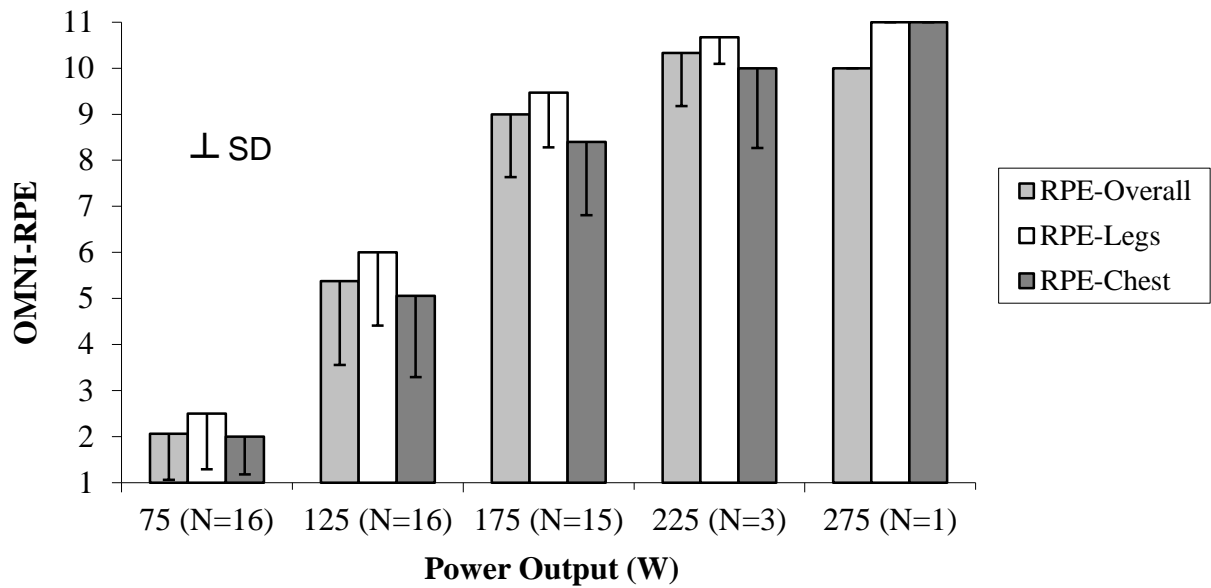


Figure 4-1 Alternative I Adult OMNI-Cycle Scale: Ratings of perceived exertion (RPE) for the overall body, (RPE-Overall), legs, (RPE-Legs), and chest (RPE-Chest). N: Number of subjects for whom means (\pm SD) were calculated at that power output exercise stage. Data are mean \pm SD.

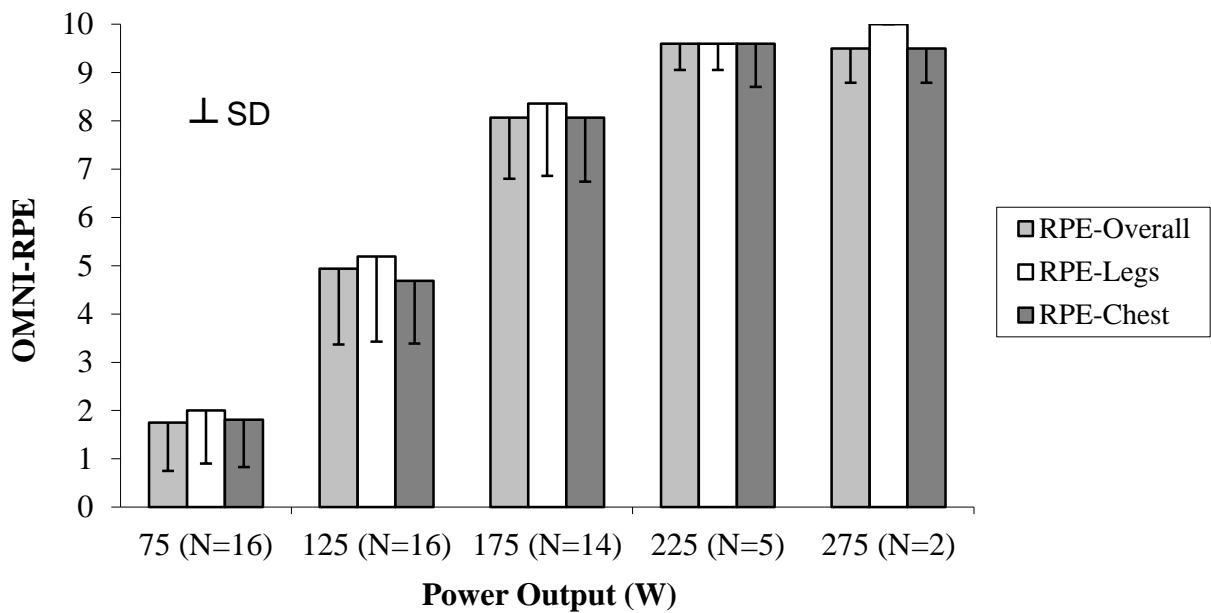


Figure 4-2 Alternative II Adult OMNI-Cycle Scale: Ratings of perceived exertion (RPE) for the overall body, (RPE-Overall), legs, (RPE-Legs), and chest (RPE-Chest). N: Number of subjects for whom means (\pm SD) were calculated at that power output exercise stage. Data are mean \pm SD.

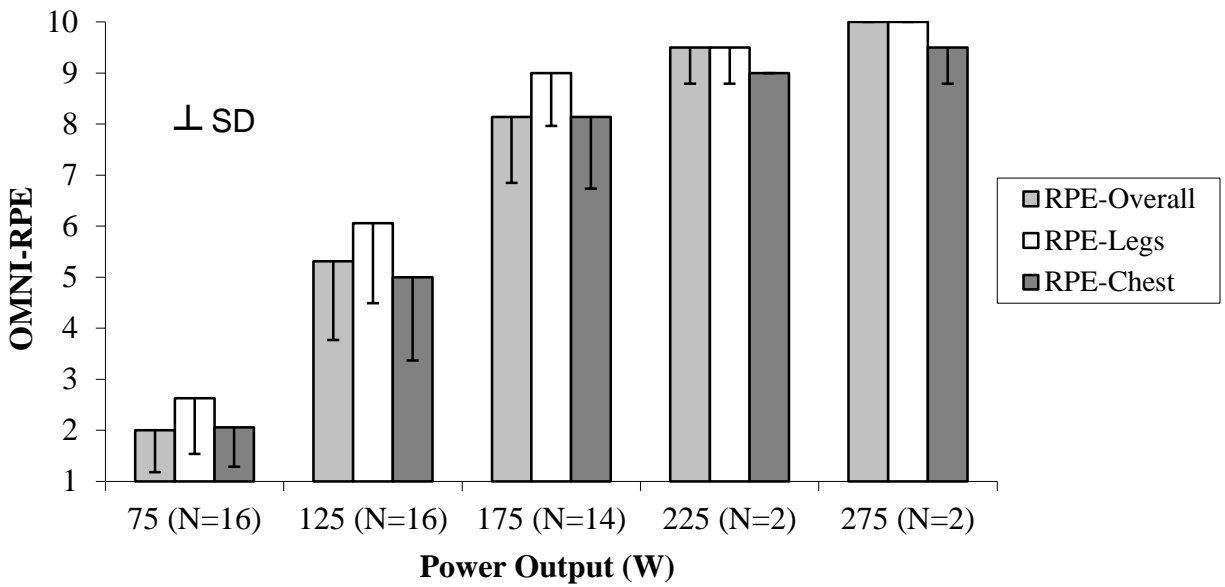


Figure 4-3 Alternative III Adult OMNI-Cycle Scale: Ratings of perceived exertion (RPE) for the overall body, (RPE-Overall), legs, (RPE-Legs), and chest (RPE-Chest). N: Number of subjects for whom means (\pm SD) were calculated at that power output exercise stage. Data are mean \pm SD.

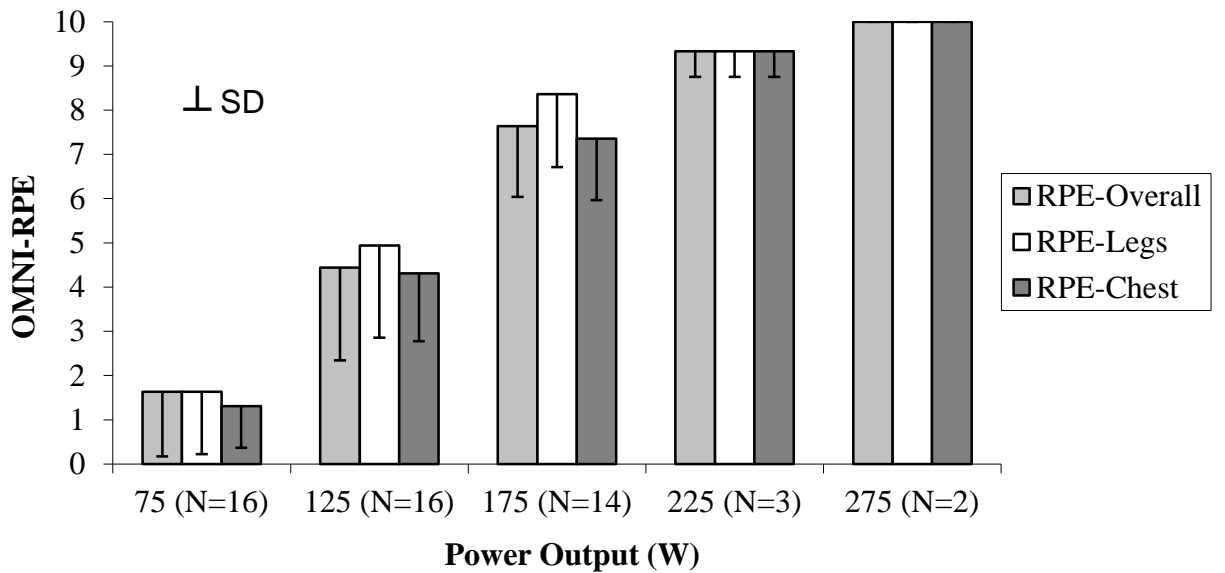


Figure 4-4 Original Adult OMNI-Cycle Scale: Ratings of perceived exertion (RPE) for the overall body, (RPE-Overall), legs, (RPE-Legs), and chest (RPE-Chest). N: Number of subjects for whom means (\pm SD) were calculated at that power output exercise stage. Data are mean \pm SD.

4.3 AIM 1 - CONCURRENT VALIDITY: THREE ALTERNATIVE ADULT OMNI-CYCLE SCALES

Concurrent validity was examined by regressing RPE at 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ against corresponding values for VO_2 ($\text{L}\cdot\text{min}^{-1}$) and HR ($\text{beats}\cdot\text{min}^{-1}$). Regression analyses were computed separately for data derived from the four experimental trials where the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale were presented.

Regression analyses (Tables 4-3, 4-4, 4-5, 4-6) indicated that RPE-Overall, RPE-Legs, and RPE-Chest derived from all three Alternative Adult OMNI-Cycles Scales and the Original Adult OMNI-Cycle Scale distributed as positive functions of both VO_2 and HR. All regression analyses were statistically significant ($P < 0.001$). The correlation coefficients for the four scales ranged from $r = 0.87$ to 0.93 for RPE-Overall, $r = 0.85$ to 0.94 for RPE-Legs, and $r = 0.81$ to 0.93 for RPE-Chest. These correlations established concurrent validity for each of the three Alternative Adult OMNI-Cycle Scales as well as the Original Adult OMNI Scale.

Table 4-3 Alternative I Adult OMNI-Cycle Scale: Regression analyses of RPE expressed as a function of VO_2 and HR during cycle exercise for adult males (N=16).

Variable								
Criterion	RPE Predictor	Slope	SEE	Intercept	SEE	r^*	r^2	SEE
VO_2	Overall	0.20	0.01	0.91	0.07	0.93	0.87	0.24
	Legs	0.20	0.01	0.82	0.07	0.94	0.88	0.22
	Chest	0.20	0.01	0.93	0.07	0.93	0.86	0.24
HR	Overall	7.47	0.57	103.23	3.32	0.89	0.79	11.70
	Legs	7.57	0.51	99.30	3.21	0.91	0.83	10.66
	Chest	7.19	0.70	106.00	3.94	0.84	0.70	14.04

RPE, rating of perceived exertion; VO_2 , oxygen consumption ($\text{L}\cdot\text{min}^{-1}$); HR, heart rate ($\text{beats}\cdot\text{min}^{-1}$); SEE, standard error of estimate.

* $P < 0.001$.

Table 4-4 Alternative II Adult OMNI-Cycle Scale: Regression analyses of RPE expressed as a function of VO₂ and HR during cycle exercise for adult males (N=16).

Variable								
Criterion	RPE Predictor	Slope	SEE	Intercept	SEE	r [*]	r ²	SEE
VO ₂	Overall	0.21	0.01	0.92	0.08	0.91	0.83	0.28
	Legs	0.21	0.02	0.84	0.09	0.90	0.80	0.30
	Chest	0.22	0.01	0.89	0.07	0.93	0.87	0.24
HR	Overall	7.73	0.52	102.95	3.01	0.91	0.83	10.62
	Legs	7.71	0.57	99.98	3.47	0.90	0.80	11.41
	Chest	7.74	0.59	103.78	3.36	0.89	0.79	11.81

RPE, rating of perceived exertion; VO₂, oxygen consumption (L·min⁻¹); HR, heart rate (beats·min⁻¹); SEE, standard error of estimate.

* $P < 0.001$.

Table 4-5 Alternative III Adult OMNI-Cycle Scale: Regression analyses of RPE expressed as a function of VO₂ and HR during cycle exercise for adult males (N=16).

Variable								
Criterion	RPE Predictor	Slope	SEE	Intercept	SEE	r [*]	r ²	SEE
VO ₂	Overall	0.21	0.01	0.84	0.08	0.92	0.85	0.26
	Legs	0.20	0.01	0.76	0.09	0.90	0.81	0.29
	Chest	0.20	0.02	0.91	0.09	0.88	0.78	0.32
HR	Overall	7.67	0.58	100.76	3.46	0.89	0.79	11.67
	Legs	7.68	0.54	96.02	3.52	0.90	0.82	11.02
	Chest	7.12	0.77	105.04	4.45	0.81	0.65	15.16

RPE, rating of perceived exertion; VO₂, oxygen consumption (L·min⁻¹); HR, heart rate (beats·min⁻¹); SEE, standard error of estimate.

* $P < 0.001$.

Table 4-6 Original Adult OMNI-Cycle Scale: Regression analyses of RPE expressed as a function of VO₂ and HR during cycle exercise for adult males (N=16).

Variable								
Criterion	RPE Predictor	Slope	SEE	Intercept	SEE	r [*]	r ²	SEE
VO ₂	Overall	0.18	0.02	1.12	0.08	0.87	0.76	0.34
	Legs	0.18	0.02	1.08	0.09	0.85	0.73	0.36
	Chest	0.20	0.01	1.09	0.07	0.92	0.85	0.27
HR	Overall	7.14	0.52	109.76	2.84	0.90	0.81	11.43
	Legs	7.03	0.52	107.57	3.01	0.90	0.80	11.54
	Chest	7.20	0.59	111.09	3.07	0.88	0.77	12.50

RPE, rating of perceived exertion; VO₂, oxygen consumption (L·min⁻¹); HR, heart rate (beats·min⁻¹); SEE, standard error of estimate.

* $P < 0.001$.

4.4 AIM 2 - CONSTRUCT VALIDITY: ALTERNATIVES I, II, AND III ADULT OMNI-CYCLE SCALES

Construct validity was examined by regressing RPE derived separately from each of the three Alternative Adult OMNI-Cycle Scales against RPE derived from the Original OMNI-Cycle Scale. RPE derived from the Alternative and Original Scales corresponded to 40%, 65%, and 90% VO_{2peak}.

Listed in Tables 4-7, 4-8, and 4-9 are the regression models for Alternative I, Alternative II, and Alternative III Adult OMNI-Cycle Scales, respectively. The regression analyses indicated that RPE (Overall, Legs, Chest) derived from the three Alternative Adult OMNI-Cycle Scales, were positively related to the RPE derived from the Original Adult OMNI-Cycle Scale. All regression analyses were statistically significant ($P < 0.001$). The correlation coefficients for the three alternative scales ranged from $r = 0.93$ to 0.98 for RPE-Overall, $r = 0.93$ to 0.98 for

RPE-Legs, and $r = 0.94$ to 0.98 for RPE-Chest. These correlations established construct validity for each of the three Alternative OMNI-Cycle Scales.

Table 4-7 Regression analyses: RPE from Alternative I Adult OMNI-Cycle Scale expressed as a function of RPE from Original Adult OMNI-Cycle Scale for adult males (N=16).

Alternative I - RPE Predictor							
Criterion							
Original Scale	Slope	SEE	Intercept	SEE	r[*]	r²	SEE
RPE-Overall	1.05	0.04	-0.79	0.20	0.98	0.95	0.71
RPE-Legs	1.05	0.04	-0.91	0.22	0.98	0.95	0.73
RPE-Chest	1.04	0.03	-0.77	0.19	0.98	0.95	0.69

RPE, rating of perceived exertion; SEE, standard error of estimate.

* $P < 0.001$.

Table 4-8 Regression analyses: RPE from Alternative II Adult OMNI-Cycle Scale expressed as a function of RPE from Original Adult OMNI-Cycle Scale for adult males (N=16).

Alternative II - RPE Predictor							
Criterion							
Original Scale	Slope	SEE	Intercept	SEE	r[*]	r²	SEE
RPE-Overall	1.04	0.04	-0.71	0.25	0.97	0.93	0.87
RPE-Legs	1.07	0.04	-0.90	0.27	0.96	0.93	0.89
RPE-Chest	1.04	0.05	-1.05	0.27	0.96	0.92	0.89

RPE, rating of perceived exertion; SEE, standard error of estimate.

* $P < 0.001$.

Table 4-9 Regression analyses: RPE from Alternative III Adult OMNI-Cycle Scale expressed as a function of RPE from Original Adult OMNI-Cycle Scale for adult males (N=16).

Alternative III - RPE Predictor							
Criterion							
Original Scale	Slope	SEE	Intercept	SEE	r[*]	r²	SEE
RPE-Overall	1.01	0.06	-0.83	0.36	0.93	0.86	1.22
RPE-Legs	1.02	0.06	-1.11	0.38	0.93	0.87	1.18
RPE-Chest	1.02	0.05	-1.31	0.33	0.94	0.89	1.05

RPE, rating of perceived exertion; SEE, standard error of estimate.

* $P < 0.001$.

4.5 PERCEPTUAL SIGNAL DOMINANCE: THREE ALTERNATIVE ADULT OMNI-CYCLE SCALES AND ORIGINAL ADULT OMNI-CYCLE SCALE

To determine signal dominance, RPE-Legs was statistically compared to RPE-Chest using data derived from the three Alternative Adult OMNI-Cycle Scales (i.e. I, II, III) and the Original Adult OMNI-Scale. The ANOVA used RPE responses corresponding to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ determined separately for each exercise trial.

4.5.1 Aim 3 - Signal Dominance

To examine perceptual signal dominance ($\text{RPE-Legs} > \text{RPE-Chest}$), a within subjects three-factor (Rating Site X % $\text{VO}_{2\text{peak}}$ X Scale) ANOVA (2 X 3 X 4) was computed. This analysis examined the main effects of a) scale type i.e. the three Alternative Adult OMNI-Cycle Scales (I, II, and III), and the Original Adult OMNI-Cycle Scale, b) two rating sites (i.e. Legs and Chest), and c) relative aerobic metabolic rate (i.e. 40%, 65%, 90% $\text{VO}_{2\text{peak}}$). Significant main effects and *a priori* selected interactions were selectively decomposed with pair wise comparisons using a Simple Main Effects *post-hoc* analysis.

Presented in Table 4-10 are the group mean ($\pm\text{SD}$) RPE-Legs and RPE Chest responses corresponding to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale. These differentiated perceptual responses were used in the factorial analysis to examine signal dominance for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale.

Table 4-10 Ratings of perceived exertion (RPE-Legs and RPE-Chest) during cycle exercise at 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$ for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale (N=16).

Scale	40%		65%		90%	
	RPE-Legs Mean (\pm SD)	RPE-Chest Mean (\pm SD)	RPE-Legs Mean (\pm SD)	RPE-Chest Mean (\pm SD)	RPE-Legs Mean (\pm SD)	RPE-Chest Mean (\pm SD)
Alternative I	1.94 (0.85)	1.48 (0.70)	5.48 (0.77)	4.83 (0.88)	9.03 (0.82)	8.19 (1.24)
Alternative II	1.94 (0.89)	1.52 (0.86)	5.37 (0.73)	4.87 (0.83)	8.81 (0.74)	8.21 (1.01)
Alternative III	2.33 (0.79)	1.84 (0.65)	5.86 (0.66)	5.05 (1.01)	9.38 (0.67)	8.27 (1.61)
Original	1.24 (1.46)	0.80 (1.24)	4.85 (1.27)	4.25 (1.19)	8.47 (1.34)	7.70 (1.46)

Data are means \pm standard deviation (SD).

4.5.2 ANOVA to determine perceptual signal dominance for the Alternative and Original Adult OMNI-Cycle Scales

The results of the three-factor ANOVA (Rating Site X % $\text{VO}_{2\text{peak}}$ X Scale) are presented in Table 4-11. Marginal means are listed in [Appendix E Table A-1](#). There was a significant ($P = 0.012$) main effect for Site. The significant main effect indicated that the marginal mean for RPE-Legs was greater than the marginal mean for RPE-Chest. Next, there was a significant ($P < 0.001$) main effect for % $\text{VO}_{2\text{peak}}$. The main effect indicated that the marginal means for RPE increased from 40% to 65% and from 65% to 90% % $\text{VO}_{2\text{peak}}$. Finally there was a significant ($P = 0.002$) main effect for Scale format. The main effect indicated that the marginal means for RPE differed between the four Adult OMNI-Cycle Scales formats (i.e. the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Scale). There was a significant ($P < 0.05$) two factor (Scale X Site) interaction. However, *post-hoc* analysis of the Scale X Site interaction was not required to examine any of the research aims. As such, further decomposition of the interaction was not taken. There were no significant effects for the Scale X % $\text{VO}_{2\text{peak}}$ interaction

($P = 0.358$) and the Site X %VO_{2peak} ($P = 0.060$) interaction. Finally, there was no significant ($P = 0.183$) three factor (Rating Site X %VO_{2peak} X Scale) interaction effect.

Table 4-11 Results of the three-factor ANOVA to determine perceptual signal dominance: RPE-Legs vs. RPE-Chest (N=16).

Main Effects	df	F	P	η^2
Site	1	8.28	0.012*	0.356
Error	15			
%VO _{2peak}	2	1277.48	<.001*	0.988
Error	30			
Scale	3	9.20	0.002*	0.38
Error	45			
Interaction Effects				
Scale X Site	3	3.96	0.033*	0.209
Error	45			
Scale X %VO _{2peak}	6	1.08	0.358	0.067
Error	90			
Site X %VO _{2peak}	2	4.12	0.06	0.216
Error	30			
Scale X Site X %VO _{2peak}	6	1.86	0.183	0.11
Error				

* Statistically significant $P < .05$

4.6 PERCEPTUAL SIGNAL INTEGRATION

4.6.1 Aim 4 - Signal Integration

To examine perceptual signal integration, a within subjects three-factor (Rating Site X % VO_{2peak} X Scale) ANOVA (2 X 3 X 4) was computed. This analysis examined the main effects of a) scale type; i.e. the three Alternative Adult OMNI-Cycle scales (I, II, or III) and the Original Adult OMNI-Cycle Scale, b) rating sites RPE-Overall and Avg RPE(L,C), and c) relative metabolic rate (40%, 65%, 90% VO_{2peak}). Significant main effects and *a priori* selected interactions were selectively decomposed with pair wise comparisons using a Simple Main Effects *post-hoc* analysis.

Presented in Table 4-12 are the RPE-Overall and the Avg RPE(L,C) corresponding to 40%, 65% and 90% VO_{2peak} for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale. These perceptual responses were used in the factorial analysis to examine signal integration for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale.

Table 4-12 RPE-Overall and the Avg RPE(L,C) at 40%, 65%, and 90% VO_{2peak} for the three Alternative Adult OMNI-Cycle RPE Scales and the Original Adult OMNI-Cycle Scale (N=16).

Scale	40%		65%		90%	
	RPE-Overall Mean (±SD)	RPE-Legs & RPE-Chest Mean (±SD)	RPE-Overall Mean (±SD)	RPE-Legs & RPE-Chest Mean (±SD)	RPE-Overall Mean (±SD)	RPE-Legs & RPE-Chest Mean (±SD)
Alternative I	1.53 (0.76)	1.71 (0.71)	5.03 (0.81)	5.16 (0.70)	8.53 (0.95)	8.61 (0.86)
Alternative II	1.55 (0.92)	1.73 (0.81)	4.98 (0.89)	5.12 (0.68)	8.41 (1.02)	8.51 (0.72)
Alternative III	1.76 (0.64)	2.08 (0.66)	5.24 (0.66)	5.45 (0.69)	8.72 (0.80)	8.83 (0.96)
Original	0.94 (1.41)	1.02 (1.29)	4.47 (1.34)	4.55 (1.13)	8.01 (1.42)	8.08 (1.27)

Data are means ± standard deviation.

4.6.2 ANOVA to determine perceptual signal integration for the Alternative and Original Adult OMNI-Cycle Scales

To examine signal integration, the Avg RPE(L,C) was statistically compared to the RPE-Overall. The ANOVA examined data derived from the three Alternative Adult OMNI-Cycle Scales (i.e. I, II, III) and the Original Adult OMNI-Scale. Marginal means are listed in [Appendix E Table A-2](#). For each scale format, RPE responses corresponded to 40%, 65%, and 90% $\text{VO}_{2\text{peak}}$.

The results of the three-factor ANOVA to examine perceptual signal integration for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale are presented in Table 4-13. There was a significant ($P < 0.001$) main effect for % $\text{VO}_{2\text{peak}}$. The main effect indicated that the marginal mean RPE increased from 40% to 65% $\text{VO}_{2\text{peak}}$ and from 65% to 90% $\text{VO}_{2\text{peak}}$ with data collapsed over all four scales. There was a significant ($P = 0.006$) main effect for Scale. The main effect indicated that the marginal mean RPE differed between the four OMNI Scale formats (i.e. three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale). There was not a significant main effect for Site ($P = 0.185$). There was not a significant two factor Site X Scale ($P = 0.165$), % $\text{VO}_{2\text{peak}}$ X Scale ($P = 0.423$), and Site X % $\text{VO}_{2\text{peak}}$ ($P = 0.481$) interaction. There was not a significant effect for the three factor Site X % $\text{VO}_{2\text{peak}}$ X Scale ($P = 0.360$). These findings indicated that perceptual signal integration was demonstrated for RPE derived from the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale where relative aerobic metabolic rates ranged from 40% to 90% $\text{VO}_{2\text{peak}}$.

Table 4-13 Results of the three factor ANOVA to determine perceptual signal integration: RPE-Overall = Avg RPE(L,C) (N=16).

Main Effects	df	F	P	η^2
Site	1	1.931	0.185	0.114
Error	15			
%VO _{2peak}	2	1870.821	<.001*	0.992
Error	30			
Scale	3	7.349	0.006*	0.329
Error	45			
Interaction Effects				
Scale X Site	3	1.863	0.165	0.11
Error	45			
Scale X %VO _{2peak}	6	0.895	0.423	0.056
Error	90			
Site X %VO _{2peak}	2	0.523	0.481	0.034
Error	30			
Scale X Site X %VO _{2peak}	6	1.045	0.36	0.065
Error	90			

* Statistically significant $P < 0.05$

Statistical effects were: Site: non-significant main effect; %VO_{2peak}: significant main effect; Scale: significant main effect.

4.7 SUMMARY

4.7.1 Aim 1 - Concurrent Validity

- It was hypothesized that during load incremented cycle ergometry oxygen uptake and heart rate would be positively correlated with RPE-Overall, RPE-Legs, and RPE-Chest when data were derived separately from the Alternative Adult OMNI-Cycle Scales I, II, and III.
- The regression analyses for Alternative I, Alternative II, and Alternative III Adult OMNI-Cycle Scales indicated that the RPE-Overall, RPE-Legs, and RPE-Chest distributed as a positive function ($P < 0.001$) of both VO_2 ($\text{L} \cdot \text{min}^{-1}$) and HR ($\text{beats} \cdot \text{min}^{-1}$) for young adult males ($N=16$).
- These findings established concurrent validity of the three Alternative Adult OMNI-Cycle Scales across relative aerobic metabolic rates ranging from 40% to 90% $\text{V O}_{2\text{peak}}$.

4.7.2 Aim 2 - Construct Validity

- It was hypothesized that during load incremented cycle ergometry there would be a positive correlation between RPE (Overall, Legs, and Chest) derived separately from the Alternative Adult OMNI-Cycle Scales I, II, and III and the Original Adult OMNI-Cycle Scale.
- The regression analyses demonstrated that RPE-Overall, RPE-Legs, and RPE-Chest derived separately for the Alternative I, II, and III Adult OMNI-Cycle Scales were

positively correlated with perceptual responses derived from the Original Adult OMNI-Cycle Scale for young adult males (N=16).

- These findings established construct validity of the three Alternative Adult OMNI-Cycle Scales across relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$.

4.7.3 Aim 3 - Perceptual Signal Dominance: Alternative OMNI-Cycle Scales and Original Adult OMNI-Cycle Scale.

- It was hypothesized that during load incremented cycle ergometry that RPE-Legs would be greater than RPE Chest for data derived from the Alternative Adult OMNI-Cycle Scales I, II, and III, and the Original Adult OMNI-Cycle Scale. These findings would indicate that the three alternative scales identify perceptual signal dominance consistent with the predictions of the Differentiated Perceived Exertion Model.
- **Main Effects:**
 - The ANOVA indicated a significant ($P = 0.012$) main effect for Site.
 - The main effect indicated that the marginal mean of RPE-Legs was greater ($P < 0.05$) than the marginal mean of RPE-Chest when perceptual responses were averaged across % $\text{VO}_{2\text{peak}}$ and Scale.
 - The ANOVA indicated a significant ($P < 0.001$) main effect for % $\text{VO}_{2\text{peak}}$.
 - The main effect indicated that the marginal mean of RPE increased from 40% to 65% and from 65% to 90% $\text{VO}_{2\text{peak}}$ when perceptual responses were averaged across Site and Scale.

- The ANOVA indicated a significant ($P < 0.002$) main effect for Scale format for the three Alternative Adult OMNI-Cycle Scales (i.e. I, II, III) and the Original Adult OMNI-Cycle Scale.
 - The main effect indicated that the marginal mean of RPE differed between the three Alternative Scales (i.e. I, II, III) and the Original Adult OMNI-Scale when perceptual responses were averaged across %VO_{2peak} and Site.
- **Interaction Effects:**
 - The ANOVA indicated a significant ($P < 0.05$) two-factor (Scale X Site) interaction effect.
 - No significant effects were found for the Site X %VO_{2peak}, Scale X % VO_{2peak}, and the Site X %VO_{2peak} X Scale interactions.
 - These findings indicated that perceptual signal dominance was demonstrated for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale when comparisons were made across relative aerobic metabolic rates ranging from 40% to 90% VO_{2peak}.

4.7.4 Aim 4 - Perceptual Signal Integration: Alternative Adult OMNI-Cycle Scales and Original Adult OMNI-Cycle Scale.

- It was hypothesized that during load incremented cycle ergometry that RPE-Overall would not differ from the Avg RPE(L,C) for data derived from the Alternative Adult OMNI-Cycle Scales I, II, and III, and the Original Adult OMNI-Cycle Scale. These

findings would indicate that the three alternative scales identify perceptual signal integration consistent with the prediction of the Differentiated Perceived Exertion Model.

- **Main Effects:**

- There was a significant ($P < 0.001$) main effect for % $\text{VO}_{2\text{peak}}$.
 - When data were averaged over Site and Scale effects, the analysis indicated that the marginal mean of RPE increased from 40% to 65% and from 65% to 90% % $\text{VO}_{2\text{peak}}$ intensities.
- There was not a significant main effect for Site ($P = 0.185$)
- There was a significant main effect for Scale ($P = 0.006$).
- There was not a significant effect for the two factor Site X Scale ($P = 0.165$), % $\text{VO}_{2\text{peak}}$ X Scale ($P = 0.423$), and Site X % $\text{VO}_{2\text{peak}}$ ($P = 0.481$) interactions.
- There was not a significant effect for the three factor Site X % $\text{VO}_{2\text{peak}}$ X Scale ($P = 0.360$) interaction.
- These findings indicated that perceptual signal integration was demonstrated for RPE derived from the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale where relative aerobic metabolic rates ranged from 40% to 90% $\text{VO}_{2\text{peak}}$.

5.0 DISCUSSION

5.1 INTRODUCTION

The purpose of this investigation was to determine the concurrent and construct validity of three alternative versions of the OMNI-Cycle Scale of Perceived Exertion. In addition, the investigation determined whether the alternative scales identified perpetual signal dominance and integration as predicted by the Differentiated Perceived Exertion Model. Previous investigations support concurrent validity and construct validity of the various mode specific formats of the Original OMNI Perceived Exertion Scale for use during cycling, walking/running, stepping, resistance exercise, kayaking, and elliptical movements (52,59,74,80,81,84,88,92,101,102). Such validity evidence supports the use of the OMNI Scale by female and male children and adults performing weight bearing and non-weight bearing aerobic exercise and upper and lower body resistance exercise. Moreover, the OMNI Scale demonstrates precision in distinguishing between an anatomically regionalized perceptual signal (i.e., RPE-Legs, RPE-Chest) and a total body perceptual signal (i.e., RPE-Overall) when both types of assessments are made at approximately the same time during aerobic and resistance exercise (64,74,83,84,88,102).

The above described psychometric versatility of the OMNI Scale notwithstanding, under selected applications it's verbal-numerical format may present measurement difficulties owing to the presence of a "0" as the lower terminal category in the perceptual response range. In some

cases the “0” category acts as an integer and presents statistical and mathematical limitations when calculating derived indices such as the PAI (103), and conditioning related indices that measure load, monotony, and strain, and also indices of thermal strain (11,31,89,100). Calculation of these indices using RPE derived from the Original OMNI-Scale could be complicated when a zero rating response is considered an exercise response.

Thus, there is a need to modify the original Adult OMNI Scale format by either eliminating the “0” category as a possible exercise response or to specifically link the “0” category to a resting (i.e., pre- or post-exercise) state. Such a modification would facilitate research and clinical applications of the OMNI Scale where derived indices are computed using perceptual, physiological, sensory, psychobehavioral, and/or physical activity variables.

The purpose of the present investigation was to determine both the concurrent validity and the construct validity of three alternative Adult OMNI-Cycle Perceived Exertion Scale formats that meet the above modification regarding a zero response category. The investigation also examined perceptual signal dominance and mode of perceptual signal integration using RPE-Overall, RPE-Legs, and RPE-Chest derived from the three Alternative Adult OMNI-Cycle Scales of Perceived Exertion. Cycle ergometry was chosen as the testing mode for this investigation because the Original Adult OMNI Scale was validated using a load incremented cycle ergometer protocol terminating at peak exercise intensity (84). At present, no published studies have examined the validity of an Adult OMNI Perceived Exertion Scale that (a) does not employ a zero category as a possible exercise response or (b) specifically links the zero category to a resting (i.e., non-exercise) state.

Males ranging in age from 18-30 years were recruited as subjects for this investigation. All subjects were recreationally active and healthy. Recreationally active individuals were

defined as those who currently performed aerobic exercise a minimum of 2 days/week for 60 min with a weekly total of no more than 150 min, and who were not participating in collegiate or professional sports. Resistance training did not count toward the weekly physical activity total. The findings of the present investigation are generalizable to this cohort of young adult males.

A within subject multiple observation design consisting of one orientation session followed by four counterbalanced experimental trials was used in this investigation. The purpose of the orientation was to familiarize subjects with cycle ergometer testing and use of either one of the three Alternative Adult OMNI-Cycle Scale formats (i.e., I, II, III) or the Original Adult OMNI-Cycle Scale format. During each of the four counterbalanced experimental trials either one of the three Alternative Adult OMNI-Cycle Scale formats (i.e., I, II, III) or the Original Adult OMNI-Cycle Scale was presented. All subjects performed the four experimental trials which involved a load incremented cycle ergometer exercise protocol terminating at peak intensity.

The Original Adult OMNI-Cycle Scale format includes a zero category as the lowest numerical rating of exertion. The exertional scale categories range from a number 0 (i.e., extremely easy) to number 10 (i.e., extremely hard). The original scale positions verbal descriptors next to the numerical categories 0, 2, 4, 6, 8, and 10. Pictorial descriptors are placed in juxtaposition to the 0, 3, 6, and 9 numerical categories.

The Alternative I Adult OMNI-Cycle Scale employs numerical categories ranging from 1 (i.e., extremely easy) to 11 (i.e., extremely hard) with pictorial descriptors positioned next to the numerical categories 1, 4, 7, and 10. Verbal descriptors are positioned at the numerical categories 1, 3, 5, 7, 9, and 11.

The Alternative II Adult OMNI-Cycle Scale eliminates the “extremely easy” verbal descriptor and adds a “rest” verbal descriptor. This scale uses numerical categories ranging from 0 (i.e., rest) to 10 (i.e., extremely hard) with pictorial descriptors placed next to the numerical categories 1, 4, 7, and 10. The Alternative II Adult OMNI-Cycle Scale positions verbal descriptors next to the numerical categories 0, 2, 4, 6, 8, and 10.

The Alternative III Adult OMNI-Cycle Scale is identical to the Alternative II Scale except that it eliminates the 0 (i.e., rest) category. This scale presents numerical categories ranging from 1 (i.e., no verbal descriptor) to 10 (i.e., extremely hard) with pictorial descriptors placed next to the numerical categories 1, 4, 7, and 10. The Alternative III Adult OMNI-Cycle Scale positions verbal descriptors next to the numerical categories 2, 4, 6, 8, and 10. The juxtaposition of numerical and verbal categories for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale is presented in Table 5-1. The pictorial descriptors used in the three alternative Adult OMNI-Cycle Scales are identical to the pictorial descriptors used in the Original Adult OMNI-Cycle Scale.

Table 5-1 Numerical categories and verbal descriptors for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale.

Scales		Numerical Categories and Verbal Descriptors									
Alternative Adult OMNI-Cycle Scale I		1 extremely easy	2	3 easy	4	5 somewhat easy	6	7 somewhat hard	8	9 hard	10 extremely hard
Alternative Adult OMNI-Cycle Scale II	0 rest	1	2 easy	3	4 somewhat easy	5	6 somewhat hard	7	8 hard	9	10 extremely hard
Alternative Adult OMNI-Cycle Scale III		1	2 easy	3	4 somewhat easy	5	6 somewhat hard	7	8 hard	9	10 extremely hard
Original Adult OMNI-Cycle Scale		0 extremely hard	1	2 easy	3	4 somewhat easy	5	6 somewhat hard	7	8 hard	9 extremely hard

5.2 CONCURRENT VALIDITY OF THE THREE ALTERNATIVE VERSIONS OF THE ADULT OMNI-CYCLE SCALE OF PERCEIVED EXERTION

5.2.1 Conceptual Background

The first reported experiments to validate RPE metrics using a concurrent perceptual-physiological paradigm involved the Borg 15 category numerical-verbal scale (19), the Children's Effort Rating Table (CERT) (106), the Cart and Load Effort Rating Scale (CALER)(29), the Pictorial Children's Effort Rating Table (PCERT) (107) and the various OMNI Perceived Exertion Scale formats for aerobic and resistance exercise. The present investigation used a concurrent validity paradigm developed by Robertson et al. where VO_2 and HR served as criterion variables and RPE derived from a category metric served as the concurrent variable (84). This is generally accepted as a standard paradigm to validate perceived exertion numerical category scales.

Perceptual-physiological paradigms to establish concurrent validity of category rating scales are based on Borg's Range Model and Borg's Effort Continua Model. Borg's Range Model, first proposed in 1961, describes a continuum of perceptual categories from "0" or very low to a high number indicating a very high effort level. This perceptual range provides a frame of reference that employs two important assumptions (11,13,16). First, it is expected that for any given exercise range between rest and maximum, there is a corresponding and equal perceived exertion range. The second assumption maintains that both the RPE range and the intensity of perceptions at low and high exercise levels are equal between clinically normal individuals regardless of their physical fitness (11,13,16). In 1977 Borg developed the Effort Continua

Model. This model has three main *effort continua*: 1) perceptual, 2) physiological, and 3) performance (8,16). The basic tenet underlying the Effort Continua Model is that as exercise performance intensity increases from low to high there are *corresponding* and *interdependent* increases in perceptual (i.e., RPE) and physiological responses such as VO_2 , HR, V_E , and blood lactate concentration. To the extent that a valid category metric is employed, it is expected that the perceptual responses provide the same information as do physiological responses regarding exercise tolerance, exercise intensity self-regulation, and exercise intensity preference. As such, RPE can be used independently and/or in conjunction with physiological responses for the forgoing exercise performance applications. The concurrent increase in the perceptual and physiological continua as the performance intensity increases is a central assumption in establishing perceived exertion scale validity. Thus, the psychometric predictions of these two models served as the conceptual rationale underlying the use of a concurrent perceptual-physiological paradigm to validate the Alternative Adult OMNI-Cycle Perceived Exertion Scales that were examined in the present investigation.

5.2.2 Purpose and Hypothesis

The first aim of this investigation was to determine concurrent validity of three Alternative versions of the Original Adult OMNI-Cycle Scale of Perceived Exertion for young adult males performing load incremented cycle ergometer exercise. The concurrent validity paradigm used RPE-Overall, RPE-Legs, and RPE-Chest responses derived from the three alternative formats of the Adult OMNI-Cycle Scale as the concurrent variables. Oxygen uptake and HR were used as criterion variables. Concurrent validity was examined separately for each Alternative OMNI-

Cycle Scale. It was hypothesized that: a) VO_2 would be positively correlated with RPE-Overall, RPE-Legs, and REP-Chest when data were derived separately from Alternative Adult OMNI-Cycle Scales I, II, and III, and b) HR would be positively correlated with RPE-Overall, RPE-Legs, and REP-Chest when data were derived separately from Alternative Adult OMNI-Cycle Scales I, II, and III. These statistical correlations would establish concurrent measurement validity for the three Alternative Adult OMNI-Cycle Scales for young adult males performing load incremented cycle ergometer exercise at relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$.

5.2.3 Summary of Research Findings

In the present investigation, regression analyses indicated that RPE derived from the three Alternative Adult OMNI-Cycle Scales distributed as a positive function of VO_2 and HR responses over the submaximal cycle ergometer exercise intensities. It was expected that the concurrent variables (i.e., OMNI Scale RPE) derived from the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale would distribute as a positive function of VO_2 and HR. All regression analyses were statistically significant ($P < 0.001$). The regression correlation coefficients for the three scales ranged from $r = 0.89$ to 0.93 for RPE-Overall, $r = 0.90$ to 0.94 for RPE-Legs, and $r = 0.81$ to 0.93 for RPE-Chest. These findings supported the hypotheses, establishing concurrent validity for each of the three Alternative Adult OMNI-Cycle Scales.

The findings in the present investigation are in agreement with the predictions of both Borg's Range Model and Borg's Effort Continua Model. Moreover, the strong positive

correlations between the three Alternative Adult OMNI-Cycle Scales and both VO_2 and HR are consistent with previous investigations that employed a concurrent paradigm to validate perceived exertional category metrics. These previous investigations demonstrated that during aerobic exercise, correlations between criterion physiological (i.e. VO_2 and HR) variables and RPE were both strong and positive. For example, during earlier validation studies where RPE was derived from the PCERT and the Child OMNI-Walk/Run and where VO_2 and HR served as criterion variables, validity correlations ranged from $r = 0.89$ to 0.92 (107).

The Original Adult OMNI-Cycle Scale was included in the research paradigm to provide an internal manipulation check on the experimental design. It was expected that the strong validity coefficients observed for both the Alternative and Original OMNI Scales would demonstrate that the load incremented forcing function was appropriate to test concurrent validity of category metrics to assess exertional perceptions for submaximal aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$. In the present investigation, regression analyses indicated that RPE derived from the Original Adult OMNI-Cycle Scale distributed as a positive function of VO_2 and HR responses over the submaximal cycle ergometer exercise intensities. All regression analyses were statistically significant ($P < 0.001$). The regression correlation coefficients for the Original Adult OMNI-Cycle Scale ranged from $r = 0.87$ to 0.90 for RPE-Overall, $r = 0.85$ to 0.90 for RPE-Legs, and $r = 0.88$ to 0.92 for RPE-Chest. The fact that strong positive validity correlations were observed for both the Original and Alternative Scales is consistent with a previous report where the Original OMNI-Cycle format was evaluated for young adult males performing load incremented protocols (84).

5.2.4 Comparisons with Previous Research

The linear regression models derived in the present investigation are consistent with previous validation paradigms that administered age specific versions of the OMNI scales and other perceived exertion scales for pediatric population sub-sets. Earlier investigations using the child version of the OMNI-Cycle Scale, OMNI-Walk/Run Scale, OMNI RPE Scale for Stepping, Cart and Load Effort Rating (CALER) Scale, and Pictorial Children's Effort Rating Table (PCERT) demonstrated strong correlations ($r = 0.80$ to 0.94) between RPE and both VO_2 and HR (4,29,81,88,90,102). These findings established concurrent validity for the above metrics. In addition, an investigation by Balasekaran et al. demonstrated that when using the Child OMNI-Cycle Scale for separate cohorts of male and female, Chinese, Malay, and Indian children (12–14 years) strong correlations were observed between RPE and both VO_2 and HR with coefficients ranging from $r = 0.81$ to 0.99 (3).

Similar results have been observed for investigations that examined concurrent validity of perceived exertion scales that involved adult cohorts. Strong correlations ($r = 0.67$ to 0.97) between RPE and both VO_2 and HR were found when perceptual responses were derived from the Original Adult OMNI-Cycle Scale, the Adult OMNI-Walk/Run Scale, the newly developed Adult OMNI-Elliptical Ergometer Scale and the OMNI-Bench Stepping RPE Scale (44,52,84,101). Moreover, recent concurrent validation studies that used the OMNI-Cycle Scale in elderly populations exhibited strong correlations between RPE and both VO_2 and HR with coefficients ranging from $r = 0.81$ to 0.99 (92).

5.2.5 Explanatory Mechanisms

Concurrent validity refers to a measure that correlates well with a criterion measure that has previously been shown to change in a predicted direction in response to a standard forcing function such as load incremented exercise. The first use of a concurrent perceptual-physiological paradigm to validate an RPE scale was reported by Borg in 1962. This early investigation employed the Borg 15 category (i.e., 6-20) numerical-verbal scale (19). Previous investigations of various OMNI Scale formats have used VO_2 and HR as criterion measures to establish concurrent scale validity (74,84). The present findings indicated that as submaximal cycle ergometer power outputs increased incrementally, perceptual intensity changed from a “0” or very low to the highest numerical scale response (i.e., 10 or 11) for a given Alternative Adult OMNI-Cycle Scale. The findings of concurrent validity for all three Alternative Adult OMNI-Cycle Scales satisfy the two assumptions of Borg’s Range Model: 1) that a given RPE can be evaluated in relation to its position in the individual’s perceptual response range and 2) that a given RPE can be compared across individuals regardless of its position in the individual’s perceptual response range (11,13,16).

Furthermore, the findings for all three Alternative Adult OMNI-Cycle Scales demonstrated that changes in the physiological (i.e., VO_2 and HR) response continuum corresponded to changes in the perceptual continuum as performance intensity increased according to the load incremented protocol. This perceptual-physiological congruence is consistent with the predictions of Borg’s Effort Continua Model. The RPE derived from each of the three Alternative Adult OMNI-Cycle Scales distributed as a positive function of both VO_2 and HR responses over the submaximal cycle ergometer power outputs employed in the present

investigation. As such, the results satisfy the assumption of mechanistic interdependence between the three main *effort continua*: 1) perceptual, 2) physiological, and 3) performance as depicted in Borg's Effort Continua Model. Moreover, the interdependence between the three effort continua shows that perceptual responses derived from the three Alternative OMNI-Cycle Scales provide the same information regarding exercise performance as do selected physiological responses. This interdependence between the three effort continua becomes important when establishing concurrent scale validity using perceptual and physiological response measures during incremented cycle ergometer exercise loads.

The basic tenet of Borg's Effort Continua Model depicts the corresponding and interdependent change in perceptual and physiological responses as performance intensity increase. Such responsiveness has been observed in previous validation experiments involving the Borg 15-Category RPE Scale and age and mode specific OMNI Scales. The strong correlation coefficients observed in the present investigation demonstrated that as the physiological criterion measures (i.e., VO_2 and HR) increased with incremented exercise intensity, RPE-Overall, RPE-Legs, and RPE-Chest derived from the three Alternative Adult OMNI-Cycle Scales increased concurrently. As such, the findings of this investigation demonstrated a high level of concurrent validity for all three Alternative Adult OMNI-Cycle Scales.

5.2.6 Summary of Findings

It was hypothesized that: a) VO_2 would be positively correlated with RPE-Overall, RPE-Legs, and RPE-Chest when data were derived separately from Alternative Adult OMNI-Cycle Scales I,

II, and III, and b) HR would be positively correlated with RPE-Overall, RPE-Legs, and RPE-Chest when data were derived separately from alternative Adult OMNI-Cycle Scales I, II, and III. The present findings supported both of these hypotheses. The high level of concurrent validity observed presently is in agreement with (a) the predictions of both Borg's Range Model and Borg's Effort Continua Model and (b) results of previous concurrent validation studies involving category metrics. This leads to the conclusion that all three Alternative Adult OMNI-Cycle Scales are valid perceptual metrics to determine exertional responses of young adult males performing load incremented cycle ergometer exercise.

5.3 CONSTRUCT VALIDITY OF THE THREE ALTERNATIVE ADULT OMNI-CYCLE SCALES OF PERCEIVED EXERTION

5.3.1 Conceptual Background

The first investigations to validate RPE metrics using a construct (cross-scale) perceptual paradigm examined the Borg CR-10 Scale, the Marks-Borg CR-13 Scale, the Pittsburgh Nine-Category Scale, and the Adult OMNI-Cycle Scale (12,51,60,84). The results of these earlier studies to establish construct validity of perceived exertion scales demonstrated modest to strong correlations ($r = 0.38$ to 0.97) between RPE derived from the above listed conditional scales and that derived using the Borg 21-Category Scale and Borg (6-20) Scale as the criterion metrics (84). Pertinent to the present investigation, the procedures employed by Robertson et al. to examine construct validity using the Borg (6-20) Scale and the Original OMNI-Cycle Scale as

criterion metrics has been accepted as a standard paradigm when developing category scales to measure exertional perceptions.

The theoretical basis for use of construct perceptual paradigms evolved from Borg's Range Model. Borg developed the Range Model to justify interindividual comparisons of perceived exertion derived from category metrics. The model described a range of perceptual categories from "0" (very low effort) to a high numerical category (very high effort). The perceptual range serves as a frame of reference that employs two important assumptions (11,13,16). First, it is expected that for any given exercise range between rest and maximum, there is a corresponding and equal perceived exertion range. The second assumption maintains that both the RPE range and the intensity of perceptions at low and high exercise levels are equal between clinically normal individuals regardless of their physical fitness (11,13,16). In describing the construction of the original RPE scale, Borg indicated that during ergometer testing, exertional perceptions increased as the exercise load increased (11,13,16). To develop the Range Model Borg used a mathematical power function (i.e. $R = a + c(S-b)^n$) where R is the perceived intensity, c is a measurement constant, S is the physical intensity and n is the exponent of the growth function (16). It is important to note that the value for rest where there is no response to S is represented by to the constant a . Moreover, earlier investigations by Borg and Dahlström describe the minimal subjective intensity linked to the constant "a" as a small level of perceptual "noise" that is close the resting state in the psychophysical function (13,15). As such, Borg's Range Model and the designation of the lower intensity range as "0", (very low effort or perceptual noise) provides the underlying psychophysical rationale in developing the formats for the three Alternative Adult OMNI-Cycle Scales and establishing their respective construct validity.

5.3.2 Purpose and Hypothesis

The second aim of this investigation was to determine the construct validity of three alternative versions of the Original Adult OMNI-Cycle Scale of Perceived Exertion for young adult males performing load incremented cycle ergometer exercise. The research paradigm employed the three Alternative Adult OMNI-Cycle Scale formats as the conditional metrics and the Original Adult OMNI-Cycle Scale as the criterion metric. The RPE-Overall, RPE-Legs, and RPE-Chest served as the construct variables. Construct validity was examined separately for each Alternative Adult OMNI-Cycle Scale. It was hypothesized that there would be a positive correlation between RPE (Overall, Legs, and Chest) derived separately from the Alternative Adult OMNI-Cycle Scales I, II, and III and the Original Adult OMNI-Cycle Scale. These responses would establish construct measurement validity of the three Alternative Adult OMNI-Cycle Scales for young adults performing load incremented cycle ergometer exercise at relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$.

5.3.3 Summary of Research Findings

The regression analyses indicated that RPE (Overall, Legs, Chest) derived from the three Alternative Adult OMNI-Cycle Scales were positively related to the RPE derived from the Original Adult OMNI-Cycle Scale when responses were measured during an incremented test protocol. All regression analyses were statistically significant ($P < 0.001$). The construct correlation coefficients for the three alternative scales ranged from $r = 0.93$ to 0.98 for RPE-Overall, $r = 0.93$ to 0.98 for RPE-Legs, and $r = 0.94$ to 0.98 for RPE-Chest. Moreover, the

findings of this investigation are in agreement with the predictions of Borg's Range Model and consistent with previous investigations that demonstrated construct validity of the Original Adult OMNI-Cycle Scale. As such, the findings supported the hypothesis, establishing construct validity for each of the three Alternative OMNI-Cycle Scales.

5.3.4 Comparison with Previous Research

The strong construct validity correlation coefficients observed in the present investigation are consistent with previous research that used a construct paradigm to validate the Borg (6-20) Scale, Borg CR-10 Scale, Marks-Borg CR-13 Scale, and the Pittsburgh Nine-Category Scale (12,18,51,60). In addition, previous investigations demonstrated strong correlation coefficients ranging from $r = 0.92$ to 0.98 between RPE derived from (a) the Original Adult OMNI-Cycle Scale and the Borg (6-20) Scale, (b) the Adult OMNI-Walk/Run Scale and the Borg (6-20) Scale and (c) the newly developed Adult OMNI-Elliptical Ergometer Perceived Exertion Scale and the Borg (6-20) Scale in separate and combined cohorts of adult males and females (52,84,101).

It is also noted that the construct validity coefficients determined presently were similar to those observed in previous investigations that examined perceived exertion scales for children. Using separate and combined cohorts of male and female children, strong correlations ranging from $r = 0.93$ to 0.98 were found between RPE derived from (a) the Child OMNI-Stepping Scale and the Child OMNI-Cycle Scale, (b) the PCERT and the Child OMNI-Walk/Run Scale, (c) the Child OMNI-Cycle Scale and the Cart and Load Effort Rating (CALER) scale (4,29,81,88,90).

5.3.5 Explanatory Mechanisms

The concept of construct validity was first introduced in 1955 by Cronbach et al. (22) and refers to whether measures of a given construct obtained from a new scale correlate with measurements obtained from an established scale. It should be noted that each of the perceived exertion scales described in the preceding paragraphs (Sections 5.3.4) were used as criterion metrics in previous investigations that employed construct validity paradigms. Each of these criterion metrics had in themselves been shown to have a high level of construct validity using standardized experimental paradigms. The high level of construct validity observed in the present investigation indicates that the exertional measures for all three Alternative Adult OMNI-Cycle Scales correlated strongly with exertional measures obtained from the Original Adult OMNI-Cycle Scale. In addition, the correlation coefficients observed for the three Alternative Adult OMNI-Cycle Scales were further strengthened by the previous independent research that demonstrated construct validity of the Original Adult OMNI-Cycle Scale (84).

In the present investigation, strong correlations between RPE derived from the conditional (i.e., Alternative I, II, III) and criterion (i.e., Original) Adult OMNI-Cycle Scales were observed across relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$. These findings are consistent with those investigations described in the preceding paragraphs where a high level of construct validity was observed across a wide range of relative aerobic metabolic rates (52,84,101). In these previous investigations, RPE derived from the Original Adult OMNI-Cycle Scale was correlated with RPE derived from the Borg (6-20) Scale.

Borg's Range Model of category scaling can be used to provide a theoretical basis for the present findings regarding construct validity of the alternative scales. According to Borg (16),

construct validity of an RPE category scale depends on the ratings from both the criterion and conditional metrics growing as a direct function of workload increases during an ergometer exercise test. The findings for all three Alternative Adult OMNI-Cycle Scales in the present investigation are in agreement with the predictions of Borg's Range Model for category scaling. That is, for a given alternative scale: (1) there is a corresponding and equal exercise intensity and perceived exertion range and (2) that both the RPE range and the intensity of perceptions at low and high exercise levels are equal as demonstrated by both the criterion and conditional scales (16).

It is important to note that the findings for the present investigation are consistent with a previous report by Lagally et al. that used a construct perceptual paradigm to develop a system to interchange scale categories between the Adult OMNI-Resistance Scale and the criterion Borg 15 (6-20) Category Scale. (46). Similarly, the strong construct validity correlations observed presently allow the development of an inter-scale RPE conversion paradigm between the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale. That is, due to the comparatively high level of construct validity between the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale, the derived RPE responses may be used interchangeably to quantify exertional responses during exercise. For example, an interpretation of the construct validity model demonstrates that the numerical category variations for Alternative Adult OMNI-Cycle Scale 1 (1,2,3,4,5,6,7,8,9,10,11), Alternative Adult OMNI-Cycle Scale II (0,1,2,3,4,5,6,7,8,9,10), and Alternative Adult OMNI-Cycle Scale III (1,2,3,4,5,6,7,8,9,10) correspond to the Original Adult OMNI-Cycle Scale (0,1,2,3,4,5,6,7,8,9,10) as demonstrated in Table 5.1. The proposed RPE conversion model would permit health-fitness professionals and clinical specialists to assess target training zones

using either one of the three Alternative Adult OMNI-Cycle Scales or the Original Adult OMNI-Cycle Scale. This interchange makes it possible to compare RPE responses and derived perceptual indices between previous investigations that employed the Original Adult OMNI-Cycle Scale and future investigations that employ one of the three Alternative Adult OMNI-Cycle Scales. As such, the findings of a high level of construct validity for all three Alternative Adult OMNI-Cycle Scales allows significant generalizability of perceptual responses across various OMNI Scale rating formats.

5.3.6 Summary of Findings

It was hypothesized that there would be a positive correlation between RPE (Overall, Legs, and Chest) derived separately from the Alternative Adult OMNI-Cycle Scales I, II, and III and the Original Adult OMNI-Cycle Scale. The findings of the investigation supported this hypothesis. The present findings of a high level of construct validity for the three Alternative Adult OMNI-Cycle Scales are consistent with (a) the predictions of Borg's Range Model and (b) results of previous construct validation studies involving perceived exertion scales. These findings lead to the conclusion that the three Alternative Adult OMNI-Cycle Scales are valid perceptual metrics to determine exertional responses of young adult males performing load incremented cycle ergometer exercise.

5.4 DIFFERENTIATED PERCEPTUAL-SIGNAL DOMINANCE:

5.4.1 Conceptual Background

Differentiated RPE's are methodologically defined as exertional signals that are localized or regionalized to specific anatomical areas including the arms (RPE-Arms), legs (RPE-Legs), and/or chest (RPE-Chest). Perceptual signal dominance as defined by the Differentiated Perceived Exertion Model predicts that the most intense perceptual signals arise from the body regions predominately used in exercise. This in turn results in a comparatively higher RPE for the predominately involved anatomical region. For example, in the present investigation where a load incremented cycle ergometer exercise protocol was employed, the model predicts that the differentiated RPE-Legs will be higher than the differentiated RPE-Chest. It was expected that dominance of the perceptual signal arising from the legs would be evident for all three Alternative Adult OMNI- Cycle Scales (i.e., I, II, III).

Previous investigations demonstrated that the intensity of the peripheral signals arising from the involved limbs during cycling and walking were more intense than the respiratory-metabolic signals arising from the chest during submaximal exercise. Such perceptual signal dominance involving the active peripheral musculature was observed during weight bearing exercise where RPE was derived from the Borg (6-20) Scale and the Borg CR-10 Scale. In addition, dominance of the peripheral signal arising from the active limbs was observed using the Child and Adult OMNI Scales during load incremented cycle ergometer exercise, treadmill exercise, and resistance exercise (3,46,74,80,84,101,102).

5.4.2 Purpose and Hypothesis

The third aim of this investigation was to determine if the differentiated RPE-Legs and RPE-Chest derived from the three alternative Adult OMNI- Cycle Scales (i.e., I, II, III) demonstrated signal dominance (i.e., RPE-Legs > RPE-Chest) as predicted by the Differentiated Perceived Exertion Model. The present investigation employed a cycle ergometer to provide a standardized exercise forcing function in order to examine differentiated exertional responsiveness as measured by the three Alternative Adult OMNI-Cycle Scales. As such, it was expected that the perceptual signals arising from the legs would be more intense than respiratory-metabolic signals arising from the chest at a given intensity during submaximal cycle exercise. It was hypothesized that using the data derived separately from the Alternative Adult OMNI-Cycle Scales I, II, and III, RPE-Legs would be greater than RPE Chest. These findings would indicate that the three Alternative Adult OMNI-Cycle Scales exhibited psychometric properties appropriate to identify perceptual signal dominance during load incremented cycle ergometry at relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$. The identification of a dominant perceptual signal arising from the legs during cycle ergometer would be consistent with the prediction of the Differentiated Perceived Exertion Model.

5.4.3 Summary of Research Findings

The present findings demonstrated signal dominance for RPE derived separately from the three Alternative Adult OMNI-Cycle Scales where relative aerobic metabolic rates ranged from 40% to 90% $\% \text{VO}_{2\text{peak}}$. Using data from each of the three Alternative Adult OMNI-Cycle Scales the

RPE-Legs was greater than the RPE-Chest for low (i.e., 40%), moderate (i.e., 65%), and high (i.e., 90%) relative aerobic metabolic rates. The present findings for the three Alternative Adult OMNI-Cycle Scales are consistent with previous reports that demonstrated perceptual signal dominance where RPE-Legs was greater than RPE-Chest during load incremented up-right cycle ergometry (33,76,78,84). Moreover, the findings are in agreement with the predictions of the Differentiated Perceived Exertion Model across a comparatively wide range of relative aerobic metabolic rates. These findings supported the hypothesis that RPE-Legs derived separately using the Alternative Adult OMNI-Cycle Scales I, II, and III would be greater than RPE-Chest across relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$.

Similar results for perceptual signal dominance were found for RPE responses obtained from the Original Adult OMNI-Cycle Scale. The present findings for the Original Adult OMNI-Cycle Scale indicated that RPE-Legs was greater than RPE-Chest for relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$.

It is important to note that the finding of signal dominance (RPE-Legs > RPE-Chest) as identified for three Alternative Adult OMNI-Cycle Scales was the same as that identified for the Original Adult OMNI-Cycle Scale. As such, this manipulation check whereby the Original Adult OMNI-Cycle Scale was included in the data analysis supported the integrity of the experimental research design.

5.4.4 Comparisons with Previous Research

The present findings regarding the presence of a dominant perceptual signal during cycle ergometry was observed for all three Alternative Adult OMNI-Cycle Scales. As such, the

identification of the dominant perceptual signal arising from the legs conforms to the predictions of the Differentiated Perceived Exertion Model. The present findings are also consistent with previous investigations that demonstrated the perceptual signal arising from the legs during cycling and walking was more intense than the respiratory-metabolic signal. These previous investigations measured RPE using the Borg (6-20) Scale, Borg CR-10 Scale, and the Child and Adult OMNI Scales (3,46,74,80,84,101,102). These experiments involved load incremented cycle ergometer exercise, treadmill exercise, and resistance exercise (3,46,74,80,84,101,102). For example, perceptual signal dominance was established in the original validation of the Adult OMNI-Cycle by Robertson et al. (84). In this investigation, the RPE-Legs responses were higher than RPE-Chest at all four PO stages for adult males and females performing cycle ergometry. However, the findings of the present investigation are inconsistent with an investigation by Bolgar et al. (5) involving separate groups of recreationally active adult females and aerobically trained adult females. Bolgar et al, (5) observed perceptual signal dominance at a higher relative aerobic metabolic rate (i.e., 80% $\text{VO}_{2\text{peak}}$) but not at lower relative aerobic metabolic rates (i.e., 40% and 60% $\text{VO}_{2\text{peak}}$) for the recreationally active group. In contrast, the trained adult women demonstrated perceptual signal dominance across relative aerobic metabolic intensities ranging from 40% to 80% $\text{VO}_{2\text{peak}}$ during a cycle ergometer exercise protocol (5).

Moreover, the results of the present study were not entirely consistent with previous investigations that involved pediatric population sub-sets. For example, Robertson et al. (81) used the Child OMNI-Step Scale to measure RPE-Legs and REP-Chest for female and male children performing a multistage exercise protocol. The findings demonstrated that RPE-Legs did not differ from RPE-Chest at step stage I. However, RPE-Legs were higher than RPE-Chest at step stage II, III, and IV. The results suggest that female and male children experiencing a

dominant perceptual signal arising from the legs at higher but not lower step intensities. Similarly, Balasekaran et al. (3) used the Child OMNI-Cycle Scale to examine perceptual signal dominance in a cohort of male children of Chinese, Malay, and Indian ethnicities. No significant differences were found between RPE-Overall, RPE-Legs, and RPE-Chest measured for the initial 7 stages of the load incremented cycle protocol. However, significant differences were found at the more intense test stages where RPE-Legs were greater than both RPE-Overall and RPE-Chest. The results indicated that RPE-Legs reflected the dominant signal at the higher intensities during the cycle ergometer exercise test. As such, it was concluded that male children were able to differentiate between RPE-Legs and RPE-Chest only at the comparatively high exercise intensities and not at low to moderate intensities.

It is interesting to note that the findings of these previous studies where exertional perceptions were measured with the Child OMNI-Step Scale and Child OMNI-Cycle Scale identified a differentiation threshold (DT). The DT described in these earlier studies indicated the point at which the differentiated perceptual signals (i.e., limbs, chest) first appear to be respectively greater and less than the RPE-Overall (3,5). In these studies, both male and female children were able to differentiate between RPE-Legs and RPE-Chest only at the comparatively high exercise intensities where the DT had been exceeded.

However, there was no evidence of a DT for perceptual ratings derived from any of the three Alternative Adult OMNI-Cycle Scales where load incremented exercise was performed by recreationally active males. Such a finding is consistent with that reported by Rutkowski (91) for children performing slow to moderate treadmill walking speeds. Perhaps the lowest exercise intensity employed presently (i.e., 40%) was never-the-less higher than that required to observe a DT in the cohort that was studied. Such a mechanism is conceptually similar to that proposed by

Rutkowski et al. (91). These findings indicate that each of the three Alternative OMNI-Cycle Scales demonstrated psychometric properties that allowed identification of perceptual signal dominance in a manner similar to the Original OMNI-Cycle Scale for the male cohort that was studied.

5.4.5 Explanatory Mechanisms

Differentiated RPE are localized or regionalized to anatomical areas including the arms (RPE-Arms), legs (RPE-Legs), and/or chest (RPE-Chest). The first model to illustrate the sensory link between subjective symptoms and physiological responses to exercise was developed by Weiser and Stamper (62,76,105). Briefly, the Weiser-Stamper model (see Chapter II) places an overall body rating of exertion at the superordinate sensory processing level. The model does not recognize the separate and/or combined influence of differentiated exertional signals in shaping the overall body perceptual experience (62,76,105). Pandolf et al. (66,68) revised the previously described Weiser and Stamper model and proposed that differentiated exertional signals were linked to muscular exertion and cardiopulmonary exertion. These differentiated signals functioned at the subordinate level of sensory processing.

The subsequent third generation Differentiated Perceived Exertion Model developed by Robertson (62,76) replaced the terms local factors and central factors in the previously described Pandolf model with peripheral (i.e., muscles, joints of active limbs) and respiratory-metabolic (i.e., chest/respiration) differentiated perceptual signals respectively. The Differentiated Perceived Exertion Model by Robertson (76) formalizes the concept of perceptual signal dominance and is described in more detail in Chapter II.

In the present investigation, the findings demonstrated RPE derived from all three Alternative Adult OMNI-Cycle Scales demonstrated perceptual signal dominance. That is, RPE-Legs was greater than RPE-Chest for relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$ during load incremented cycle ergometer exercise performance. It is important to note that the findings for all three Alternative Adult OMNI-Cycle Scales are consistent with the predictions of the Differentiated Perceived Exertion Model where peripheral signals from involved limbs during exercise are expected to dominate the perceptual process. Moreover, the dominant legs perceptual signal observed for all three Alternative Adult OMNI-Cycle Scales is consistent with previous investigations that employed cycle ergometry (76). The emergence of signal dominance during cycle ergometer exercise is normally observed in the RPE-Legs response as the active muscle mass required to perform the external work primarily involves the lower limbs. During upright cycle ergometer exercise, peripheral muscle tension in the lower limbs is increased by a greater discharge of central feedforward commands arising from the motor cortex. Copies of these commands travel through corollary channels to the sensory cortex eliciting a differentiated perceptual signal. The resulting differentiated perceptual signal arising from the legs during the cycle ergometer exercise protocol produced a comparatively higher RPE. As such, the RPE-Legs reflected the dominant perceptual signal for all three Alternative Adult OMNI-Cycle Scales in the present investigation (76).

In addition, the findings that the legs signal was dominant for all three Alternative Adult OMNI-Cycle Scales are consistent with an investigation by Robertson et al. (84) that employed the Original Adult OMNI-Cycle Scale. The findings demonstrated signal dominance as denoted by a higher RPE-Legs at all PO stages for adult males performing an incremented cycle ergometer protocol. Similarly, the findings for the Original Adult OMNI-Cycle Scale in the

present investigation demonstrated that the RPE-Legs response was greater than the RPE-Chest for relative aerobic metabolic rates ranging from 40% to 90% $\% \text{VO}_{2\text{peak}}$. This further strengthens the findings of a dominant legs perceptual signal (RPE-Legs) for all three Alternative Adult OMNI-Cycle Scales where the same cycle ergometer protocol was employed for all four experimental trials. As such, the finding of this investigation demonstrated signal dominance (i.e., RPE-Legs >RPE-Chest) for all three Alternative Adult OMNI-Cycle Scales. The findings in this study are consistent with the predictions of the Differentiated Perceived Exertion Model (76).

5.4.6 Summary of Findings

It was hypothesized that during load incremented cycle ergometry that RPE-Legs would be greater than RPE Chest for data derived from the Alternative Adult OMNI-Cycle Scales I, II, and III, and the Original Adult OMNI-Cycle Scale. The present findings agreed with the predictions of the Differentiated Perceived Exertion Model, as well as results of previous investigations of perceptual signal dominance. As such, it can be concluded that the three Alternative Adult OMNI-Cycle Scales are valid perceptual metrics to identify perceptual signal dominance for young adult males performing load incremented cycle ergometer exercise.

5.5 DIFFERENTIATED PERCEPTUAL-SIGNAL INTEGRATION:

5.5.1 Conceptual Background

During cycle ergometer exercise the undifferentiated RPE for the overall body is assumed to reflect the integration of differentiated perceptual signals arising from the activated peripheral skeletal muscle in the legs and chest. As such, the Differentiated Perceived Exertion Model predicts that the RPE-Overall will be equal to the Avg RPE(L,C) during a non-weight bearing exercise such as cycle ergometry. In the present investigation, the mode of perceptual signal integration was examined separately for the three Alternative Adult OMNI-Cycle Scales (i.e., I, II, III). Using a load incremented cycle ergometer exercise protocol, the model predicts that the undifferentiated RPE-Overall will be equal to an average of the differentiated RPE-Legs and RPE-Chest. It was expected that integration of the differentiated perceptual signal arising from the legs and chest would equal the overall perceptual ratings with calculations made separately for three Alternative Adult OMNI-Cycle Scales (i.e., I, II, III).

Previous investigations have proposed that the differentiated perceptual signals are integrated centrally (most likely in the sensory cortex) to form the RPE-Overall. These previous reports indicate that the mode of perceptual integration is likely dependent on the type of exercise, the number of active limbs involved, and the exercise environment (i.e., land, water) (40,64,76,87). Such perceptual signal integration involving the active peripheral musculature was observed (a) when using reciprocal pedal rate and break resistance to maintain a constant power output during cycle exercise, (b) using arm and leg water immersion cycle ergometry, and (c) during maximal treadmill running (33,37,76). Moreover, when external payloads were

carried at the waist level as opposed to a head pack, transverse yoke or frontal yoke, the RPE-Overall was similar to the Avg RPE (L,C) (6,76).

5.5.2 Purpose and Hypothesis

The fourth aim of this investigation was to determine if the undifferentiated RPE-Overall represented an average of the differentiated RPE-Legs and the RPE-Chest when perceptual responses were determined separately for the three alternative Adult OMNI-Cycle Scales (i.e., I, II, III). The present investigation employed cycle ergometry to provide a standardized exercise forcing function in order to examine validity of the three Alternative Adult OMNI-Cycle Scales. As such, it was expected that the perceptual response for the overall body would be equal to an average of perceptual signals arising separately from the legs and the respiratory-metabolic signals arising from the chest when measured at a given intensity during submaximal cycle exercise. Such a finding would be consistent with the mode of perceptual signal integration as predicted by the Differentiated Perceived Exertion Model. It was hypothesized that when using data derived separately from each of the Alternative Adult OMNI-Cycle Scales I, II, and III, that RPE-Overall would not differ from the Avg RPE(L,C). These findings would indicate that the three Alternative Adult OMNI-Cycle Scales identify perceptual signal integration consistent with the prediction of the Differentiated Perceived Exertion Model across relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$.

5.5.3 Summary of Research Findings

The results of the three-factor ANOVA indicated that perceptual signal integration was demonstrated for RPE derived separately from the three Alternative Adult OMNI-Cycle Scales, where relative aerobic metabolic rates ranged from 40% to 90% $\text{VO}_{2\text{peak}}$. These findings using data from each of the three Alternative Adult OMNI-Cycle Scales demonstrated that the RPE-Overall appeared as an average of the perceptual signals arising from lower limbs and chest anatomical regions during cycle exercise at intensities ranging from comparatively low (i.e., 40%) to high (i.e., 90%) relative aerobic metabolic rates. The present findings for the three Alternative Adult OMNI-Cycle Scales are consistent with previous reports that perceptual signal integration during cycling results in an RPE-Overall that is similar to the Avg RPE(L,C) response patterns during load incremented up-right cycle ergometry (76,78). Moreover, these findings are in agreement with the prediction of the Differentiated Perceived Exertion Model across a comparatively wide range of relative aerobic metabolic rates. These present findings supported the hypothesis. The mode of perceptual signal integration was consistent for each of the three Alternative OMNI-Cycle Scales where the exercise forcing function involved a load incremented cycle ergometer protocol at intensities ranging from comparatively low to high.

Similar results for perceptual signal integration were found for RPE responses obtained from the Original Adult OMNI-Cycle Scale. The differentiated RPE from the Original Scale appeared to represent a central sensory integration process where perceptual signals arising from lower limbs and respiratory-metabolic regions were averaged to form the RPE-Overall. This mode of perceptual integration held for exercise intensities ranging from comparatively low (i.e. 40%) to high (i.e. 90%) relative aerobic metabolic rates. The present findings for the Original

Adult OMNI-Cycle Scales are consistent with previous reports that perceptual signal integration during cycling results in an RPE-Overall that is similar to the Avg RPE(L,C) response patterns during load incremented up-right cycle ergometry.

It is important to note that the mode of signal integration to form the RPE-Overall appeared as an Avg RPE(L,C) for responses derived from the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale where the same cycle ergometer protocol was employed for all four experimental trials. As such, this finding provided a manipulation check, supporting the integrity of the experimental research design.

5.5.4 Comparison with Previous Research

Early studies examining the mode of perceptual signal integration determined that the undifferentiated RPE for the RPE-Overall appeared to be a weighted average of the differentiated RPE for the chest/breathing and the RPE arising from the active limbs during cycle ergometer, arm ergometer, and arm-leg ergometer exercise (76). For example, an investigation by Robertson et al. (78) that examined mode of perceptual signal integration found the RPE-Overall to be the weighted average of the differentiated RPE-Legs and RPE-Chest when using reciprocal pedal rate and break resistance to maintain a constant power output (PO) during cycle exercise. A subsequent investigation by Robertson et al. involving arm and leg water immersion ergometry determined that the RPE-Overall appeared as a weighted average of the RPE-Arms and RPE-Legs (75,76). Moreover, the RPE-Overall appeared to be a weighted average of the differentiated RPE-Legs and RPE-Chest during investigations of maximal treadmill running (33,37,76). In addition, when external payloads were carried at the waist level as opposed to a

head pack, transverse yoke or frontal yoke, the RPE-Overall was similar to the weighted average of the RPE-Legs and RPE-Chest (6,76). Although the RPE-Overall appeared to be similar to the Avg RPE(L,C) in an investigation by Bolgar et al. (5) involving both recreationally active adult females and trained adult females, signal integration could not be statistically determined. This was likely caused by the absolute differences between RPE-Legs and RPE-Chest being small despite being statistically significant at all relative aerobic metabolic rates (40% to 80% $\text{VO}_{2\text{peak}}$) during a cycle ergometer protocol (37). Bolgar et al. (5) speculated that the differentiated signals are integrated centrally (most likely in the sensory cortex) to form the RPE-Overall and that the mode of perceptual integration is dependent not only upon the type of exercise, the number of active limbs involved, and the exercise environment (i.e., land, water), but also the gender and training status of individuals (5,40,64,76,87).

5.5.5 Explanatory Mechanisms

The final common neurophysiological pathway for exertional perceptions has been described by Cafarella (21). According to this pathway, discharge frequency of central feed-forward commands from the motor cortex increases to produce greater leg peripheral muscle tension in response to incremented cycle ergometer exercise power outputs. Corollary pathways carrying copies of these central commands are sent to the sensory cortex. Upon arriving in the sensory cortex, these corollary signals are modulated according to the contents of the individual's perceptual cognitive reference filter. The role of the perceptual cognitive reference filter is to compare the corollary signals with past and present inputs regarding exercise performance, psychobehavior factors, and mental health status. Moreover, afferent feedback arising from

peripheral and/or respiratory muscle tension provides a fine-tuning adjustment to the corollary perceptual signals of exertion. However, a recent theoretical model by Marcora (50) proposes that the perception of effort during exercise is independent of afferent feedback from small-diameter muscle afferents, heart, and lungs. Marcora describes the neural signals underlying perception of effort as a “sensation of innervation” and is the result of central feed-forward commands identified as corollary discharges or efference copies that are forwarded to the motor and sensory cortex (50). For example, when the pharmacological agent curare was used in a low dose to produce skeletal muscle weakness without affecting afferent pathways in an investigation by Gallagher et al. (32), RPE increased during a cycle ergometer exercise.

As such, the model describing the final common neurophysiological pathway predicts that the resulting undifferentiated perceptual response for the overall body reflects the integration of differentiated perceptual signals arising from the activated peripheral skeletal muscle in the legs and chest. The resulting undifferentiated overall body rating in the present investigation appeared as an integration of perceptual responses arising from the legs and chest for all three Alternative Adult OMNI-Cycle Scales (76,78).

The findings for the Original Adult OMNI-Cycle Scale in the present investigation demonstrated signal integration where RPE-Overall appeared as the Avg RPE(L,C) at relative aerobic metabolic rates ranging from 40% to 90% $\% \text{VO}_{2\text{peak}}$ for recreationally active adult males performing an incremented cycle ergometer protocol. This further strengthens the findings of signal integration (i.e., $\text{RPE-O} = \text{Avg RPE(L,C)}$) for all three Alternative Adult OMNI-Cycle Scales during an incremented cycle ergometry as the same test protocol was used for all four experimental trials. The findings in this investigation regarding detection of perceptual signal integration by all three Alternative OMNI-Cycle Scales are consistent with the predictions of the

Differentiated Perceived Exertion Model and previous investigations using the Original OMNI-Cycle Scale (76).

5.5.6 Summary of Findings

It was hypothesized that during load incremented cycle ergometry RPE-Overall would not differ from the average of the RPE-Legs and RPE-Chest for data derived from the Alternative Adult OMNI-Cycle Scales I, II, and III, and the Original Adult OMNI-Cycle Scale. The agreement of the present findings with the predictions of the Differentiated Perceived Exertion Model, as well as results of previous studies involving signal integration, leads to the conclusion that the three Alternative Adult OMNI-Cycle Scales are valid perceptual metrics to determine both signal dominance and integration for young adult males performing load incremented cycle ergometer exercise.

6.0 CONCLUSIONS

6.1 SUMMARY OF FINDINGS

In the present investigation, the correlation/regression analyses indicated that RPE derived from the three Alternative Adult OMNI-Cycle Scales distributed as a positive function of VO_2 and HR responses over the submaximal cycle ergometer power outputs. These findings supported the hypothesis, establishing concurrent validity for each of the three Alternative Adult OMNI-Cycle Scales as well as the Original Adult OMNI-Cycle Scale. The correlation/regression analyses also indicated that RPE (Overall, Legs, Chest) derived from the three Alternative Adult OMNI-Cycle Scales were positively related to the RPE derived from the Original Adult OMNI-Cycle Scale. This finding supported the hypothesis, establishing construct validity for each of the three Alternative OMNI-Cycle Scales. The high levels of concurrent and construct validity of the three Alternative Adult OMNI-Cycle Scales are consistent with the predictions of both Borg's Range Model of Category Scaling and Borg's Effort Continua Model.

The three-factor ANOVA demonstrated that RPE-Legs was greater than RPE-Chest at relative aerobic metabolic rates ranging from 40% to 90% $\% \text{VO}_{2\text{peak}}$ for all three Alternative Adult OMNI-Cycle Scales. Comparable results were demonstrated for the Original Adult OMNI-Cycle Scale. These findings supported the hypothesis, establishing signal dominance when RPE were derived from each of the three Alternative Adult OMNI-Cycle Scales and the

Original Adult OMNI-Cycle Scale at relative aerobic metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$. The three-factor ANOVA also demonstrated that RPE-Overall did not differ from the Avg RPE(L,C) at the 40%, 65%, and 90% $\% \text{VO}_{2\text{peak}}$ intensities for all three Alternative Adult OMNI-Cycle Scales. These findings supported the hypothesis, establishing signal integration when RPE were derived from each of the three Alternative OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale at metabolic rates ranging from 40% to 90% $\text{VO}_{2\text{peak}}$. The identification of signal dominance and mode of signal integration using the three Alternative OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale was consistent with the prediction of the Differentiated Perceived Exertion Model for cycle ergometer exercise at intensities ranging from 40% to 90% $\text{VO}_{2\text{peak}}$.

6.2 TRANSLATION/APPLICATION:

6.2.1 Derived perceptual index

The rationale underlying this investigation recognized that the presence of a “0” perceptual category in the response range of the Original OMNI Scale presented measurement difficulties when computing derived activity indices. The “0” category acts as an integer and presents statistical and mathematical limitations when calculating derived indices such as the Physical Activity Index (PAI) developed by Resler et al. (73) and Weary et al. (103), and the Exercise Discomfort Index (EDI) developed by Kane et al. (39). Other derived indices involving RPE include those used to evaluate training load, training monotony, training strain, and thermal

strain (30,31,89,100). Calculation of these indices could be complicated when a “0” rating response from the OMNI Scale is presented as an exertion level. For example, when an RPE of “0” is multiplied by the corresponding pedometer step count, the calculated PAI is “0”. According to mathematical principles, any integer multiplied by a “0” will result in a “0”. Thus, there appears to be a need to modify the Original Adult OMNI Scale format by either eliminating the “0” category as a possible exercise response or to specifically link the “0” category to a resting (i.e., pre- or post-exercise) state.

In the present investigation, concurrent and construct validity were established for all three Alternative Adult OMNI-Cycle Scales. These alternative scale formats either eliminated the “0” category as a possible exercise response or specifically linked the “0” category to a verbal descriptor indicating a resting state. The elimination of the “0” as an exercise response for Alternative Adult OMNI-Cycle Scale I and III and the insertion of a “0” category as a true resting response for Alternative Adult OMNI-Cycle Scale II eliminates any mathematical limitations when computing derived indices such as the PAI and EDI. The format of the three Alternative Adult OMNI-Cycle Scales would facilitate research and clinical applications when computing derived indices using perceptual, physiological, sensory, psychobehavioral, and/or physical activity variables that are associated with cycle ergometer exercise intensities ranging from 40% to 90% $\text{VO}_{2\text{peak}}$.

The present findings are consistent with an investigation by Mays et al. (52) that demonstrated high construct validity for RPE responses derived from a modified Adult OMNI-Elliptical Scale where the criterion metric was the Borg 6-20 category scale. The modified Adult OMNI-Elliptical Scale inserted a “0” as a true resting category before the start of the visually discernible exercise response gradient. The “0” category was placed in juxtaposition to the

verbal descriptor “rest” and to a “rest” pictorial. Similar to the three Alternative Adult OMNI-Cycle Scales examined presently, the modified Adult OMNI-Elliptical Scale eliminates potential statistical complications when computing derived indices such as the PAI and EDI for a partial weight bearing aerobic exercise such as elliptical ergometry.

6.2.2 RPE conversions

The findings of the present investigation are consistent with a previous investigation by Lagally et al. (46) that used a construct perceptual-physiological paradigm to develop a conversion chart for interchanging RPE between the OMNI-Resistance Scale and the Borg 15 (6-20) Category Scale. Using such charts practitioners can easily convert target RPE training zones that have been determined using one of the three Alternative Adult OMNI-Cycle scale formats to training zones based on the Original Adult OMNI-Cycle Scale, Borg 6-20 scale and the Borg CR-10 scale formats as needed. The Original RPE Conversion Chart is present in Figure 6-1.

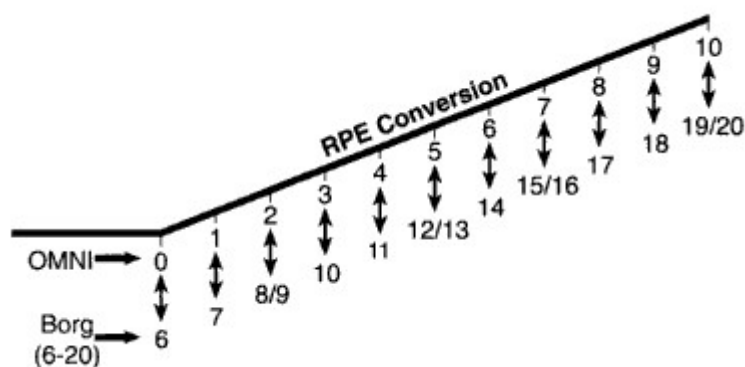


Figure 6-1 Original RPE Conversion Chart (89).

As discussed in the previous sections, the strong construct validity correlations for the three Alternative Adult OMNI-Cycle Scales using the Original Adult OMNI-Cycle Scale responses as criterion variables allows the development of a revised interscale RPE conversion paradigm. The revised conversion chart for the Original Adult OMNI Scale, Borg 6-20 scale, and all three Alternative Adult OMNI-Cycle scales is presented in Figure 6-2.

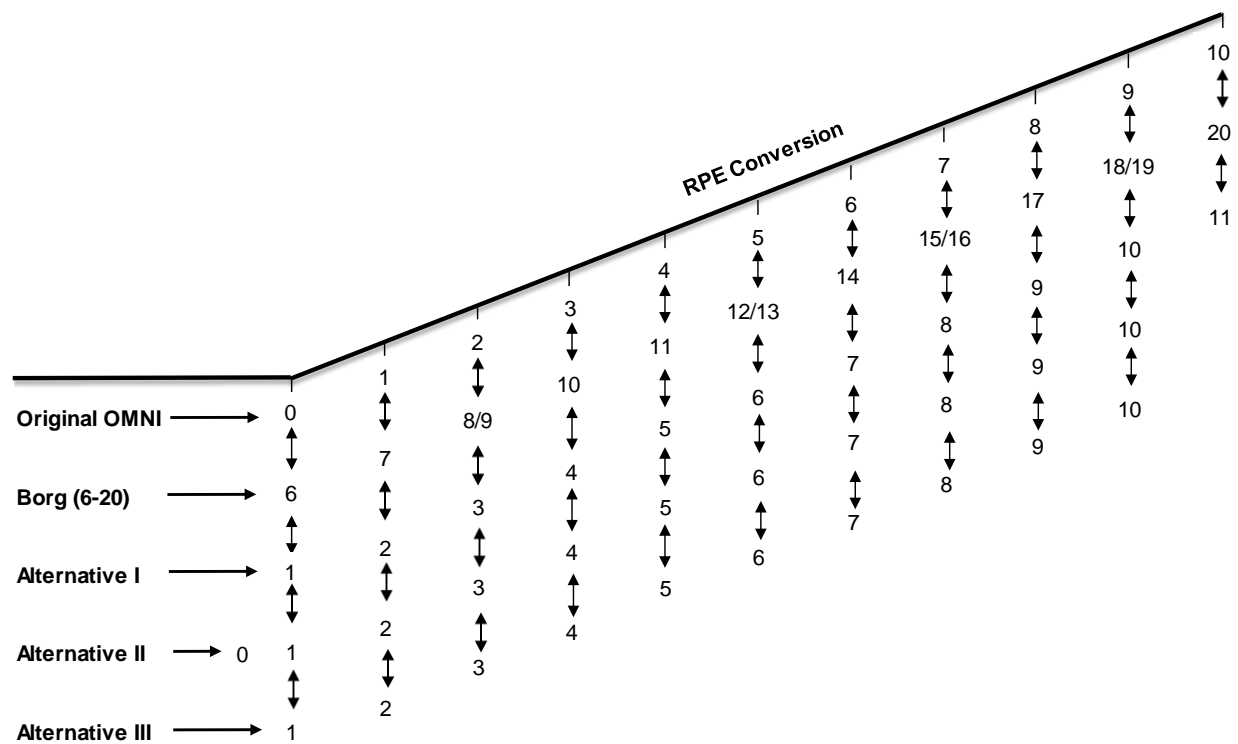


Figure 6-2 Revised RPE Conversion Chart for all three Alternative Adult OMNI-Cycle Scales.

6.2.3 RPE equivalent to %VO_{2peak}: Methodological advantage

As discussed in the data analysis section, due to inter-individual differences in VO_{2peak} a novel statistical procedure was used in the research design where VO₂ at each stage was converted to %VO_{2peak} for each subject. The VO₂ and HR corresponding to 40%, 65%, and 90% VO_{2peak} were then identified. Finally RPE associated with the derived VO₂ at the three relative aerobic intensities were identified for each of the three Alternative Adult OMNI-Cycle Scales and the Original OMNI-Cycle Scale.

The advantages of this data reduction procedure were, (a) concurrent and construct scale validity were determined using RPE (Overall, Legs, Chest) that were equivalent to 40%, 65%, and 90% VO_{2peak} for each subject insuring that the derived perceptual responses reflected the same level of relative aerobic metabolic strain across all three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale and (b) RPE comparisons were made at the same relative aerobic metabolic rate for each subject when examining perceptual signal dominance and integration separately for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale. As such, the use of a relative data reduction procedure avoided the problem that would have been encountered using an isotime paradigm where the number of completed test stages varied between subjects owing to interindividual differences in VO_{2peak}. This data reduction procedure is consistent with the investigation of Smith, et al. (94) that used exercise bouts equivalent to 30%, 55%, and 80% VO_{2peak} to derive the PAI (steps x RPE) for a cohort of females performing a treadmill exercise protocol.

6.2.4 Selection of the Alternative Scale Format:

The findings of the present investigation demonstrated that a high level of concurrent and construct validity was determined for all three Alternative Adult OMNI-Cycle Scales. Moreover, the finding of this investigation demonstrated that both perceptual signal dominance (i.e., $RPE\text{-}Legs > RPE\text{-}Chest$) and perceptual signal integration (i.e., $RPE\text{-}O = Avg\ RPE(L,C)$) could be identified using RPE responses from all three Alternative Adult OMNI-Cycle Scales. In selecting one of the three Alternative Adult OMNI-Cycle Scales for health-fitness and clinical application, the decision was based on established psychometric criteria that provided the underlying rationale for the investigation as follows: 1) satisfy the two assumptions of Borg's Range Model (a) the lower end of the perceptual range is indicated by a "0" or very low number and (b) that a given RPE can be evaluated in relation to its position in the individual's perceptual response range, 2) satisfy the basic tenet of Borg's Effort Continua Model that predicts a mechanistic interdependence between the three main *effort continua*: (a) perceptual, (b) physiological, and (c) performance, 3) satisfy the prediction of the Differentiated Perceived Exertion Model that during cycle ergometer exercise the emergence of signal dominance is normally observed in the RPE-Legs response as the volume of active muscle mass required to perform external work primarily involves the lower body for recreationally active adult males, 4) satisfy the prediction of the Differentiated Perceived Exertion Model that during a load incremented cycle ergometer exercise protocol, signal integration is established when the undifferentiated overall body rating is equal to the average of the differentiated legs and differentiated chest ratings for recreationally active adult males, 5) the concurrent and construct validity of each the three Alternative Adult OMNI-Cycle Scales as well as determination of

signal dominance and integration was consistent with the RPE responses derived from the Original Adult OMNI-Cycle Scale where all observations involved the same young adult male cohort performing at a priori determined relative metabolic rates, 6) eliminate the statistical and mathematical limitations in calculating PAI or EDI where the “0” category acts as an integer as is the case when perceptual responses are derived from the Original Adult OMNI-Cycle Scale, 7) is in agreement with the mathematical power functions underlying Borg’s Range Model where the constant a in the equation corresponds to a resting response, usually “0”, 8) is consistent with the previous investigation that validated a modified Adult OMNI-Elliptical Scale where the “0” category was inserted as a true resting category prior to the beginning of the visually discernible exercise response gradient and juxtaposition to the verbal descriptor “rest” and/or to a “rest” pictorial, and 9) ease of establishing the low perceptual anchor where the lowest numerical category (i.e., “0”) is directly linked to verbal and/or pictorial descriptors indicating a resting state.

The findings of the present investigation indicated that all three Alternative Adult OMNI-Cycle Scales meet the first six criteria described in the previous paragraph. However, only Alternative Adult OMNI-Cycle Scale II satisfies all nine criteria described in the above list. With respect to criterion seven, the insertion of “0” as a true rest category for Alternative Adult OMNI-Cycle Scale II is in agreement with the mathematical power function underlying Borg’s Range Model. In the equation depicting this power function the constant a corresponds to a resting value, usually a “0” and there is no exertional response in the absence of a physical stimulus (S).

Criterion eight notes that the psychometric format of the modified Adult OMNI-Elliptical Scale employs a “0” category as a true resting value. This category is positioned prior to both

the visual and pictorial descriptors that are linked to actual exercise conditions. Alternative Adult OMNI-Cycle Scale II satisfies the requirements of criterion eight. Moreover, Alternative Adult OMNI-Cycle Scale II facilitates development of an instructional set that describes the lower perceptual anchor (i.e., criterion nine) where the resting numerical category “0” can be cognitively linked to the verbal descriptor of “rest”. As such, owing to agreement with all nine selection criteria, it is proposed that Alternative Adult OMNI-Cycle II be chosen for use in future research and health-fitness applications relating to the perceived exertion domain. This leads to a revised conversion chart involving the Original Adult OMNI Scale and Alternative Adult OMNI-Cycle II as presented in Figure 6-3.

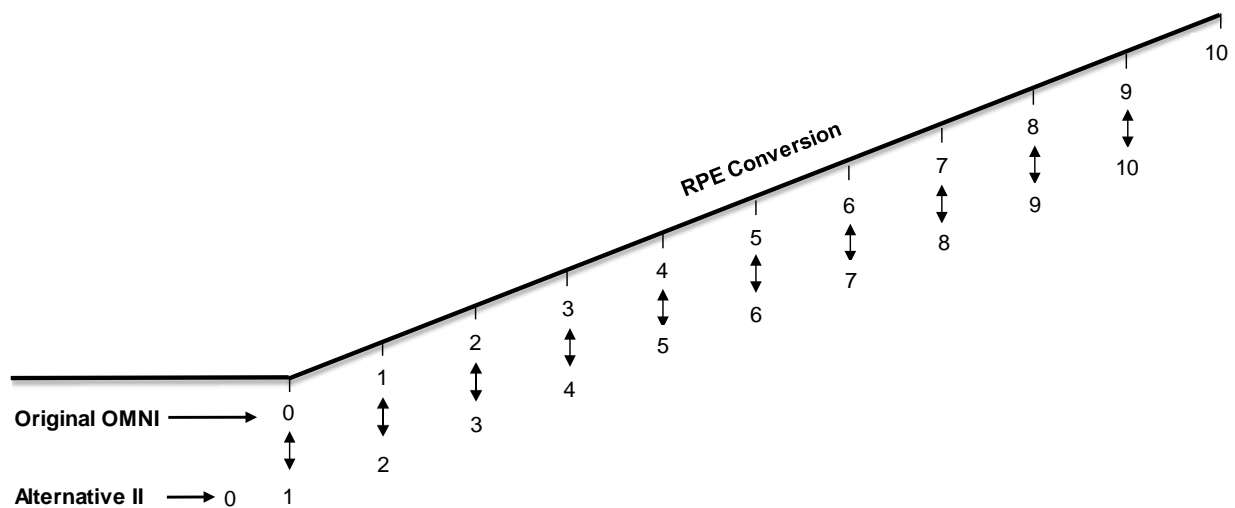


Figure 6-3 Revised RPE Conversion Chart for Alternative Adult OMNI-Cycle Scale II.

The revised RPE Conversion Chart (Figure 5-3) will permit health fitness professionals and clinical specialists to establish target training zones using the Alternative Adult OMNI-Cycle Scale II or the Original Adult OMNI-Cycle Scale.

6.3 LIMITATIONS OF RESEARCH:

A potential limitation of the present study concerns the pre-screening phone interview of all subjects to determine recent physical activity levels and any previous exposure to RPE scales. The screening may not have been sufficiently precise to allow recruitment of a sample of young males who were homogenous with respect to peak aerobic power. Four subjects from the total pool of 16 subjects reached Stage V of the cycle ergometer protocol while the remaining subjects reached Stage IV. This made isotime comparison of RPE responses between scales inappropriate owing to interindividual differences in relative aerobic metabolic rate at each power output stage. Use of the three individually determined sub-maximal relative aerobic metabolic rates (i.e., %VO_{2peak}) to derive data for statistical computation may have mitigated the effect of this pre-screening limitation.

A within subject repeated measures paradigm was used in the present investigation. The advantages of this design were 1) decrease inter-subject variability, 2) offer greater comparability across experimental trials, and 3) require fewer total subjects (41). However, the within subject repeated measures paradigm required that all subjects be exposed to the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale. This may have limited the internal validity of the investigation owing to demand bias resulting from multiple exposure to the four OMNI-Cycle Scale formats.

6.4 FUTURE RESEARCH LIST:

- a. Perform test, re-test reliability studies of the three Alternative Adult OMNI-Cycle Scales.
- b. Determine if there are statistically significant differences in RPE responses at the lower perceptual range (i.e., “0” and “1”) between the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale.
- c. Examine the validity of an Alternative OMNI-Cycle Scale format that includes a pictorial descriptor of a person at rest that is specific to the exercise mode to be performed.
- d. Use larger sample sizes that will provide greater statistical power, further strengthening the generalization of the regression models.
- e. Repeat the investigation using subjects of the following subject characteristics: female, children, adolescents, older adults, sedentary/overweight/obese, and/or elite athletes.
- f. Follow on research should employ heterogeneous samples that demonstrate the characteristics in e. above to make the Alternative OMNI Scale format II generalizable to more diversified population sub-sets.
- g. Examine other modes of exercise and corresponding pictorial descriptors.
- h. Repeat the by investigation by assigning different subject groups to each Alternative OMNI-Cycle Scale.
- i. Develop statistical regression models to develop conversion table to interchange RPE derived from the Original Adult OMNI-Cycle Scale, Alternative Adult OMNI Scale I, II, III, Borg (6-20) Perceived Exertion Scale and Borg Cr-10 Perceived Exertion Scale.

APPENDIX A

RECRUITMENT FLYER



University of Pittsburgh

Research Study

DEPARTMENT OF HEALTH AND PHYSICAL ACTIVITY

CENTER FOR EXERCISE AND HEALTH-FITNESS RESEARCH

- Now recruiting study participants for 5 separate exercise sessions investigating four different numerical scales of perceived exertion during cycle exercise.
 - The 5 sessions will be completed within a two to three-week period.
 - Each session will be no longer than 45 minutes.
 - You will be provided a personal report of your body fat analysis and your aerobic fitness level.
 - You will receive \$90.00 upon completion of the study.
- If you are between the ages of *18 to 30 years* and you participate in recreational activity*, you may qualify for this study.
- Please call 412-648-8251, Department of Health & Physical Activity, University of Pittsburgh, or email glpst3@pitt.edu for more details.

*Recreational activity: aerobic activity for at least 20 minutes two times per week, for a weekly total of no more than 150 minutes per week. However, no more than 30 minutes of cycle exercise per week.

APPENDIX B

SUBJECT RECRUITMENT PACKET

B.1 PHONE INTERVIEW

ID # _____

**University of Pittsburgh
Center for Exercise and Health-Fitness Research
Phone Interview
Physical Activity Questionnaire**

YES/NO

1. Do you participate in weekly aerobic exercise? _____
 - a. If yes, how many days per week? _____
 - b. How many minutes per exercise session? _____
 - i. Total minutes per week? _____
 - c. What types of exercise? _____
2. Do you participate in any collegiate or professional athletics (i.e. NCAA, club, etc.)? _____
3. Do you have any previous experience with ratings of perceived exertion scales? _____

B.2 INFORMED CONSENT



University of Pittsburgh

School of Education
Department of Health and Physical Activity

140 Trees Hall
Pittsburgh, PA 15261
412-648-8320
Fax: 412-648-7092

Institutional Review Board
Approval Date:
Renewal Date:
IRB Number:

CONSENT TO ACT AS A PARTICIPANT IN A RESEARCH STUDY

TITLE: CONCURRENT AND CONSTRUCT VALIDITY OF THREE ALTERNATIVE VERSIONS OF THE STANDARD OMNI CYCLE SCALE OF PERCEIVED EXERTION IN YOUNG ADULT MALES

PRINCIPAL INVESTIGATOR: George L. Panzak, MS, RN
107 Trees Hall
Pittsburgh, PA 15216
Phone: 412-648-8251
Email: glpst3@pitt.edu
Department of Health and Physical Activity
School of Education

CO-INVESTIGATORS: Robert J. Robertson, PhD
Professor Emeritus, Center for Exercise and
Health-Fitness Research
Department of Health and Physical Activity
School of Education
107 Tress Hall
Pittsburgh, PA 15216
Phone: (412) 648-8251 Fax: (412) 648-7092
Email: rrobert@pitt.edu

SOURCE OF SUPPORT: University of Pittsburgh School of Education Research Grant



University Of Pittsburgh
Institutional Review Board

Approval Date: «Approval Date»
Renewal Date: «Renewal Date»

IRB #: «IRBNo»

Why is this research being done?

A rating of perceived exertion (RPE) is determined by a numerical scale and can be used to measure and control exercise intensity. Perceived exertion is defined as your feelings of effort, strain, discomfort, and/or fatigue that you experience during exercise. The basis for use of perceived exertion to prescribe exercise is the link between a target RPE and both heart rate and the amount of oxygen the body uses. The OMNI Scale of Perceived Exertion developed by Dr. Robertson uses a system of pictures that are combined with short verbal cues and arranged along a numerical continuum. The OMNI scale pictures depict an individual performing exercise activities at varying intensities. The term OMNI is contemporary contraction of the word omnibus, which in this context means that the perceived exertion scale is applicable for a wide range of clients and physical activity modes (i.e., running, cycling). The purpose of this study is to determine the validity of four different OMNI scales to measure your perception of physical exertion during cycle exercise.

Who is being asked to take part in this research study?

Sixteen males ranging in age from 18-30 years will participate as subjects for this investigation. The investigation will last approximately three weeks. You are being asked to take part in this research study because you are healthy and are considered for study purposes to be of normal weight and recreationally active (participating in aerobic exercises at least 2 times per week for no more than 150 minutes per week). To minimize risks with maximal aerobic exercise testing, you will be requested to complete a Physical Activity Readiness Questionnaire (PAR-Q) and a medical history form which ask questions about your current health status. If you have orthopedic (muscle or bone), cardiovascular (i.e. coronary artery disease/heart disease), prior myocardial infarction (heart attack), peripheral vascular disease (blockages in legs), chronic obstructive pulmonary disease (lung disease), and diabetes mellitus (high/low blood sugar) and/or if you are a current smoker, you will not be eligible to participate in this research study.

What procedures will be performed for research purposes?

If you decide to take part in this research study, you will be required to complete five, 20-30 minute exercise testing sessions, each separated by a 3-4 day period. Each testing session will involve stationary cycle ergometer exercise. The first session will provide an orientation to a cycle exercise test. Each of the following four sessions will involve a cycle exercise trial.

If an abnormal response occurs during exercise such as chest pain, the test will be immediately stopped and you will be given proper medical attention. Emergency equipment will be available on site for all testing procedures and research staff are certified in CPR and First Aid by the American Red Cross. If you have an abnormal response to the cycle test, you will be told of the findings and will be encouraged to contact your primary care clinician.

All procedures will take place in the Human Energy Research Laboratory at the Center for Exercise and Health-Fitness Research located in Tress Hall at the University of Pittsburgh. All testing sessions will be administered by trained staff members from the Center for Exercise and Health-Fitness Research.

Pre-Testing Procedures:

1. Before starting the study protocol, you will complete a Medical History Form, Physical Activity Readiness



University Of Pittsburgh
Institutional Review Board

Approval Date: «Approval Date»
Renewal Date: «Renewal Date»

IRB #: «IRBNo»

Questionnaire (PAR-Q), and a physical activity questionnaire. All three forms will take less than ten minutes to complete.

2. Your body height and weight will be measured using a standard physicians' scale. These measurements will be used to determine your Body Mass Index (BMI). In addition, your body composition will be measured using a standard Bioelectrical Impedance Analyzer (BIA). The BIA is a non-invasive pain-free procedure that transmits a low-level electrical impulse through your body. The BIA measures your percent body fat and percent muscle mass.

Orientation Session Cycle Exercise:

3. During the orientation session, a heart rate monitor will be positioned around your chest and secured in place with an elastic strap. A rubber mask, connected to a headset, will be placed over your mouth and nose during a cycle exercise to determine the amount of oxygen that you use during exercise. Some individuals become anxious when fitted with the rubber mask. If this occurs to you, please inform the investigator and the test will be stopped. Your heart rate and amount of oxygen that your body uses will be measured every minute during the cycle exercise test.
4. Prior to the exercise test, you will receive standard instructions on RPE procedures. The investigator will first read to you the following definition of RPE: *"The rating of perceived exertion (RPE) is defined as a measure of your feelings of effort, strain, discomfort, and/or fatigue that are experienced during exercise."* A set of instructions on how to use the Adult OMNI-Cycle Scale will then be read to you.
5. If you do not have any conditions that limit your ability to exercise based on the information you provide on the Medical History Form and PAR-Q, you will complete a stationary cycle test to determine your fitness level. Following a 2-minute warm-up, the exercise test will begin at a low level (75 watts of resistance) for the first three minutes of exercise. It will increase by 50 watts of resistance every three minutes up to nine minutes of exercise. After nine minutes of exercise, it will increase by 25 watts of resistance every three minutes. You will maintain a pedal rate of 50 revolutions per minute. You will be encouraged to continue until fatigued. However, you may stop the test at any time for any reason.

Four Experimental Trials Cycle Exercise Tests:

6. During the exercise tests, a heart rate monitor will be positioned around your chest and secured in place with an elastic strap. A rubber mask, connected to a headset, will be placed over your mouth and nose to determine the amount of oxygen that you use during exercise. Some individuals become anxious when fitted with the rubber mask. If this occurs to you, please inform the investigator and the test will be stopped. Your heart rate and amount of oxygen that your body uses will be measured every minute during the cycle exercise test.
7. Prior to the exercise test, you will receive standard instructions on RPE procedures. The investigator will first read to you the definition of RPE. A set of instructions on how to use the Adult OMNI-Cycle Scale format designated for that test will then be read to you.
8. You will then undertake the exercise test on a stationary cycle. Following a 2-minute warm-up, the exercise test will begin at a low level (75 watts of resistance) for the first three minutes of exercise. It will increase by 50 watts of resistance every three minutes. You will maintain a pedal rate of 50 revolutions per minute. You will be encouraged to continue until fatigued. However, you may stop the test at any time for any reason.



University Of Pittsburgh
Institutional Review Board

Approval Date: «Approval Date»
Renewal Date: «Renewal Date»

IRB #: «IRBNo»

What are the possible risks, side effects, and discomforts of this research study?

Risks of the Graded Exercise Test

Abnormal responses, such as excessive rises in blood pressure, mental confusion, shortness of breath, chest pain, heart attack, and death, to maximal aerobic exercise tests in young healthy adults are rare, occurring in less than 1% of people (less than 1 out of 100 people tested). However, some common risks of maximal exercise testing occurring in 1% to 25% of people (1 to 25 out of 100 people tested) include; heavy breathing, dizziness, muscle fatigue, headache, and overall fatigue.

Risks of the Study Monitors

Risk associated with study monitors (e.g. heart rate monitor and mouthpiece) include skin redness, irritation, and chafing.

Risk of Confidentiality Breach

As with all studies there is a risk of potential breach of confidentiality with questionnaires and exercise data. However, every step will be taken to avoid this breach.

What are possible benefits from taking part in this study?

You will likely receive no direct benefit from taking part in this research study. However, you will receive information regarding your aerobic fitness level (peak oxygen consumption), percent body fat, percent muscle mass, and the importance of regular exercise in promoting cardiovascular health.

What treatments or procedures are available if I decide not to take part in this research study?

If you decide not to take part in this research study, there are no other procedures available.

If I agree to take part in this research study, will I be told of any new risks that may be found during the course of the study?

You will be promptly notified if, during the conduct of this research study, any new information develops which may cause you to change your mind about continuing to participate.

Will my insurance provider or I be charged for the costs of any procedures performed as part of this research study?

Neither you, nor your insurance provider, will be charged for the costs of any of the procedures performed for the purpose of this research study (i.e., the Screening Procedures, Experimental Procedures described above).

Will I be paid if I take part in this research study?

You will be paid a total of \$90 upon completion of the five exercise tests. You will not be paid for any partial completion of the five exercise tests.



University Of Pittsburgh
Institutional Review Board

Approval Date: «Approval Date»
Renewal Date: «Renewal Date»

IRB #: «IRBNo»

In addition, any parking fees related to your participation in this study will not be paid for by the study.

Who will pay if I am injured as a result of taking part in this study?

University of Pittsburgh researchers and their associates who provide services at UPMC recognize the importance of your voluntary participation in their research studies. These individuals and their staff will make reasonable efforts to minimize, control, and treat any injuries that may arise as a result of this research. If you believe that the research procedures have resulted in an injury to you, immediately contact the Principal Investigator who is listed on the first page of this form.

Emergency medical treatment for injuries solely and directly related to your participation in this research study will be provided to you by the hospitals of UPMC.

It is possible that the UPMC may bill your insurance provider for the costs of this emergency treatment, but none of those costs will be charged directly to you. If your research-related injury requires medical care beyond this emergency treatment, you will be responsible for the costs of this follow-up care. At this time, there is no plan for any additional financial compensation.

Who will know about my participation in this research study?

Any information about you obtained from this research will be kept as confidential (private) as possible. All records related to your involvement in this research study will be stored in a locked file cabinet. Your identity on these records will be indicated by a case number rather than by your name, and the information linking these case numbers with your identity will be kept separate from the research records. You will not be identified by name in any publication of the research results unless you sign a separate consent form giving your permission (release).

Will this research study involve the use or disclosure of my identifiable medical information?

This research study will not involve the recording of current and/or future identifiable medical information from your hospital and/or other (e.g., physician office) records.

Who will have access to identifiable information related to my participation in this research study?

In addition to the investigators listed on the first page of this authorization (consent) form and their research staff, the following individuals will or may have access to identifiable information (which may include your identifiable medical information) related to your participation in this research study:

- Authorized representatives of the University of Pittsburgh Research Conduct and Compliance Office may review your identifiable research information (which may include your identifiable medical information) for the purpose of monitoring the appropriate conduct of this research study.
- In unusual cases, the investigators may be required to release identifiable information (which may include your identifiable medical information) related to your participation in this research study in response to an



University Of Pittsburgh
Institutional Review Board

Approval Date: «Approval Date»
Renewal Date: «Renewal Date»

IRB #: «IRBNo»

- order from a court of law. If the investigators learn that you or someone with whom you are involved is in serious danger or potential harm, they will need to inform, as required by Pennsylvania law, the appropriate agencies.
- Authorized representatives of the sponsor of this research study, University of Pittsburgh School of Education, will review and/or obtain identifiable information (which may include your identifiable medical information) related to your participation in this research study for the purpose of monitoring the accuracy and completeness of the research data and for performing required scientific analyses of the research data.

For how long will the investigators be permitted to use and disclose identifiable information related to my participation in this research study?

The investigators may continue to use and disclose, for the purposes described above, identifiable information (which may include your identifiable medical information) related to your participation in this research study for a minimum of six years after final reporting or publication of a project.

May I have access to my medical information that results from my participation in this research study?

In accordance with the UPMC Notices of Privacy Practices document that you have been provided, you are permitted access to information (including information resulting from your participation in this research study) contained within your medical records filed with your health care provider.

Is my participation in this research study voluntary?

Your participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above, is completely voluntary. (Note, however, that if you do not provide your consent for the use and disclosure of your identifiable information for the purposes described above, you will not be allowed to participate in the research study.) Whether or not you provide your consent for participation in this research study will have no effect on your current or future relationship with the University of Pittsburgh. Whether or not you provide your consent for participation in this research study will have no effect on your current or future medical care at a UPMC hospital or affiliated health care provider or your current or future relationship with a health care insurance provider. If you are a student, the decision to participate or not in this study will have no influence on class standing or grades.

May I withdraw, at a future date, my consent for participation in this research study?

You may withdraw, at any time, your consent for participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above. Any identifiable research or medical information recorded for, or resulting from, your participation in this research study prior to the date that you formally withdrew your consent may continue to be used and disclosed by the investigators for the purposes described above.

To formally withdraw your consent for participation in this research study you should provide a written and dated notice of this decision to the principal investigator of this research study at the address listed on the first page of this form.



University Of Pittsburgh
Institutional Review Board

Approval Date: «Approval Date»
Renewal Date: «Renewal Date»

IRB #: «IRBNo»

Your decision to withdraw your consent for participation in this research study will have no effect on your current or future relationship with the University of Pittsburgh. Your decision to withdraw your consent for participation in this research study will have no effect on your current or future medical care at a UPMC hospital or affiliated health care provider or your current or future relationship with a health care insurance provider.

If I agree to take part in this research study, can I be removed from the study without my consent?

It is possible that you may be removed from the research study by the researchers if, for example, you experience dizziness or chest pain during the exercise test.



University Of Pittsburgh
Institutional Review Board

Approval Date: «Approval Date»
Renewal Date: «Renewal Date»

IRB #: «IRBNo»

VOLUNTARY CONSENT

The above information has been explained to me and all of my current questions have been answered. I understand that I am encouraged to ask questions about any aspect of this research study during the course of this study, and that such future questions will be answered by a qualified individual or by the investigator(s) listed on the first page of this consent document at the telephone number(s) given. I understand that I may always request that my questions, concerns or complaints be addressed by a listed investigator.

I understand that I may contact the Human Subjects Protection Advocate of the IRB Office, University of Pittsburgh (1-866-212-2668) to discuss problems, concerns, and questions; obtain information; offer input; or discuss situations that have occurred during my participation.

By signing this form, I agree to participate in this research study. A copy of this consent form will be given to me.

Participant's Signature

Printed Name of Participant

Date

CERTIFICATION of INFORMED CONSENT

I certify that I have explained the nature and purpose of this research study to the above-named individual(s), and I have discussed the potential benefits and possible risks of study participation. Any questions the individual(s) have about this study have been answered, and we will always be available to address future questions as they arise."

Printed Name of Person Obtaining Consent

Role in Research Study

Signature of Person Obtaining Consent

Date



University Of Pittsburgh
Institutional Review Board

Approval Date: «Approval Date»
Renewal Date: «Renewal Date»

IRB #: «IRBNo»

B.3 MEDICAL HISTORY

ID # _____

University of Pittsburgh Center for Exercise and Health-Fitness Research

Medical History

	YES	NO
1. History of heart problems, chest pain, or stroke?	_____	_____
2. Have you ever been diagnosed with MI or Peripheral Vascular Disease?	_____	_____
3. Increased blood pressure?	_____	_____
4. Any chronic illness or condition?	_____	_____
5. Difficulty with physical exercise?	_____	_____
6. Advice from physician not to exercise?	_____	_____
7. Recent surgery? (Last 12 months)	_____	_____
8. Pregnancy? (Now or within the last three months)	_____	_____
9. History of breathing or lung problems	_____	_____
10. Muscle, joint, back disorder, or any previous injury still affecting you?	_____	_____
11. Diabetes or thyroid conditions?	_____	_____
12. Cigarette smoking habit?	_____	_____
13. Increased blood cholesterol?	_____	_____
14. History of heart problems in your immediate family?	_____	_____
15. Do you have any implantable devices (i.e. pacemaker, defibrillator)?	_____	_____
16. Hernia or any condition that may be aggravated by lifting weights?	_____	_____
17. Do you have any condition limiting your movement?	_____	_____
18. Are you aware of being, allergic to any drugs or insect bites?	_____	_____
19. Do you have asthma?	_____	_____
20. Do you have epilepsy, convulsions, or seizures of any kind?	_____	_____
21. Do you follow any specific diet?	_____	_____

Please explain in detail any "YES" answers:

Family History

Has any member of your family had any of those listed above?

B.4 PAR-Q

ID # _____

Physical Activity Readiness Questionnaire (PAR-Q) and You

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly:

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered:	YES to one or more questions Talk to your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES. <ul style="list-style-type: none">You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.Find out which community programs are safe and helpful for you.			
	<table border="1"><thead><tr><th>NO to all questions</th><th>Delay becoming much more active:</th></tr></thead><tbody><tr><td>If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:<ul style="list-style-type: none">Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.</td><td><ul style="list-style-type: none">If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; orIf you are or may be pregnant – talk to your doctor before you start becoming more active.</td></tr></tbody></table>	NO to all questions	Delay becoming much more active:	If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can: <ul style="list-style-type: none">Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.
NO to all questions	Delay becoming much more active:			
If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can: <ul style="list-style-type: none">Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.	<ul style="list-style-type: none">If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; orIf you are or may be pregnant – talk to your doctor before you start becoming more active.			

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed use of the PAR-Q: Reprinted from ACSM's Health/Fitness Facility Standards and Guidelines, 1997 by American College of Sports Medicine

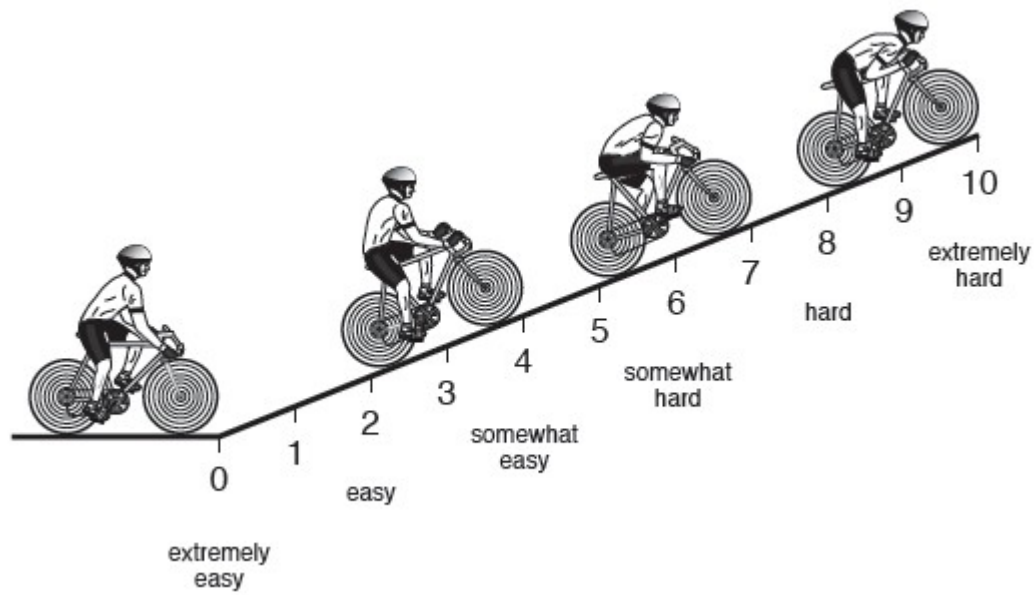
APPENDIX C

INSTRUCTIONS, PROCEDURES, AND DATA SHEETS FOR EXERCISE TRIALS

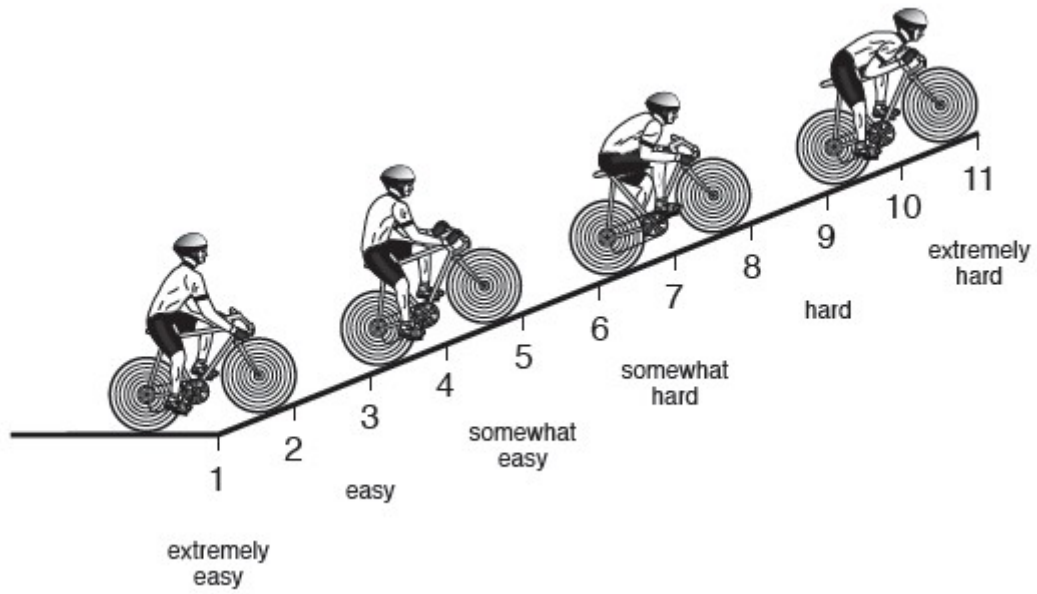
C.1 CLINICAL EXCLUSION CRITERIA

1. History of diabetes, hypothyroidism, or other medical conditions that would affect energy metabolism.
2. Non-medicated resting systolic blood pressure > 160mmHg or non-medicated resting diastolic blood pressure > 100mmHg, or taking medication that would affect blood pressure.
3. Medication that would affect resting heart rate or the heart rate response during exercise (i.e. beta blockers).
4. Any history of myocardial infarction or valvular or peripheral vascular disease.
5. Any implantable physiological devices (such as defibrillator).
6. Any history of asthma or chronic obstructive pulmonary disease.
7. Any history of orthopedic complications (i.e. bone spurs, joint diseases or related conditions) that would prevent complete participation in the exercise tests.
8. Current history of smoking, defined as anyone who continues to smoke or has quit less than six months ago.

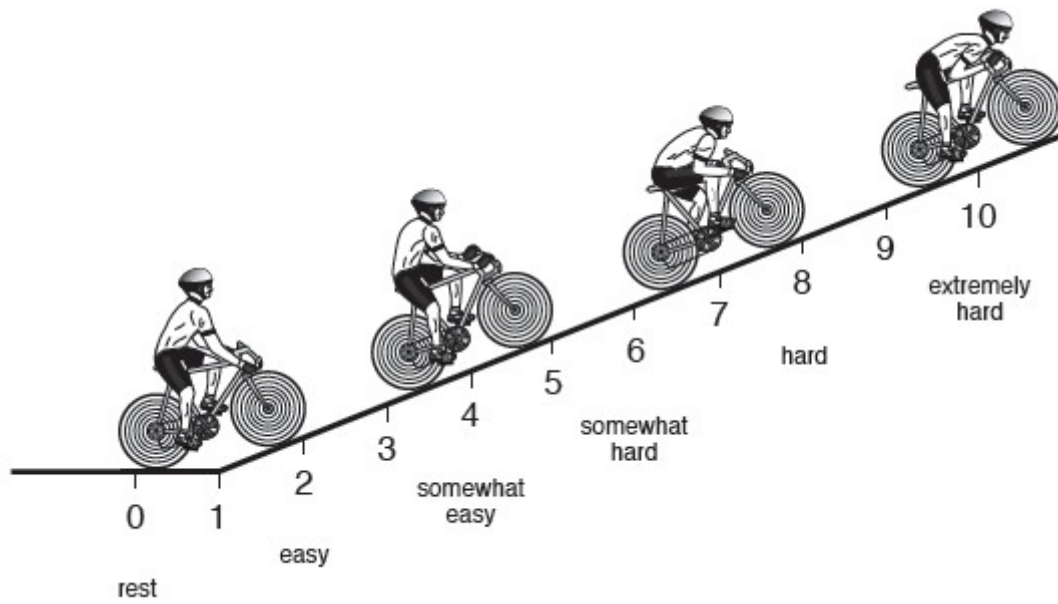
C.2 ORIGINAL ADULT OMNI-CYCLE SCALE



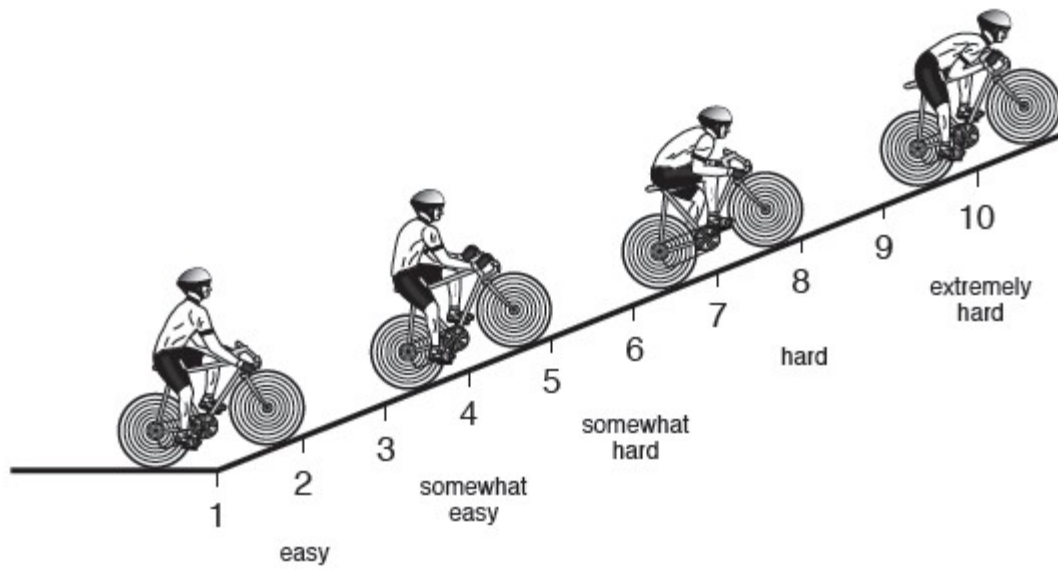
C.3 ALTERNATIVE I ADULT OMNI CYCLE-SCALE



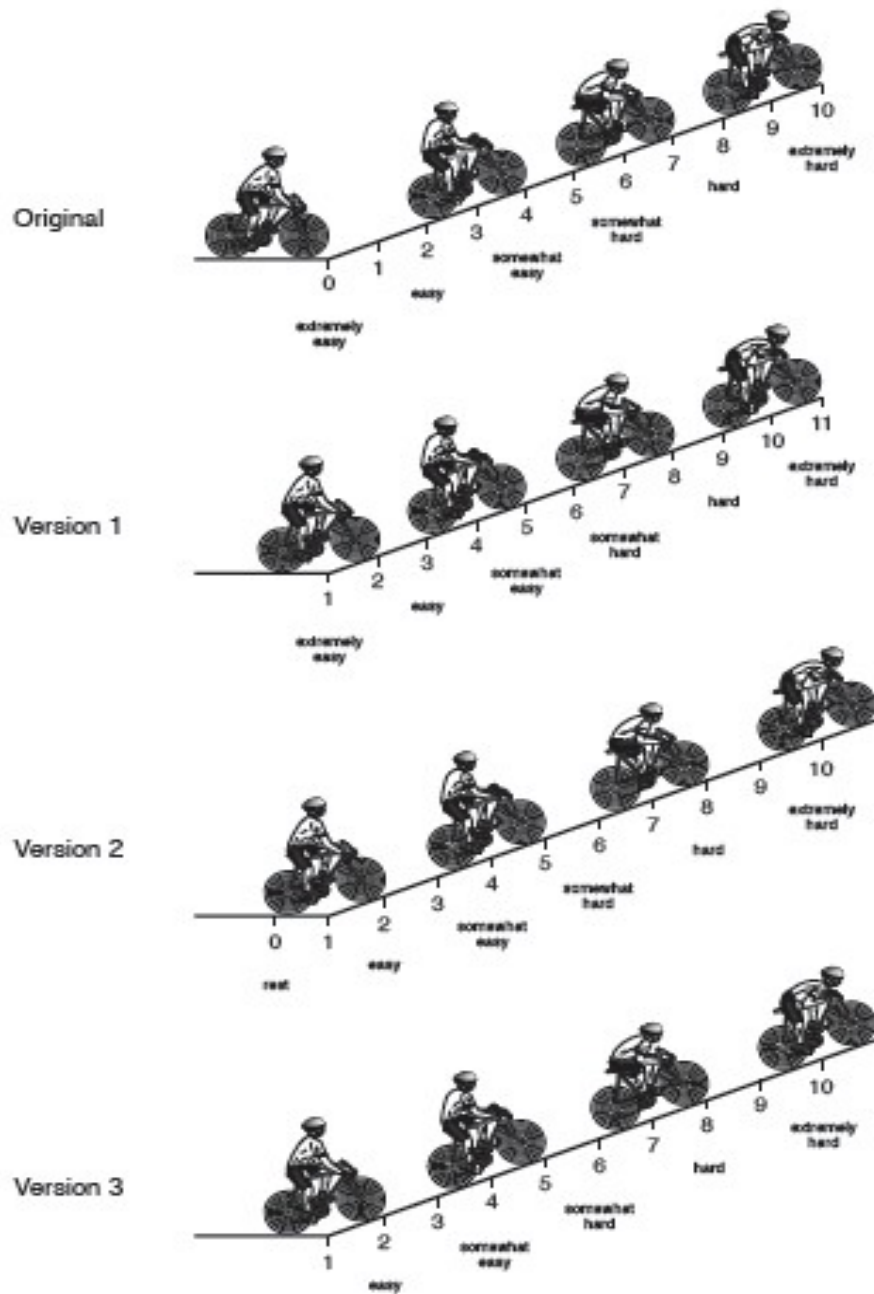
C.4 ALTERNATIVE II ADULT OMNI-CYCLE SCALE



C.5 ALTERNATIVE III ADULT OMNI-CYCLE SCALE



C.6 COMPARISON ORIGINAL ADULT OMNI-CYCLE SCALE AND THREE ALTERNATIVE ADULT OMNI-CYCLE SCALES



C.7 ORIGINAL ADULT OMNI-CYCLE SCALE INSTRUCTIONS

Definition of RPE:

“The perception of physical exertion is defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that you feel during exercise”.

Instructions:

“We would like you to ride on a bicycle ergometer. Please use the numbers on this scale to tell us how your body feels when you are cycling. Please look at the person at the bottom of the hill who is just starting to ride a bicycle. If you feel like this person when you are cycling, the exertion will be EXTREMELY EASY. In this case, your rating should be a zero. Now look at the person who is exhausted at the top of the hill. If you feel like this person when cycling, the exertion will be EXTREMELY HARD. In this case, your rating should be a 10. If you feel somewhere between Extremely Easy (0) and Extremely Hard (10) then give a number between 0 and 10.

We will ask you to point to a number that tells how your whole body feels, then to the number that tells how your legs feel, and then to the number that tells how your chest and breathing feel. Remember, there are no right or wrong numbers. Use both the pictures and words to help you select a number. Use any of the numbers to tell us how you feel when cycling.

C.8 ALTERNATIVE I ADULT OMNI-CYCLE SCALE INSTRUCTIONS

Definition of RPE:

“The perception of physical exertion is defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that you feel during exercise”.

Instructions:

“We would like you to ride on a bicycle ergometer. Please use the numbers on this scale to tell us how your body feels when you are cycling. Please look at the person at the bottom of the hill who is just starting to ride a bicycle. If you feel like this person when you are cycling, the exertion will be EXTREMELY EASY. In this case, your rating should be a 1. Now look at the person who is exhausted at the top of the hill. If you feel like this person when cycling, the exertion will be EXTREMELY HARD. In this case, your rating should be a 11. If you feel somewhere between Extremely Easy (1) and Extremely Hard (11) then give a number between 1 and 11.

We will ask you to point to a number that tells how your whole body feels, then to the number that tells how your legs feel, and then to the number that tells how your chest and breathing feel. Remember, there are no right or wrong numbers. Use both the pictures and words to help you select a number. Use any of the numbers to tell us how you feel when cycling.”

C.9 ALTERNATIVE II ADULT OMNI-CYCLE SCALE INSTRUCTIONS

Definition of RPE:

“The perception of physical exertion is defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that you feel during exercise”.

Instructions:

“We would like you to ride on a bicycle ergometer. Please use the numbers on this scale to tell us how your body feels when you are cycling. Please look at the person at the bottom of the hill who is just starting to ride a bicycle. If you feel like this person when you are cycling, then in your rating should be a 1. Now look at the person who is exhausted at the top of the hill. If you feel like this person when cycling, the exertion will be EXTREMELY HARD. In this case, your rating should be a 10. If you feel somewhere between Rest (0) and Extremely Hard (10) then give a number between 0 and 10.

We will ask you to point to a number that tells how your whole body feels, then to the number that tells how your legs feel, and then to the number that tells how your chest and breathing feels. Remember, there are no right or wrong numbers. Use both the pictures and words to help you select a number. Use any of the numbers to tell us how you feel when cycling.”

C.10 ALTERNATIVE III ADULT OMNI-CYCLE SCALE INSTRUCTIONS

Definition of RPE:

“The perception of physical exertion is defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that you feel during exercise”.

Instructions:

“We would like you to ride on a bicycle ergometer. Please use the numbers on this scale to tell us how your body feels when you are cycling. Please look at the person at the bottom of the hill who is just starting to cycling. If you feel like this person when you are cycling, then your rating should be a 1. Now look at the person who is exhausted at the top of the hill. If you feel like this person when cycling, the exertion will be EXTREMELY HARD. In this case, your rating should be a 10. If you feel somewhere between 1 and Extremely Hard (10) then give a number between 1 and 10.

We will ask you to point to a number that tells how your whole body feels, then to the number that tells how your legs feel, and then to the number that tells how your chest and breathing feels. Remember, there are no right or wrong numbers. Use both the pictures and words to help you select a number. Use any of the numbers to tell us how you feel when cycling.”

C.11 OMNI-RPE Orientation: Cycle Exercise Data Sheet

Date: _____

ID: _____

CB Scale Code: _____

Room Temp: _____ °C

Relative Humidity: _____ %

Age: _____ Height (in/cm): _____ / _____ Weight (kg): _____ %Fat: _____ %LBM: _____

Resting Heart Rate (bpm): _____ APMHR (bpm): _____ 85% APMHR (bpm): _____

Pedal Rate = 50 rpm

Males:

Stage	Time	R	PO		HR	RPE Sequence			VO ₂	VO ₂
	(min)	(kg)	(kgm/min)	(Watts)	(bpm)				(l/min)	(ml/kg/min)
I	1	1.5	450	75						
	2									
	3									
II	1	2.5	750	125						
	2									
	3									
III	1	3.5	1050	175						
	2									
	3									
IV	1	4.0	1200	200						
	2									
	3									
VI	1	4.5	1350	225						
	2									
	3									
VII	1	5.0	1400	250						
	2									
	3									
VIII	1	5.5	1550	275						
	2									
	3									
IX	1	6.0	1650	300						
	2									
	3									

Cool-down: 2 min free wheeling at 0W

Staff initials _____

Ventilatory Breakpoint (from computer)

VO₂: _____ L/min % VO_{2peak}: _____

Time: _____

PO: _____

Reminders:

APMHR = 226 – Age

RPE Measurement from 30 sec. to 60 sec. of each minute of each PO stage.

HR Measurement during last 30 sec. of each minute of each PO stage.

C.12 OMNI-RPE Experimental Tests: Cycle Exercise Data Sheet

Date: _____ ID: _____

Room Temp: _____ °C CB Scale Cluster _____

Relative Humidity: _____ %

Age: _____ Height (in/cm): _____ / _____ Weight (kg): _____ %Fat: _____ %LBM: _____

Resting Heart Rate (bpm): _____ APMHR (bpm): _____ 85% APMHR (bpm): _____

Pedal Rate = 50 rpm

Males:

Stage	Time	R	PO		HR	RPE sequence			VO ₂	VO ₂
	(min)	(kg)	(kgm/min)	(Watts)	(bpm)				(l/min)	(ml/kg/min)
I	1	1.5	450	75						
	2									
	3									
II	1	2.5	750	125						
	2									
	3									
III	1	3.5	1050	175						
	2									
	3									
IV	1	4.5	1350	225						
	2									
	3									
VI	1	5.5	1650	275						
	2									
	3									
VII	1	6.5	1950	325						
	2									
	3									
VIII	1	7.5	2250	375						
	2									
	3									
IX	1	8.5	2550	425						
	2									
	3									

Cool-down: 2 min free wheeling at 0W

Staff initials _____

Ventilatory Breakpoint (from computer)

VO₂: _____ L/min % VO_{2peak}: _____ Time: _____ PO: _____

Reminders:

APMHR = 226 – Age

RPE Measurement from 30 sec. to 60 sec. of each minute of each PO stage.

HR Measurement during last 30 sec. of each minute of each PO stage.

APPENDIX D

LETTER FROM PRIMARY INVESTIGATOR FOLLOWING STUDY COMPLETION



University of Pittsburgh

School of Education
Department of Health and Physical Activity

140 Trees Hall
Pittsburgh, PA 15261
412-648-8320
Fax: 412-648-7092

Dear Participant,

In the past few months, you participated in a research study at the Center for Exercise and Health-Fitness Research at the University of Pittsburgh. You visited the laboratory on five separated occasions where you performed one orientation cycle exercise session and four experimental cycle exercise tests. Upon completion of your participation, you were compensated \$90.00.

When you consented to participated in this investigation you were informed that the purpose of the study was to determine the validity of four different OMNI scales to measure your perception of physical exertion during cycle exercise.

For your additional information, here are the results of your health-related status:

Maximal Oxygen Uptake (VO_{2max}): _____ ml/kg/min

Aerobic Fitness Classification according to sex/age criteria (based on VO_{2max}): _____

Percent Body Fat (% BF): _____ Ideal Range: _____

Percent lean body mass (% LBM) : _____

Body Mass Index (BMI; kg/m^2): _____ BMI: $< 25 kg/m^2$ is considered normal weight

The findings of this investigation will be analyzed and conclusions will be developed as my doctoral dissertation. Thank you for your participation in this investigation. If you have any further questions, please feel free to contact me at 724-272-7322 or email glpst3@pitt.edu

Sincerely yours in Health & Strength,

George L .Panzak, MS, RN
Principle Investigator

APPENDIX E

Table A-1 Ratings of perceived exertion (RPE-Legs and RPE-Chest) for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale used to determine signal dominance (RPE-Legs > RPE-Chest) (N=16). Data are marginal means derived from the three-factor ANOVA.

Site	Scale			
	Alternative I Marginal Mean (\pm SD)	Alternative II Marginal Mean (\pm SD)	Alternative III Marginal Mean (\pm SD)	Original Marginal Mean (\pm SD)
RPE-Legs	5.48 (0.77)	5.37 (0.73)	5.86 (0.66)	4.85 (1.27)
RPE-Chest	4.83 (0.88)	4.87 (0.83)	5.05 (1.01)	4.25 (1.19)

Table A-2 Ratings of perceived exertion (RPE-Legs and RPE-Chest) for the three Alternative Adult OMNI-Cycle Scales and the Original Adult OMNI-Cycle Scale used to determine signal integration (RPE-Overall=Avg RPE(L,C) (N=16). Data are marginal means from the three-factor ANOVA.

Site	Scale			
	Alternative I Marginal Mean (\pm SD)	Alternative II Marginal Mean (\pm SD)	Alternative III Marginal Mean (\pm SD)	Original Marginal Mean (\pm SD)
RPE-Overall	5.03 (0.20)	4.98 (0.22)	5.24 (0.17)	4.47 (0.34)
Avg RPE(L,C)	5.16 (0.18)	5.12 (0.17)	5.45 (0.17)	4.55 (0.28)

BIBLIOGRAPHY

1. ACSM. *Guidelines for Exercise Testing and Prescription*. 8th ed. Philadelphia, PA: Lippincot Williams and Wilkins; 2010. p.18-39.
2. Albert I, Williams MH. Effects of post-hypnotic suggestions on muscular endurance. *Percept Mot Skills* 1975;40:131-139.
3. Balasekaran G, Loh MK, Govindaswamy VV, Robertson RJ. OMNI scale of perceived exertion: mixed gender and race validation for singapore children exercise. *Eur J appl Physiol*. 2012;DOI 10.1007/s00421-012-2334-8.
4. Barkley JE, Roemmich JN. Validity of the CALER and OMNI-bike ratings of perceived exertion. *Med Sci Sports Exerc*. 2008;40(4):760-766.
5. Bolgar MR, Baker CE, Goss FL, Nagle E, Robertson RJ. Effect of exercise intensity on differentiated and undifferentiated ratings of perceived exertion during cycle and treadmill exercise in recreationally active and trained women. *Journal of Sports Science and Medicine*. 2010;9:557-563.
6. Bolgun JA, Robertson RJ, Goss FL, Edwards MA, Cox RC, Metz K. Metabolic and perceptual responses while carrying external loads on the head and yoke. *Ergonomics*. 1986;29:1623-1635.
7. Borg G. A Ratio scaling method for interindividual Comparisons. *Reports from the Institute of Applied Psychology*, Stockholm University. 1972;27.
8. Borg G. General Introduction: Psychophysiological studies of the three effort continua. In: Borg G, editor. *Physical Work and Effort*. Oxford: Pergamon Press, Inc.; 1977. p.1-10.
9. Borg G. On Quantitative semantics in connection with psychophysics. *Educational and Psychological Research Bulletin*. Umeå University. 1964;No. 3
10. Borg G. Perceived exertion during walking: a psychophysical function with two additional constants. *Reports from the Institute of Applied Psychology*, Stockholm University. 1973;b:36.
11. Borg G. Perceived exertion in relation to physical work and pulse rate. *Kungliga Fysiogr. Sällsk. Lind Förh*. 1961;31:105-115

12. Borg G. Perceived exertion: a note on “history” and methods. *Med Sci Sports*. 1982;5:90-93.
13. Borg G. Physical performance and perceived exertion. *In Studia Psychologia et Paedagogica*. 1962;b:vol.11: 1-35. Lund, Sweden: Gleerup.
14. Borg G. *Physical Work and Effort*. Wenn-Gren Center International Symposium Series. vol. 28 Oxford:Pregamon Press; 1977. p 434.
15. Borg G. Psychological bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14:377-81.
16. Borg G: *Borg’s Perceived Exertion and Pain Scales*. Human Kinetics (IL); 1998. p. 2-39.
17. Borg GA, Lindblad I. The Determination of subjective intensities in verbal descriptions of symptoms. *Reports from the Institute of Applied Psychology*. 1976;No. 75. Stockholm University.
18. Borg, G, Borg E. A new generation of scaling methods: level-anchored ratio scaling. *Psychologica*. 2001;28:15-45.
19. Borg, G. A simple rating scale for use in physical work test. *Kungl. Fysiografiska Sallskapet I Lund Forhandlingar*. 1962;21:7-15.
20. Bruin, G, Kuipers, H, Keizer, A, Vandervuisse, GJ. Adaptation in overtraining in horses subjected to increasing training loads. *J Appl Physiol*. 1994;76:1908-1913.
21. Cafarelli E. Peripheral contributions to the perception of effort. *Med Sci Sports Exerc*. 1982;14(5):382-389.
22. Cronbach, LJ, Meehl, PE. Construct validity in psychological tests. *Psychological Bulletin*. 1955;52(4):281-302.
23. Damann N, Voets T, Nilius B. TRPs in Our Senses. *Current Biology*. 2008;18(18):R880-R889.
24. Dunbar CC, Kalinski MI, Robertson RJ. A new method for prescribing exercise: three-point ratings of perceived exertion. *Perceptual Mot Skills*. 1996;82(1)139-46.
25. Dunbar CC, Kalinski MI. Using the RPE to regulate exercise intensity during a 20-week training program for postmenopausal women: A pilot Study. *Perceptual & Motor Skills*. 2004;99(2):688-690.

26. Dunbar CC, Robertson RJ, Baun R, Blandin MF, Metz K, Burdett R, Goss FL. The validity of regulating exercise intensity by ratings of perceived exertion. *Med Sci Sports Exerc.* 1992;24(1):94-99.
27. Ekblom B, Goldbarg, AN. The influence of training and other factors on the subjective rating of perceived exertion. *Acta Physiol Scand.* 1971;83:399-406.
28. Ekkekakis P, Hall EE, Petruzzello SJ. Practical markers of the transition from aerobic to anaerobic metabolism during exercise: rationale and a case for affect-based exercise prescription. *Preventive Medicine.* 2004;38(2):149-159.
29. Eston RG, Parfitt G, Campbell L, Lamb KL. Reliability of effort perception for regulating exercise intensity in children using the Cart and Load Effort Rating (CALER) scale. *Pediatr Exerc Sci.* 2000;12:388-397.
30. Foster C, Lehmann, M. Overtraining syndrome. Guten GN, editor. *In: Running Injuries.* Philadelphia:W.B. Saunders; 1997. p.173-188.
31. Foster C, Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc.* 1998;30(7):1164-1168.
32. Gallagher MA, Fadel PJ, Stromstad M, Ide K, Smith SA, Querry RG, Raven, PB, Secher NH. Effects of partial neuromuscular blockade on carotid baroreflex function during exercise in humans. *J Physiol.* 2001;533:861-870.
33. Gamberale F, Perception of exertion, heart rate, oxygen uptake and blood lactate in different work operations. *Ergonomics.* 1972;15:454-554.
34. Gandevia SC, Killian KJ, Campbell EJ. The effect of respiratory muscle fatigue on respiratory sensations. *Clin Sc.* 1981;60:463-466.
35. Gandevia SC, McCloskey DI. Changes in motor commands as shown by changes in perceived heaviness during partial curarization and peripheral anesthesia in man. *J Physiol.* 1977;272:673-689.
36. Gandevia SC. The perception of motor commands or effort during muscular paralysis. *Brain.* 1982;105:151-159.
37. Hortstman DH, Morgan WP, Cymerman A, Stokes J. Perception of effort during constant work to self-imposed exhaustion. *Percept Motor Skills.* 1979;48:1111-1126.

38. Hosman J, Borg G. The mean and standard deviation of cross-modality matches: a study of individual scaling behavior. *Reports from the Institute of Applied Psychology*. Stockholm University. 1970;No.3.
39. Kane I. Predicted and actual exercise discomfort, self-efficacy, and enjoyment in middle school children: a match-mismatch paradigm [dissertation]. Pittsburgh (PA): University of Pittsburgh; 2007.
40. Kang J, Robertson RJ, Goss FL, DaSilva SG, Visich P, Suminski RR, Utter AG, Denys BG. Effect of carbohydrate substrate availability on ratings of perceived exertion during prolonged exercise of moderate intensity. *Percept Mot Skills*. 1996;82:495-506.
41. Keppel G, Wickens TD. *Design and Analysis, A Researcher's Handbook*. 4th ed. Pearson Prentice Hall; 2004. p.350-429.
42. Kinsman R, Weiser P, and Stamper D. Multidimensional analysis of subjective symptomatology during prolonged strenuous exercise. *Ergonomics* 1973;16:211-226.
43. Kraemer WJ, Lewis RV, Triplett NT, Koziris LP, Heyman S, Noble BJ. Effects of hypnosis on plasma proenkephalin peptide F and perceptual and cardiovascular responses during submaximal exercise. *Eur J Appl Physiol*. 1992;65(6):573-578.
44. Krause MP, Goss FL, Robertson RJ, Kim K, Elsangedy HM, Krinski K, da Silva SG. Concurrent validity of an OMNI rating of perceived exertion scale for bench stepping exercise. *J Strength Cond Res*. 2012;26(2):506-512.
45. Kreider, RB, Fry, AC, O'Toole, eds. *Overtraining in Sport*. Champaign, IL: Human Kinetics; 1998.
46. Lagally KM, Robertson RJ, Construct validity of the OMNI resistance exercise scale. *J Strength Cond Res*. 2006;20(2): 252-256.
47. Lawson-Tancred H. *Aristotle De Anima*. Penquin Classics; 1987.
48. Linderholm H. Perceived Exertion during Exercise in the Discrimination between Circulatory and Pulmonary Disorders. In: Borg G, Ottoson D, editors. *Perception of Exertion in Physical Work*. London:Macmillan; 1986. p. 199-206.
49. Mahler DA, Horowitz MB. Perception of breathlessness during exercise in patients with respiratory disease. *Med Sci Sports Exerc*. 1994;26:1078-1081.

50. Marcora S. Perception of effort during exercise is independent of afferent feedback from skeletal muscles, heart, and lungs. *J Appl Physiol*. 2009;106:2060-2062.
51. Marks LE, Borg G, Ljunggren G. Individual differences in perceived exertion assessed by two new methods. *Perception & Psychophysics*. 1983;34:280-288.
52. Mays RJ, Goss FL, Schafer MA, Kim KH, Nagle-Stilley EF, Robertson RJ. Validation of adult OMNI perceived exertion scales for elliptical ergometry. *Perceptual and Motor Skills*. 2010;111:(3):848-862.
53. McCloskey DI, Gandevia EK, Porter EK, Colebatch JG. Muscle senses and effort: motor commands and judgments about muscular contractions. *Adv Neurol*. 1983;39:151-167.
54. Morgan WP, Costill DL, Flynn MG, Raglin JS, O'Connor PJ. Mood disturbance following increased training in swimmers. *Med Sci Sports Exerc*. 1998;20:408-414.
55. Morgan WP, Hirota K, Weitz GA, Balke B. Hypnotic perturbation of perceived exertion: ventilatory consequences. *Am J Clin Hypn*. 1976;189:182-190.
56. Morgan WP, Raven PB, Drinkwater BL, Horvath SM. Perceptual and metabolic responsivity to standard bicycle ergometry following various hypnotic suggestions. *Int J Clin Exp Hypn*. 1973;21:86-101
57. Morgan WP. Psychological factors influencing perceived exertion. *Med Sci Sports* 1973;5:97-103.
58. Morgan WP. Utility of exertional perception with special reference to underwater exercise. *International Journal of Sport Psychology*. 2001;32:137-161.
59. Nakamura FY, Perandini LA, Okuno NM, Borges TO, Bertuzzi RC, Robertson RJ. Construct and concurrent validation of OMNI-Kayak rating of perceived exertion scale. *Percept Mot Skills*. 2009;108(3):744-758.
60. Neely G, Ljunggren G, Sylven C, Borg G. Comparison between the visual analogue scale (VAS) and the category ratio scale (CR-10) for the evaluation of leg exertion. *Int J Sports Med*. 1992;13:133-136.
61. Noble BJ, Metz KF, Pandolf CW, Cafarelli E. Perceptual responses to exercise: a multiple regression study. *Med Sci Sports*. 1973;5:104-109.
62. Noble BJ, Robertson RJ. *Perceived Exertion*. Human Kinetics (IL); 1996. p. 93-106.

63. Okura T, Kiyoji T. A unique method for predicting cardiovascular fitness using rating of perceived exertion. *Journal of Physiological Anthropology and Applied Human Science*. 2001;20(5) p. 255-261.
64. Pandolf KB, Billings DS, Drolet LL, Pimemtal NA, Sawka MN. Differentiated ratings of perceived exertion and various physiological responses during prolonged upper and lower body exercise. *Eur J Appl Physiol*. 1984;53:5-11.
65. Pandolf KB, Burse RL, Goldman RF. Differentiated ratings of perceived exertion during physical conditioning of older individuals using leg-weight loading. *Percept Mot Skills*. 1975;40:563-574.
66. Pandolf KB. Advances in the study and application of perceived exertion. *Exerc Sport Sci Rev*. 1983;11:158-158.
67. Pandolf KB. Differentiated ratings of perceived exertion during physical exercise. *Med Sci Sports Exerc*. 1982;14:397-405.
68. Pandolf KB. Influence of local and central factors in dominating rated perceived exertion during physical work. *Percept Mot Skills*. 1978;46:683-698.
69. Pandolf, KB. Rated perceived exertion during exercise in the heat, cold or at high altitude. *International Journal of Sport Psychology*. 2001;32:162-176.
70. Pimental N, Pandolf K. Energy expenditure while standing of walking slowly uphill of downhill with loads. *Ergonomics*. 1979;22:963-973.
71. Polansky R. *Aristotle's DeAnima A Critical Commentary*. 2010 Cambridge University Press.
72. Rejeski WJ. The Perception of Exertion: A social psychophysiological integration. *J. Sport Psychol*. 1981;4:305-320.
73. Resler Kari, Weary KA, Gallagher, M Jr, Hays AE, Robertson RJ, Goss FL, Nagle-Stilley E, Aaron DJ. Development of a physical activity index for walking/running using RPE and pedometer step count. *Med Sci Sports Exerc*. 2006;38(5):S79-S80.
74. Robertson J, Goss FL, Rutkowski J, Lentz B, Dixon C, Timmer J, Frazee K, Dube J, Andreacci J. Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Med Sci Sports Exerc*. 2003;35(2):333-341.

75. Robertson R, Goss F, Michael T, Moyna N, Gordon P, Visich P, Kang J, Angelopoulos T, DaSilva S, Metz K. Metabolic and perceptual responses during arm and leg ergometry in water and air. *Med Sci Sports Exerc.* 1995;27(5):760-764.
76. Robertson R, Noble BJ. Perception of physical exertion, methods, mediators, and applications. *Exerc Sport Sci Rev.* 1997;25:407-52.
77. Robertson RJ, Caspersen CJ, Allison TG, Skrinar GS, Abbott RA, Metz KF. Differentiated perceptions of exertion and energy cost of young women while carrying loads. *Eur J Appl Physiol.* 1982;49:69-78.
78. Robertson RJ, Gillespie RL, McCarthy J, Rose D. Differentiated perception of exertion: part I. mode of integration of regional signals. *Percept Mot Skills.* 1979;49:683-689.
79. Robertson RJ, Gillespie RL, McCarthy J, Rose D. Differentiated perception of exertion: part II. relationship to local and central physiological responses. *Percept Mot Skills.* 1979;49:691-697.
80. Robertson RJ, Goss FL, Andreacci JJD, Rutkowski JJ, Frazee KM, Aaron DJ, Metz KF, Kowallis RA, Snee BM. Validation of the Children's OMNI-Resistance Exercise Scale of Perceived Exertion. *Med Sci Sports Exerc.* 2005;37(5):819-826.
81. Robertson RJ, Goss FL, Andreacci JL, Dube JJ, Rutkowski JJ, Snee BS, Lowallis RA, Crawford K, Aaron DJ, Metz KF. Validation of the Children's OMNI RPE Scale for Stepping Exercise. *Med Sci Sports Exerc.* 2005;37(2):290-298.
82. Robertson RJ, Goss FL, Auble TE, Spina R, Cassinelli D, Glickman E, Galbreath R, Metz K. Cross-modal exercise prescription at absolute and relative oxygen uptake using perceived exertion.. *Med Sci Sports Exerc.* 1990;22:653-659.
83. Robertson RJ, Goss FL, Bell JA, Dixon CB, Gallagher KI, Lagally KM, Timmer JM, Abt KL, Gallagher JD, Thompkins T. Self-regulated cycling using the Children's OMNI Scale of Perceived Exertion. *Med Sci Sports Exerc.* 2002;34(7):1168-1175.
84. Robertson RJ, Goss FL, Dube J, Rutkowski J, Dupain M, Brennan C, Andreacci J. Validation of the Adult OMNI Scale of Perceived Exertion for Cycle Ergometer Exercise. *Med Sci Sports Exerc.* 2004;36(1):102-108.
85. Robertson RJ, Metz K. Ventilatory PreCursors for Central Signals of Perceived Exertion. In: Borg G, Ottoson D, editors. *The Perception of Exertion in Physical Work.* London: Macmillian; 1986. p. 111-121.

86. Robertson RJ, Nixon PA, Casperson CJ, Metz KF, Abbott RA, Goss FL. Abatement of exertional perceptions following high intensity exercise: physiological mediators. *Med Sci Sports Exerc.* 1992;24:346-353.
87. Robertson RJ, Stanko RT, Goss FL, Spina RJ, Reilly JJ, Greenawalt KD. Blood glucose extraction as a mediator of perceived exertion during prolonged exercise. *Eur J Appl Physiol.* 1990;61:100-105.
88. Robertson RJ,, Goss FL, Boer NF, Peoples JA, Foreman AJ, Dabayeb IM, Millich NB, Balasekaran G, Riechman SE, Gallagher JD, Thompkins T. Children's OMNI Scale of Perceived Exertion: mixed gender and race validation. *Med Sci Sports Exerc.* 2000;32:452-458.
89. Robertson RJ. *Perceived Exertion for Practitioners, Rating Effort with the OMNI Picture System.* Human Kinetics (IL); 2004.
90. Roemmich JN, Barkley JE, Epstein LH, Lobarinas CL, White TM, Foster JH. Validity of PCERT and OMNI walk/run ratings of perceived exertion. *Med Sci Sports Exerc.* 2006;38(5):1014-1019.
91. Rutkowski JJ, Robertson RJ, Caputo JL, Tseh WD, Keefer DJ. Assessment of RPE signal dominance at slow-to-moderate walking speeds in children using the OMNI Perceived Exertion Scale. *Pediatric Exercise Science.* 2004;16(4):334-342.
92. Sgadari GL, Buzzachera SA, Broccatelli M, Utter AC, Goss FL, Baldari C. Validation of the OMNI-Cycle Scale of perceived exertion in the elderly. *J Aging Phys Act.* 2011;19(3):214-224.
93. Simplicius, Priscian, Huby P, Steele C. *Priscian on Theophrastus on Sense-Perception: With 'Simplicius' on Aristotle's on the Soul 2.5-12* (Ancient Commentators on Aristotle). Cornell University Press; 1997.
94. Smith KA, Gallagher Michael, Hays AE, Goss FG, Robertson RJ. Development of the physical activity index as a measure of total activity load and total kilocalorie expenditure during submaximal walking. *Journal of Physical Activity and Health.* 2012;9:757-764.
95. Stevens SS, Galanter EH. Ratio scales and category scales for a dozen perceptual continua. *Journal of Experimental Psychology.* 1957;54:377-411.
96. Stevens SS. On the psychophysical law. *The Psychological Review.* 1957;78:426-450.
97. Stevens SS. *Psychophysics: Introduction to Its Perceptual, Neural and Social Prospects.* New York, Wiley; 1975.

98. Synder, AC, Foster, C. Physiology and nutrition for skating. In D.R. Lam and H.G. Knuttgen, editors. *Perspectives in Exercise Science and Sports Medicine, Vol. 7: Physiology and Nutrition of Competitive Sports*, Indianapolis: Cooper Publishing Group; 1994. p.181-219.
99. Tabbers HK, Martens RL, van Merrienboer JJG. Multimedia instructions and cognitive load theory: effects of modality and cueing. *British Journal of Educational Psychology*. 2004;74:71-81.
100. Tikuuisis P, McIelllan, TM, Selkirk G. Perceptual versus physiological heat strain during exercise-heat stress. *Med Sci Sports Exerc*. 2002;34:1454-1461.
101. Utter AC, Robertson RJ, Green JM, Suminski RR, Mcanulty SR, Nieman DC. Validation of the Adult OMNI Scale of Perceived Exertion for Walking/Running Exercise. *Med Sci Sports Exerc*. 2004;36(10):1776-1780.
102. Utter AC, Robertson RJ, Nieman DC, Kang J. Children's OMNI Scale of Perceived Exertion: walking/running evaluation. *Med Sci Sports Exerc*. 2002;34(1):139-144.
103. Weary-Smith KA. Validation of the physical activity index (PAI) as a measure of total activity load and total kilocalorie expenditure during submaximal treadmill walking [dissertation]. Pittsburgh (PA): University of Pittsburgh; 2007.
104. Weiser PC, Kinsman A, Stamper DA. Task specific symptomatology changes resulting from prolonged submaximal bicycle riding. *Med Sci Sport*. 1973;5:79-85.
105. Weiser PC, Stamper, DA. Psychophysiological interactions leading to increased effort, leg fatigue, and respiratory distress during prolonged, strenuous bicycle riding. In: Borg G, editor. *Physical Work and Effort*. New York: Pergamon Press; 1977. p.401-416.
106. Williams JG, Eston R, Furlong B. CERT: a perceived exertion scale for young children. *Perceptual and Motor Skills*. 1994;79 1451-1458.
107. Yelling M, Lamg KL, Swaine IL. Validity of a pictorial perceived exertion scale for effort estimation and effort production during stepping exercise in adolescent children. *European Physical Education Review*. 2002;8(2):157-175.