Chapter 6
Perceived Exertion Scale Validation

Both concurrent and construct validity are important psychometric properties for perceived exertion scales applied in the clinical and performance settings. A graded exercise test that employs a perceptual estimation protocol is the standard for determination of perceived exertion scale validity for both aerobic and resistance exercise. Both undifferentiated and differentiated RPE can be measured using a scale validity experiment, but special attention should be paid to determination of the dominant RPE signal during exercise. Concurrent and construct validity evidence has been shown for both undifferentiated and differentiated RPE in various sample populations performing aerobic and resistance exercise. A perceived exertion scale that demonstrates concurrent and construct validity can be applied to both exercise testing and prescription in hospital and field settings. Such applications can include the prediction of impending exercise test termination and exercise intensity self-regulation. The primary purpose of this laboratory experiment is to establish concurrent and construct validity for an OMNI RPE Scale. Secondary purposes include the comparison of concurrent validity evidence between the OMNI RPE Scale and the Borg Scale and to determine differentiated RPE signal dominance.

6.1 Background

6.1.1 Validity

Validity can be defined as the degree to which a test or test item measures what it is intended to measure and is the most important characteristic of any specific test (Baechle and Earle 2008). Without validity, test results have no meaning. Measures of basic physical characteristics of an individual (e.g., height and weight) are relatively easy to validate. The validity of metrics to be used during exercise

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performance, especially perceived exertion scales, can be more difficult to establish. Therefore, there are two main types of validation experiments used to confirm the validity of a perceived exertion scale: concurrent validity and construct validity.

6.1.2 Concurrent Validity

Concurrent validity is the extent to which test scores are associated with those of other accepted tests when both measures are obtained along a common stimulus range. In the case of a scale that measures RPE, this definition refers to the accuracy of the metric to measure perceived exertion across one's entire physiological range as exercise intensity is systematically increased from low to high levels. A test of concurrent validity involves a statistical calculation of the relation between a criterion variable (the stimulus) and the concurrent variable (the response). This statistical paradigm often uses a Pearson correlation calculation that yields "*r*" values referred to as validity coefficients (Baechle and Earle 2008). To establish concurrent validity of a perceived exertion scale, it is expected that the concurrent variable, RPE, increases concurrently with increases in a physical and/or physiological criterion variable as intensity of exercise increases (Robertson 2004). A statistically significant concurrent validity coefficient indicates a strong relation between the concurrent and criterion variables, often resulting in high *r* values greater than 0.70.

The theoretical framework underlying the assessment of concurrent validity of a perceived exertion scale is derived from the basic tenets of Borg's Effort Continua and Range Models. There are three main effort continua: performance, physiological, and perceptual. An increase in exercise performance, usually denoted as increasing intensity, results in corresponding and interdependent increases in both physiological and perceptual responses. Exercise intensity can be measured as minute per mile pace or PO for aerobic exercise and as absolute weight lifted or %1RM for resistance exercise. Physiological responses are underlying processes that an individual subjectively monitors during exercise to ultimately mediate their RPE response. HR and VO_2 are respiratory-metabolic exertional mediators that are commonly measured during exercise serving as physiological indicators of exercise intensity. Physiological and perceptual responses display a functional interdependence. As such, the model predicts that perceptual responses will increase in correspondence with physiological responses throughout the individual's entire exercise intensity range, from a very low to a maximal level. In addition, the lowest RPE value matches the lowest exercise intensity and the highest RPE value matches maximal exercise intensity. This holds true whether exercise intensity is expressed in physical units, such as PO, or using a physiological variable such as HR or VO_2. In this context, it is the goal of scale anchoring procedures to set the low and high anchor points on an RPE scale, linking them to very low and maximal exercise intensities. Once it is known that an individual conforms to the model following scale anchoring, a concurrent validation experiment can be used to measure the physiological and perceptual effort continua across the full range of possible exercise performance intensities.

6.1.3 Construct Validity

Construct validity can be defined as the ability of a test to represent the underlying construct, or the theory developed to organize and explain aspects of existing knowledge and observations (Baechle and Earle 2008). For perceived exertion scales, construct validity is tested by comparing RPE measured using a newly developed scale for which validity has yet to be established with the RPE derived from a perceived exertion scale having well-established construct validity. In this paradigm, it is expected that both the new (i.e., conditional) scale and the criterion scale have demonstrated a high level of concurrent validity. Traditionally, construct validity of a perceived exertion scale is statistically determined by correlating RPE measured using the conditional metric with RPE measured using the 15-category Borg Scale (i.e., the criterion metric).

6.1.4 Validity Test Protocols

Concurrent and construct validity of a perceived exertion scale can be tested simultaneously using perceptual estimation test protocols. An *estimation protocol* is a GXT during which an individual estimates RPE during each exercise stage. Using commonly employed procedures for determining maximal aerobic or resistance exercise capacity, an estimation protocol allows an individual to rate RPE from a very low exercise intensity to maximal exercise intensity. For example, the Bruce treadmill protocol for the determination of VO_2max employs incremental stages of walking and running exercise. For resistance exercise, variations on 1RM or multiple-RM procedures are used. These procedures must include measurements of physiological exertional mediators (e.g., HR, VO_2) and the recording of physical markers of exercise intensity (e.g., PO, weight lifted, %1RM) necessary for the determination of concurrent validity. As such, a concurrent and construct validation experiment only requires that RPE be measured using the 15-category Borg Scale and the RPE scale for which validity is sought.

6.1.5 Use of Perceived Exertion Scaling Procedures Prior to the Estimation Protocol

It is important to note that the scale anchoring procedures should be presented separately from and prior to the estimation test protocol used for a scale validation experiment. For the concurrent/construct validation experiment to be valid, it must be known that the individual's RPE responses conform to Borg's Range Model. Individuals who have experience using perceived exertion scales and have participated in exercise anchoring procedures in the past are more likely to provide RPE responses that conform to the prediction of Borg's Range Model. However, as

discussed previously, some individuals are perceptual outliers, either overestimating or underestimating the RPE response. Such responses usually occur upon initial exposure to RPE assessment and prior to administration of full memory and exercise anchoring procedures. When possible, youth and sedentary adult subjects should undergo both the memory and exercise procedures for perceived exertion scale anchoring. However, even active adults have been known to be perceptual outliers and as such can benefit from additional anchoring and practice in estimating RPE prior to undertaking the actual exercise trial.

6.1.6 *Differentiated Versus Undifferentiated Exertional Ratings*

Experiments to validate perceived exertion scales can employ both undifferentiated and differentiated RPE. A differentiated RPE is linked to a specific anatomical region of the body. Differentiated RPE specific to the leg muscles (RPE-L) can be measured during cycle ergometry and treadmill exercise. The RPE-L reflects peripheral exertional signals resulting from localized metabolic acidosis, blood glucose level, muscle glycogen content, and muscle blood flow (Robertson 2004). Differentiated RPE specific to the chest and breathing (RPE-C) can be measured during any aerobic activity. The RPE-C reflects respiratory-metabolic exertional mediators such as V_E and total body VO_2. Differentiated RPE rated during resistance exercises are usually specific to the active muscle mass (RPE-AM). Undifferentiated RPE is a measure of the overall body (RPE-O) exertional level. It is formed by integrating the various exertional signals arising from the composite of anatomical regions involved in the exercise task. Many investigations have asked subjects to rate RPE-O only, but important information can be derived by also measuring differentiated exertional ratings.

6.1.7 *Concurrent Validity Evidence for Undifferentiated RPE*

Numerous investigations have established concurrent validity of various iterations of the OMNI Perceived Exertion Scale using mode-specific estimation protocols. Experiments have included male and female children and adults performing a wide variety of exercise modalities: cycle ergometry, treadmill walking and running, stepping exercise, elliptical ergometry, and resistance exercise. High validity coefficients were reported for male and female children and adults during cycle ergometry and treadmill exercise, with r values ranging from 0.67 to 0.99 for the associations between RPE and HR or VO_2 (Balasekaran et al. 2012; Robertson 2004; Robertson et al. 2000; Utter et al. 2004). High validity coefficients were found in a sample of male and female children and a sample of adult females performing load-incremented stepping exercise. In these stepping experiments, the relation between RPE and VO_2 exhibited r values ranging from 0.87 to 0.96. The relation between RPE and HR

exhibited r values ranging from 0.81 to 0.95 (Krause et al. 2012; Robertson et al. 2005b). High validity coefficients were found in adult males and females performing elliptical ergometry. The relation between RPE and VO_2 exhibited r values ranging from 0.93 to 0.95, while the relation between RPE and HR exhibited r values ranging from 0.95 to 0.97 (Mays et al. 2010). High validity coefficients were reported during biceps curl and knee extension exercises, with r values ranging from 0.72 to 0.91 for the association between RPE and total weight lifted in both children and adults (Robertson et al. 2003, 2005a). In addition, an $r=0.87$ was determined for the association between RPE-AM and blood lactic acid concentration in adults; providing evidence for lactacidemia as a physiological exertional mediator for resistance exercise (Robertson et al. 2003).

Concurrent validation has been tested and confirmed for other perceived exertion scales as well, such as the Children's Effort Rating Table (CERT). CERT, a 10-category scale ranging from 1 to 10, was developed specifically for children to be easily understood with verbal descriptors positioned at each numerical category. CERT, however, does not include pictorial descriptors as does the OMNI Scale. Concurrent validation of CERT has been examined for various youth populations performing stepping and cycle ergometer exercise. Validity coefficients for the relation between RPE and HR ranged from $r=0.73$ to 0.99 during stepping exercise (Williams et al. 1994) and from $r=0.70$ to 0.97 for cycle ergometry (Eston et al. 1994; Lamb 1995; Leung et al. 2002). In addition, investigations determined the relations between RPE measured by the CERT and both PO and VO_2 for cycle ergometer exercise. The relation between RPE and power output exhibited r values ranging from 0.70 to 0.98 (Eston et al. 1994; Lamb 1995; Leung et al. 2002). The relation between RPE and VO_2 exhibited r values ranging from 0.85 to 0.91 (Leung et al. 2002).

HR and VO_2 are the most commonly used physiological criterion variables to demonstrate concurrent scale validity for aerobic exercise modalities. They are the most widely used because they increase as a positive function of increases in exercise intensity. However, other physiological criterion variables have been used to study concurrent scale validity during aerobic exercise. Investigations have correlated OMNI Scale RPE with %VO_2max, %HRmax, pulmonary ventilation (V_E), respiratory rate (RR), the respiratory exchange ratio (RER), and the V_E to VO_2 ratio ($V_E \cdot VO_2^{-1}$). All of these physiological variables are expected to increase concurrently with increases in aerobic exercise intensity, demonstrating either linear or polynomial growth functions. High validity coefficients for OMNI Scale responses were found for adolescent girls performing treadmill exercise, as evidenced by the relation between RPE and %HRmax ($r=0.86$) and the relation between RPE and %VO_2max ($r=0.89$) (Pfeiffer et al. 2002). Moderate validity coefficients ranging from $r=0.33$ to 0.43 were shown between RPE with %VO_2max, V_E, RR, and $V_E \cdot VO_2^{-1}$ for children performing treadmill exercise (Utter et al. 2002). Another study involving children performing treadmill exercise found high validity coefficients ranging from $r=0.71$ to 0.81 for the relation between RPE with %VO_2max, V_E, RR, and RER using the Spanish version of the Children's OMNI-Walk/Run RPE Scale (Suminski et al. 2008). In addition, high validity coefficients

Table 6.1 Summary of OMNI Scale validation for aerobic and resistance exercise when undifferentiated RPE for the overall body (RPE-O) was the concurrent variable

				Correlation coefficient[a]					
		Scale		HR			VO_2		
Investigation	Mode	Format	Age	F	M	B	F	M	B
Robertson et al. (2000)	Cycle	Cycle	Child	0.94	0.92	0.93	0.93	0.94	0.94
Pfeiffer et al. (2002)	Treadmill	Cycle	Child	0.82	–	–	0.88	–	–
Robertson et al. (2004)	Cycle	Cycle	Adult	0.83	0.90	–	0.88	0.94	–
Utter et al. (2004)	Treadmill	Walk/run	Adult	0.84	0.75	–	0.85	0.86	–
Robertson et al. (2005b)	Step	Step	Child	0.83	0.88	–	0.88	0.93	–
Suminski et al. (2008)[b]	Treadmill	Walk/run	Child	–	–	0.85	–	–	0.85
Mays et al. (2010)	Elliptical	Elliptical	Adult	0.97	0.96	–	0.95	0.95	–
Balasekaran et al. (2012)	Cycle	Cycle	Child	0.99	0.98	0.98	0.99	0.99	0.95
Krause et al. (2012)	Step	Step	Adult	0.95	–	–	0.96	–	–
				WTtot					
				F	**M**				
Robertson et al. (2003)	BC	Resistance	Adult	0.87	0.89				
Robertson et al. (2003)	KE	Resistance	Adult	0.86	0.87				
Robertson et al. (2005a)	BC	Resistance	Child	0.87	0.80				
Robertson et al. (2005a)	KE	Resistance	Child	0.80	0.88				

The criterion variables were: *HR* heart rate, VO_2 oxygen consumption, *WTtot* total weight lifted. *F* female, *M* male, *B* both males and females, *BC* biceps curl, *KE* knee extension

[a]All correlation coefficients are significant ($p<0.05$)

[b]This study validated a Spanish version of the Children's OMNI-Walk/run Scale

ranging from $r=0.67$ to 0.88 were found for the relation between RPE with %VO_2max, V_E, RR, and RER where data were determined for adults performing treadmill exercise (Utter et al. 2004) (Tables 6.1 and 6.2).

6.1.8 Construct Validity Evidence for Undifferentiated RPE

Construct validity has also been tested and confirmed for various OMNI RPE scales using the 15-category Borg Scale as the criterion metric. Validity coefficients ranged from $r=0.92$ to 0.97 for adults performing cycle ergometry (Robertson et al. 2004),

Table 6.2 Summary of OMNI Scale validation for aerobic and resistance exercise when differentiated RPE for the legs (L), chest/breathing (C) and active muscle (AM) were the concurrent variables

					Correlation coefficient[a]					
			Scale		HR			VO_2		
Investigation	Mode	RPE	Format	Age	F	M	B	F	M	B
Robertson et al. (2000)	Cycle	L	Cycle	Child	0.92	0.93	0.92	0.93	0.93	0.93
Robertson et al. (2000)	Cycle	C	Cycle	Child	0.88	0.90	0.87	0.87	0.90	0.87
Robertson et al. (2004)	Cycle	L	Cycle	Adult	0.81	0.86	–	0.87	0.95	–
Robertson et al. (2004)	Cycle	C	Cycle	Adult	0.82	0.88	–	0.90	0.95	–
Robertson et al. (2005b)	Step	L	Step	Child	0.81	0.89	–	0.87	0.94	–
Robertson et al. (2005b)	Step	C	Step	Child	0.83	0.87	–	0.88	0.92	–
Mays et al. (2010)	Elliptical	L	Elliptical	Adult	0.97	0.96	–	0.93	0.95	–
Mays et al. (2010)	Elliptical	C	Elliptical	Adult	0.96	0.96	–	0.94	0.95	–
Balasekaran et al. (2012)	Cycle	L	Cycle	Child	0.99	0.98	0.99	0.99	0.98	0.98
Balasekaran et al. (2012)	Cycle	C	Cycle	Child	0.99	0.99	0.99	0.99	0.99	0.98
					WTtot		**[HIa]**			
					F	**M**	**B**			
Robertson et al. (2003)	BC	AM	Resistance	Adult	0.89	0.91	0.87			
Robertson et al. (2003)	KE	AM	Resistance	Adult	0.79	0.87	–			
Robertson et al. (2005a)	BC	AM	Resistance	Child	0.88	0.81	–			
Robertson et al. (2005a)	KE	AM	Resistance	Child	0.72	0.75	–			

The criterion variables were: *HR* heart rate, VO_2 oxygen consumption, *WTtot* total weight lifted, *[Hla]* lactic acid concentration. *F* female, *M* male, *B* both males and females, *BC* biceps curl, *KE* knee extension

[a]All correlation coefficients are significant ($p < 0.05$)

treadmill exercise (Utter et al. 2002), elliptical ergometry (Mays et al. 2010), and knee extension resistance exercise (Lagally and Robertson 2006). The basis for the development of child versions of perceived exertion metrics, such as the OMNI Scale and CERT, was that children often exhibited semantic limitations in understanding the verbal descriptors employed in adult formatted metrics such as the Borg Scale. The numerical categories of the Borg Scale range from 6 to 20 and many of its verbal descriptors use the word "exertion," a word not typically a part of a younger child's vocabulary. As such, researchers did not believe the Borg Scale to be a valid metric to measure a child's perceived exertion. An investigation by Robertson and colleagues (2005b) conducted a construct validation experiment for the Children's OMNI-Step RPE Scale using the previously validated Children's OMNI-Cycle RPE Scale as the criterion metric. Even though the study involved stepping exercise, the only difference between the two RPE scales was the mode-specific pictorial descriptors. Since the concurrent validity of the Children's OMNI-Cycle Scale was well established by previous investigations, using it as the criterion metric was conceptually similar to previous construct validation experiments in adults that compared OMNI RPE with the well-established Borg Scale RPE. Future investigations seeking to establish construct validity of a new perceived exertion scale for children in future investigations may also consider using as a criterion a well-established children's OMNI scale that has been shown to have a high level of concurrent validity.

6.1.9 Differentiated RPE in a Validity Experiment

Previous RPE scale validation studies have employed differentiated RPE during cycle ergometry, elliptical ergometry, and resistance exercise in adults (Lagally and Robertson 2006; Mays et al. 2010; Robertson et al. 2003, 2004); and cycle ergometry, stepping exercise, and resistance exercise in children (Balasekaran et al. 2012; Robertson et al. 2000, 2005a, 2005b). All investigations found evidence of concurrent scale validity where differentiated RPE were employed as well as the undifferentiated, overall-body RPE. In addition, construct scale validity has been confirmed using differentiated RPE measured during cycle ergometry, elliptical ergometry, and resistance exercise in adults, as well as for stepping exercise in children (Lagally and Robertson 2006; Mays et al. 2010; Robertson et al. 2004, 2005b).

It is possible to ask a subject to rate both undifferentiated and differentiated RPE's during each exercise test stage of an aerobic or resistance exercise load-incremented protocol. Three RPE values can easily be rated within a 30-s time frame at the end of each stage of the Bruce treadmill protocol (Robertson 2004). Using this procedure, it can be determined which RPE signal, the overall signal or a differentiated signal, is the dominant perception (i.e., most intense) for a specific mode of exercise. Three primary factors determine the dominant RPE response

during exercise: (1) the mode of exercise, (2) the anatomical origin of the differentiated feelings, and (3) the performance environment (i.e., air or water, temperature, humidity) (Robertson 2004). Robertson and colleagues (2001) asked child subjects to rate RPE-O, RPE-L, and RPE-C at the end of each stage of an incremental cycle ergometer exercise test. When the RPE's associated with the ventilatory threshold (VT) were calculated, it was found that RPE-L provided the dominant RPE signal with RPE-C being comparatively less intense (Robertson et al. 2001). Therefore, since RPE-O fell between the two differentiated RPE signals, it generally appeared as a mathematical average of the anatomically regionalized ratings. Such a response confirmed that the undifferentiated RPE is a good overall indicator of total body exertion level and represented an integration of differentiated perceptual signals. Also, it should be noted that differentiated RPE's can be compared with undifferentiated RPE at any intensity of exercise to identify perceptual signal dominance and mode of signal integration.

6.1.10 Application of a Valid Perceived Exertion Scale

Concurrent and construct validity evidence has been shown for scales that measured both undifferentiated and differentiated RPE signals for a wide variety of exercise modalities. This is an important confirmation of the original intent and practical importance of the OMNI perceived exertion scales and the reason for the name OMNI. The name OMNI is an abbreviation of the word omnibus, meaning "of, relating to, or providing for many things at once" (Merriam-Webster Online 2014). Even though the first iteration of the OMNI Scale focused on children's responses during cycle ergometer exercise, it was intended that the original design could be reformatted for use by female and male clients of all ages performing a wide variety of exercise modalities consequent to future scale development. However, RPE scales are not solely restricted for use during incremental exercise, such as that used in this experiment. It was reasoned that as RPE scales showed strong concurrent and construct validity and the perceptual responses conformed to Borg's Range Model, that an individual could self-regulate exercise at a prescribed intensity using a "target" RPE. For example, after an individual successfully performs perceptual scale anchoring and undergoes a separate perceptual estimation test procedure, the exercise professional chooses a specific target RPE that corresponds to an a priori determined physiological intensity, one of the most important of which is the VT. Then, in a separate production procedure, the exercise professional teaches the individual to self-adjust exercise intensity until it feels like the level of exertion equal to the target RPE. The ability to determine an appropriate target RPE and teach an individual how to accurately self-regulate exercise intensity according to the designated perceptual level is one of the most important applications of RPE to exercise prescription and programming for overall health-fitness activities.

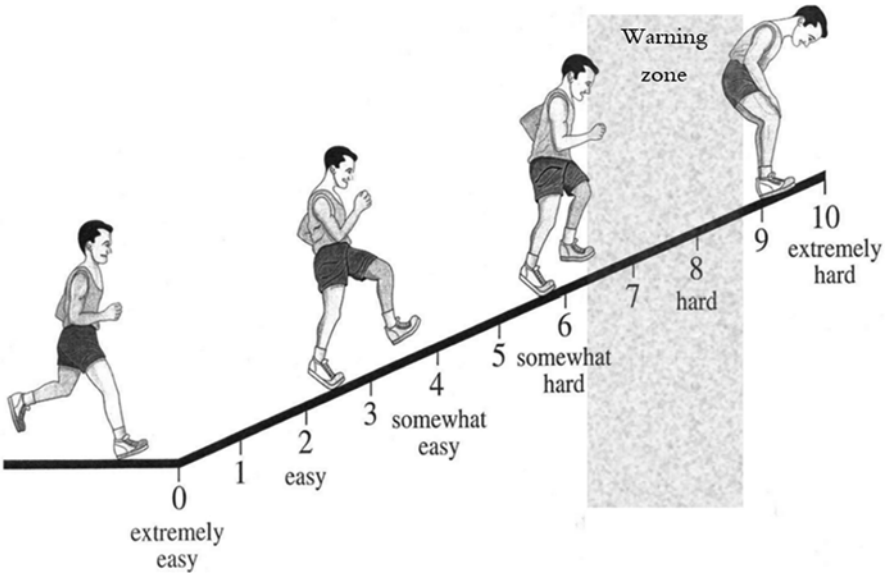

Fig. 6.1 OMNI RPE warning zone that signals impending exercise test termination (Robertson 2004)

6.1.11 Clinical Application of RPE During Maximal Exercise Testing

6.1.11.1 Use of RPE to Predict Impending Graded Exercise Test Termination

ACSM recommends the assessment of RPE throughout graded exercise testing to monitor an individual's progress toward maximal exertion in an effort to predict impending fatigue and test termination (ACSM 2013; Morgan and Borg 1976). For this reason, undifferentiated and/or differentiated RPE should be estimated at least at the end of each exercise test stage, preferably at the end of each minute of exercise in more functionally limited individuals whose exercise tolerance could deteriorate rapidly at comparatively higher intensities. Noble and Robertson (1996) identified *RPE warning zones* for graded exercise test termination using both the Borg Scale and OMNI Scales. The warning zones were defined as a range of RPE's, 15–17 on the Borg Scale and 7–8 on the OMNI Scales (Fig. 6.1). Those RPE zones signal impending test termination and as such indicate that it is the time at which procedures to safely end the GXT should be initiated. Goss and colleagues (2010a) identified the mean Borg RPE that indicated a subject would terminate the exercise test during the next 3-min stage of a Bruce treadmill protocol in apparently healthy male and female adults. Using the Borg 6–20 category scale, women terminated the exercise test an average of 142 s after an RPE of 14, while men terminated the test

an average of 120 s after an RPE of 15 (Goss et al. 2010a). Using RPE as a determinant of time until test termination can be especially important when a patient is taking a medication that affects the HR response to exercise, such as coronary artery disease patients who take beta-blockers. In such patients, the expected HR response based on a percent of age-predicted maximum is not an accurate predictor of impending test termination because the actual HR response is pharmacologically blunted. However, the RPE response is independent of cardioactive medication effects. As such, RPE will increase appropriately from rest to maximal exertion as it would without medication. Goss and colleagues (2010b) identified the mean Borg RPE that indicated a subject would terminate the exercise test during the next 3-min stage of a Bruce treadmill protocol in men with coronary artery disease. The men, who were all taking beta-blocker medication, terminated the exercise test an average of 153 s after a Borg (6–20) Scale RPE of 14 (Goss et al. 2010b), a perceptual value similar to that reported previously in apparently healthy men and women (Goss et al. 2010a).

6.1.11.2 Use of RPE as a Criterion for the Achievement of VO_2max

The "gold standard" assessment of cardiorespiratory fitness is a GXT used to determine VO_2max by indirect calorimetry. The Bruce treadmill protocol is an ideal example because it involves upright, dynamic, weight-bearing exercise using the total body. It is common for the researcher or health-fitness professional to use defined criteria to determine if the individual has achieved a "true" VO_2max. The "gold standard" criterion for the achievement of VO_2max is a plateau in VO_2 seen at the end of exercise when the individual has terminated the exercise test owing to exhaustion. A VO_2 plateau is defined as less than a 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ (or 150 $ml \cdot min^{-1}$) increase in VO_2 with an increase in workload (Siconilfi et al. 1982). However, a number of investigations have found that few individuals actually achieve a VO_2 plateau at the end of load-incremented GXTs (Day et al. 2003; Foster et al. 2007; Rossiter et al. 2006). Therefore, other VO_2max criteria that have been used include a respiratory exchange ratio (RER; VCO_2 divided by VO_2) of greater than 1.15, blood lactate concentration greater than 8 $mmol \cdot l^{-1}$, and HR within 10 $b \cdot min^{-1}$ of age-predicted maximum HR (APMHR). Yet many individuals will not achieve these supplementary criteria as well (Powers and Howley 2012).

ACSM (2013) reports that most apparently healthy individuals estimate RPE's for the overall-body from 18 to 19 (using the Borg Scale 6 to 20 format) or 9 to 10 (using a 0 to 10 format such as the OMNI Scales) at exercise test termination. According to the Range Model, if maximal exertion is reached, an individual should report the highest RPE available on the perceived exertion scale. However, since undifferentiated RPE (RPE-O) is an integration of differentiated signals, an OMNI RPE-O of 9 most likely indicates that the dominant differentiated response was a 10, such as RPE for the active musculature. Previous investigations measuring OMNI RPE during maximal or peak aerobic power testing have used the rating of an OMNI RPE ≥ 9 as a primary criterion for attainment of VO_2max/peak in

children (Andreacci et al. 2007) and adults (Krause et al. 2012). Therefore, for the purposes of this and the following laboratory experiments, the primary criterion for the successful completion of a GXT should be volitional termination due to exhaustion as indicated by maximal RPE, i.e., OMNI RPE $\geq$ 9 or Borg RPE $\geq$ 19.

6.2 Methods

6.2.1 Treadmill Procedures

6.2.1.1 Equipment

1. Adult OMNI-Walk/Run RPE Scale (Fig. A.2)
2. Borg RPE Scale
3. Treadmill
4. HR monitor
5. Respiratory-metabolic measurement system

6.2.1.2 Pre-exercise Procedures

1. Measure height (cm) and weight (kg) of subject.
2. Read the standard instructions for the Adult OMNI-Walk/Run RPE Scale to the subject for undifferentiated and differentiated RPE (Appendix B.2). Perform the memory anchoring procedure as described in Chap. 5.
3. Read the standard instructions for the Borg Scale during treadmill exercise for RPE-O, which will be used to determine construct validity of the OMNI Scale (Appendix B.3).

6.2.1.3 Graded Exercise Test

1. Position the HR monitor and respiratory-metabolic mouthpiece (with head support unit and nose clip if applicable) on the subject.
2. Instruct the subject to step onto the treadmill and review exercise termination procedures: When the subject cannot continue exercise due to exhaustion or discomfort, he/she should grasp the treadmill hand rails, at which time the test administrator will gradually slow the treadmill down for performance of a cool-down. The subject should be reminded not to step off the treadmill belt while it is still in motion.
3. Bruce Multistage Treadmill Test Protocol: this can be performed by manually adjusting treadmill speed and grade or using a program on a computer that is interfaced to the treadmill.

(a) Begin the warm-up at 1.5 miles $\cdot$ h^{-1} and 0 % grade for 3 min.
(b) Each exercise test stage will last for 3 min. The stages progress as follows:

Stage 1—1.7 miles $\cdot$ h^{-1} and 10 % grade
Stage 2—2.5 miles $\cdot$ h^{-1} and 12 % grade
Stage 3—3.4 miles $\cdot$ h^{-1} and 14 % grade
Stage 4—4.2 miles $\cdot$ h^{-1} and 16 % grade
Stage 5—5.0 miles $\cdot$ h^{-1} and 18 % grade
Stage 6—5.5 miles $\cdot$ h^{-1} and 20 % grade
Stage 7—6.0 miles $\cdot$ h^{-1} and 22 % grade
Stage 8—6.5 miles $\cdot$ h^{-1} and 24 % grade

(c) When the subject cannot continue any longer, terminate the exercise test by initiating the cool-down period at 1.5 miles $\cdot$ h^{-1} and 0 % grade. The cool-down should be 5 min in duration.
(d) Ask the subject to estimate RPE starting at 2:30 of each exercise stage using both the Borg Scale (RPE-O only) and the OMNI Scale (RPE-O, RPE-L, and RPE-C). The RPE's should be rated in a counterbalanced sequence. Because the position of the respiratory-metabolic mouth piece prevents a verbal response, instruct the subject to point to the numbers on the RPE scale, which should be conveniently positioned within the subject's arm reach. State aloud the numerical ratings for each momentary assessment to which the subject pointed and request a confirmatory nod that the number stated was correct. If incorrect, allow the subject to point to the appropriate rating on the RPE scale once more. Ask the subject to hold his or her finger on the appropriate number on the scale for approximately 1 s.
(e) Record HR (b $\cdot$ min^{-1}) at 2:55 of each exercise stage.
(f) Record the final 15-s VO_2 (ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) for each exercise stage.
(g) Record HRmax as the highest HR value recorded during the final exercise stage or immediately post-exercise.
(h) Record VO_2max as the highest 15-s VO_2 value recorded at the end of the test.

6.2.1.4 Data Organization and Analysis

1. In a Microsoft Excel spreadsheet, label columns of data for the following variables: Exercise Stage, VO_2 (ml $\cdot$ kg^{-1} $\cdot$ min^{-1}), Borg RPE-O, OMNI RPE-O, OMNI RPE-L, OMNI RPE-C, HR (b $\cdot$ min^{-1}).
2. Plot of VO_2 and Borg RPE-O for determination of concurrent scale validation.

(a) Click on the **INSERT** tab and in the **CHARTS** section click on **SCATTER**. Select the first available chart option. A blank or example scatter plot will appear on your screen.
(b) Click on the **SELECT DATA** tab. Remove any entries found in the **LEGEND ENTRIES** text box then click **ADD**. Under **SERIES NAME**, enter VO_2 and Borg RPE-O. Then click on the icon to the right of the **SERIES X VALUES** text box and highlight the VO_2 values. After the values are highlighted click

the icon on the box that appeared. Then click on the icon to the right of the **SERIES Y VALUES** text box and highlight the Borg RPE-O values. After the values are highlighted click the icon on the box that appeared. Click **OK** on the next two screens.

(c) You should now have a scatter plot with Borg RPE-O on the *y*-axis and VO_2 on the *x*-axis. Create a title for the plot and enter the appropriate axis labels and units of measure.

(d) To determine the validity coefficient, click on one of the data points to highlight the entire data series. Right click on one of the data points and a menu will appear. Click **ADD TRENDLINE** and the **FORMAT TRENDLINE** menu will appear. Select **LINEAR**, **DISPLAY EQUATION ON CHART**, and **DISPLAY R-SQUARED VALUE ON CHART** then click **CLOSE**. The trendline and equation will be displayed on the chart. Take the square root of the R^2 value to determine the Pearson correlation coefficient.

3. Repeat the above steps to plot and determine validity coefficients for the following variable pairs to establish concurrent validity: HR and Borg RPE-O, VO_2 and OMNI RPE-O, HR and OMNI RPE-O, VO_2 and OMNI RPE-L, HR and OMNI RPE-L, VO_2 and OMNI RPE-C, HR and OMNI RPE-C; and for construct validation: Borg RPE-O and OMNI RPE-O.
4. An example of these procedures with a screenshot depicting each step as performed using Microsoft Excel 2013 can be found in Appendix C.

6.2.2 Cycle Ergometer Procedures

6.2.2.1 Equipment

1. Adult OMNI-Cycle RPE Scale (Fig. 2.4)
2. Borg RPE Scale
3. Cycle ergometer
4. Metronome
5. HR monitor
6. Respiratory-metabolic measurement system

6.2.2.2 Pre-exercise Procedures

1. Measure height (cm) and weight (kg) of subject.
2. Read the standard instructions for the Adult OMNI-Cycle RPE Scale for undifferentiated and differentiated RPE to the subject (Appendix B.5). Perform the memory anchoring procedure as described in Chap. 5.
3. Read the standard instructions for use of the Borg Scale during cycle exercise emphasizing measurement of RPE-L, which will be used to determine construct validity of the OMNI Scale (Appendix B.6).

6.2.2.3 Graded Exercise Test

1. Position the HR monitor and respiratory-metabolic mouthpiece (with head support unit and nose clip if applicable) on the subject.
2. Set the proper seat height on the cycle ergometer according to leg length. When the foot is flat on the right pedal and the pedal is in the extreme down position, there should be a flexion of the right knee of approximately 5°.
3. Load-incremented protocol for electronically braked and friction-braked cycle ergometers:
   (a) Instruct the subject to maintain a 50 $rev \cdot min^{-1}$ pedal cadence. Set the metronome to 100 $b \cdot min^{-1}$ so each downward movement of each foot is synchronized with a beat of the metronome. The subject may also use the digital monitor on the cycle control panel to regulate pedal cadence.
   (b) For electronically braked cycle ergometers (e.g., Lode), begin stage 1 at 50 W then increase the resistance 25 W every 2 min.
   (c) For friction-braked cycle ergometers (e.g., Monark), begin stage 1 at 1 kg resistance then increase the resistance 0.5 kg every 2 min.
   (d) When the subject cannot maintain the pedal cadence for 10 consecutive seconds, terminate the exercise test. The test may also be volitionally terminated by the subject owing to fatigue.
   (e) Ask the subject to estimate RPE starting at 1:30 of each exercise stage using both the Borg Scale (RPE-O only) and the OMNI Scale (RPE-O, RPE-L, and RPE-C). The RPE's should be rated in a counterbalanced sequence. Because the position of the respiratory-metabolic mouth piece prevents a verbal response, instruct the subject to point to the numbers on the RPE scale, which should be conveniently positioned within the subject's arm reach. State aloud the numerical ratings for each momentary assessment to which the subject pointed and request a confirmatory nod that the number stated was correct. If incorrect, allow the subject to point to the appropriate rating on the RPE scale once more. Ask the subject to hold his or her finger on the appropriate number on the scale for approximately 1 s.
   (f) Record HR ($b \cdot min^{-1}$) at 1:55 of each exercise stage.
   (g) Record the final 15-s VO_2 ($l \cdot min^{-1}$) for each exercise stage.
   (h) Record HRpeak as the highest HR value recorded during the final exercise stage or immediately post-exercise.
   (i) Record VO_2peak as the highest 15-s VO_2 value recorded at the end of the test.

6.2.2.4 Data Organization and Analysis

1. In a Microsoft Excel spreadsheet, label columns of data for the following variables: Exercise Stage, VO_2 ($l \cdot min^{-1}$), Borg RPE-L, OMNI RPE-O, OMNI RPE-L, OMNI RPE-C, HR ($b \cdot min^{-1}$).

2. Plot of VO_2 and Borg RPE-L for determination of concurrent validity.
   (a) Click on the **INSERT** tab and in the **CHARTS** section click on **SCATTER**. Select the first available chart option. A blank or example scatter plot will appear on your screen.
   (b) Click on the **SELECT DATA** tab. Remove any entries found in the **LEGEND ENTRIES** text box then click **ADD**. Under **SERIES NAME**, enter VO_2 and Borg RPE-L. Then click on the icon to the right of the **SERIES X VALUES** text box and highlight the VO_2 values. After the values are highlighted click the icon on the box that appeared. Then click on the icon to the right of the **SERIES Y VALUES** text box and highlight the Borg RPE-L values. After the values are highlighted click the icon on the box that appeared. Click **OK** on the next two screens.
   (c) You should now have a scatter plot with Borg RPE-L on the *y*-axis and VO_2 on the *x*-axis. Create a title for the plot and enter the appropriate axis labels and units of measure.
   (d) To determine the validity coefficient, click on one of the data points to highlight the entire data series. Right click on one of the data points and a menu will appear. Click **ADD TRENDLINE** and the **FORMAT TRENDLINE** menu will appear. Select **LINEAR**, **DISPLAY EQUATION ON CHART**, and **DISPLAY R-SQUARED VALUE ON CHART** then click **CLOSE**. The trendline and equation will be displayed on the chart. Take the square root of the R^2 value to determine the Pearson correlation coefficient.
3. Repeat the above steps to plot and determine validity coefficients for the following variable pairs for concurrent scale validity: HR and Borg RPE-L, VO_2 and OMNI RPE-O, HR and OMNI RPE-O, VO_2 and OMNI RPE-L, HR and OMNI RPE-L, VO_2 and OMNI RPE-C, HR and OMNI RPE-C; and for construct validation: Borg RPE-L and OMNI RPE-L.
4. An example of these procedures with a screenshot depicting each step as performed using Microsoft Excel 2013 can be found in Appendix C.

6.2.3 Resistance Exercise Procedures

6.2.3.1 Equipment

1. Adult OMNI-Resistance Exercise RPE Scale (Fig. A.5)
2. Borg RPE Scale
3. Resistance exercise equipment of choice
4. Metronome

6.2.3.2 Pre-exercise Procedures

1. Read the standard instructions to the subject for use of the Adult OMNI-Resistance Exercise RPE Scale for undifferentiated and differentiated RPE (Appendix B.8). Perform the memory anchoring procedure as described in Chap. 5.

2. Read the standard instructions to the subject for the Borg Scale during resistance exercise emphasizing measurement of RPE-AM, which will be used to determine construct validity of the OMNI Scale (Appendix B.9).

6.2.3.3 Exercise Protocols

1. Administer a 1RM procedure for assessment of muscular strength (Baechle and Earle 2008).
   (a) Instruct the subject to warm-up with a light resistance that can be performed for 5–10 repetitions, then provide a 1-min rest.
   (b) Estimate a warm-up load that will allow the subject to complete 3–5 repetitions by adding 10–20 lb (5–10 % of weight lifted) for upper body exercise or 30–40 lb (10–20 % of weight lifted) for lower body exercise, then provide a 2-min rest.
   (c) Estimate a conservative, near maximal load that will allow the subject to complete 2–3 repetitions by adding 10–20 lb (5–10 % of weight lifted) for upper body exercise or 30–40 lb (10–20 % of weight lifted) for lower body exercise, then provide a 2–4-min rest.
   (d) Make a load increase of 10–20 lb (5–10 % of weight lifted) for upper body exercise or 30–40 lb (10–20 % of weight lifted) for lower body exercise and instruct the subject to attempt a 1RM.
   (e) If the subject successfully completed the lift using proper technique, provide a 2–4-min rest and repeat the previous step. If the subject failed to complete the lift using proper technique, provide a 2–4-min rest then decrease the resistance by 5–10 lb (2.5–5 % of weight lifted) for upper body exercise or 15–20 lb (5–10 % of weight lifted) for lower body exercise and instruct the subject to attempt a 1RM.
   (f) Continue increasing or decreasing the load until the subject can complete a 1RM with proper exercise technique.
   (g) Calculate the weight equal to the following %1RM intensities: 20, 40, 50, 60, 70, 80, and 90 %.
   (h) It may be beneficial to ask the subject to rate Borg RPE-AM, OMNI RPE-O and OMNI RPE-AM in a counterbalanced fashion immediately following each set. This will provide additional practice and feedback prior to undertaking the scale validation protocol.
2. Category scale validation will be assessed using the procedures described by Lagally and Robertson (2006).
   (a) Instruct the subject to warm-up with one set of ten repetitions at 20 % of exercise specific 1RM then provide a 1-min rest.
   (b) Instruct the subject to perform one repetition at 40, 50, 60, 70, 80, and 90 % of 1RM in a random order with a 2-min rest between intensities.
   (c) Repetition speed should be paced by a metronome set at 70 $b \cdot min^{-1}$ so each repetition is performed with a two-count-up, two-count-down pattern.

(d) Instruct the subject to estimate Borg RPE-AM, OMNI RPE-O and OMNI RPE-AM in a counterbalanced sequence immediately following each repetition.

6.2.3.4 Data Organization and Analysis

1. In a Microsoft Excel spreadsheet, label columns of data for the following variables: %1RM, Weight Lifted, Borg RPE-AM, OMNI RPE-O, OMNI RPE-AM.
2. Plot of Weight Lifted and Borg RPE-AM for determination of concurrent validity:
   (a) Click on the **INSERT** tab and in the **CHARTS** section click on **SCATTER**. Select the first available chart option. A blank or example scatter plot will appear on your screen.
   (b) Click on the **SELECT DATA** tab. Remove any entries found in the **LEGEND ENTRIES** text box then click **ADD**. Under **SERIES NAME**, enter Weight Lifted and Borg RPE-AM. Then click on the icon to the right of the **SERIES X VALUES** text box and highlight the Weight Lifted values. After the values are highlighted click the icon on the box that appeared. Then click on the icon to the right of the **SERIES Y VALUES** text box and highlight the Borg RPE-AM values. After the values are highlighted click the icon on the box that appeared. Click **OK** on the next two screens.
   (c) You should now have a scatter plot with Borg RPE-AM on the *y*-axis and Weight Lifted on the *x*-axis. Create a title for the plot and enter the appropriate axis labels and units of measure.
   (d) To determine the validity coefficient, click on one of the data points to highlight the entire data series. Right click on one of the data points and a menu will appear. Click **ADD TRENDLINE** and the **FORMAT TRENDLINE** menu will appear. Select **LINEAR**, **DISPLAY EQUATION ON CHART**, and **DISPLAY R-SQUARED VALUE ON CHART** then click **CLOSE**. The trendline and equation will be displayed on the chart. Take the square root of the R^2 value to determine the Pearson correlation coefficient.
3. Repeat the above steps to plot and determine validity coefficients for the following variable pairs to establish concurrent scale validity: Weight Lifted and OMNI RPE-O, Weight Lifted and OMNI RPE-AM; and for construct validation: Borg RPE-AM and OMNI RPE-AM.
4. An example of these procedures with a screenshot depicting each step as performed using Microsoft Excel 2013 can be found in Appendix C.

6.3 Discussion Questions

1. Define validity, in general, as it applies to the use of a perceived exertion scale during exercise.
2. Explain the differences and similarities between concurrent and construct validation as they apply to a perceived exertion scale.

3. Did your subject's perceived exertion responses conform to Borg's Range Model? Explain your data using the conceptual framework of Borg's Effort Continua Model.
4. Describe why RPE should be used as one of the criteria for the achievement of VO_2max/peak? Should the criterion be based on RPE-O, a differentiated RPE, or both? Explain.
5. Do your results for OMNI Scale concurrent and construct validity agree with previous RPE validation studies? Explain why, citing previous literature.
6. Which RPE scale demonstrated stronger concurrent validity for RPE-O, the OMNI Scale or Borg Scale? Why?
7. Choose a specific exercise test stage (treadmill and cycle) or %1RM from your data sheet.
   (a) Which OMNI RPE was the dominant signal, RPE-O or a specific differentiated RPE?
   (b) If you measured differentiated RPE (L and C) during treadmill or cycle exercise, did RPE-O represent a true integration (i.e., average) of these differentiated signals?
8. Based on your results, how would you use the perceived exertion scale from this experiment to prescribe exercise to the individual you tested?

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