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Differentiated ratings of perceived exertion during physical exercise

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ABSTRACT

PANDOLF, KENT B. Differentiated ratings of perceived exertion during physical exercise. *Med. Sci. Sports Exercise*, Vol. 14, No. 5, pp. 397-405, 1982. The typical overall (undifferentiated) rating of perceived exertion (RPE) appears to represent an individual's integration of various physiological sensations that have different subjective weightings. Two categories of physiological factors have been suggested as major determinants of RPE during physical exercise. These two factors are a local factor that relates to sensations or feelings of strain from the exercising muscles and/or joints and a central factor relating primarily to cardiopulmonary sensations. This paper attempts to characterize the relative importance of the various physiological cues in the exertional rating pertinent to these local and central factors. The majority of the related literature suggests that local factors are usually perceived as dominant; however, recent findings that evaluate differentiated RPE during exercise at high altitude imply a greater importance for central factors. When a particular physiological cue is markedly altered over others during exercise, it appears that the resultant sensation can easily dominate the overall RPE. In contrast, when this particular cue is not changed during exercise, as the result of some experimental manipulation or intervention, then another cue can become pronounced. Finally, an experimental model for evaluating differentiated RPE that allows comparisons between local and central exertion and further comparison to the general or overall exertion is discussed.

PERCEPTION OF EFFORT, LOCAL FACTORS, CENTRAL FACTORS, ENVIRONMENTAL HEAT, HYPOXIA, HYPEROXIA, CONCENTRIC EXERCISE, ECCENTRIC EXERCISE, HEART RATE, PULMONARY VENTILATION, OXYGEN UPTAKE, BLOOD LACTATE, ERGOMETRY

The two previous papers in this symposium suggest the importance of both local and central factors in the evaluation of effort sensations during physical exercise. Ekblom and Goldbarg (17) were the first to propose formally that the subjective evaluation of physical effort during exercise was based on two categories of factors: a local factor related to feelings of strain in the exercising muscles and/or joints and a central factor related primarily to sensations or feelings from the cardiopulmonary systems. In his earlier work, Borg (3,5) alluded to these two categories of factors stating that "the complex perception of exertion seems mainly to be composed of perceptions from the musculature and the system of circulation" (3, p. 105).

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Pandolf (39) has suggested an experimental model that utilizes differentiated ratings of perceived exertion (RPE) and may help provide for a more precise examination of the relationship(s) between these local and central factors. This model may also allow for a better understanding of these two factors and the underlying physiological events as compared to a single undifferentiated RPE. Earlier reports seem to indicate that local factors dominate the effort sensations during exercise (9,17,39). Since the review by Pandolf in 1978 (39), no attempt has been made to update our understanding of these two factors and/or other factors and their involvement with differentiated RPE. A recent review (33) evaluating various sensory cues and perceived exertion has been published; however, this paper does not critically evaluate these perceptual cues as related to differentiated RPE in any detail.

The purpose of this paper is to discuss briefly some of the experimental literature that led to the development of this model for evaluating differentiated RPE. Next, the observations from studies actually employing differentiated RPE are presented with particular regard for those which have further advanced our understanding of the local and central factor issue. Finally, within the framework of this experimental model, future direction for research within this area is suggested.

HISTORICAL PERSPECTIVE AND APPROACH

Specific instructions and procedures for the utilization of Borg's 15-point category scale for RPE have been presented previously (4,43). The majority of studies to be discussed in this paper employed this scale. However, some investigators have used a nine-point category rating scale (45,50) while some of the earlier research employed a 21-point version of Borg's RPE scale (15,19). Other investigators have evaluated effort sensations during physical exercise using magnitude estimation techniques (7,8,9,51), constant effort techniques (11,12), key cluster analysis (28, 52,53), and a variety of other rating methods (13,32,44).

Specific instructions have been developed for determining differentiated RPE utilizing the 15-point category scale for RPE (39,40). Subjects are asked to indicate a local muscular rating pertaining to feelings or sensations of strain in the exercising muscles and joints, a central rating that involves sensations from the cardiopulmonary system, and an overall, general rating of exertion. For the overall rating, individuals are told to integrate their local and central feelings with whatever weightings they deem appropriate. Further information is given upon request concerning the mechanics of the rating procedure, but no aid is given concerning the translation of feelings into perceptual ratings. Others have been more specific regarding the particular body area for the local and central ratings referring to these as "legs" and "chest" or "respiration," respectively (24,45).

In an earlier review, Pandolf (39) presented two tables summarizing the literature in support or dispute of local and central factor involvement for exertional ratings. Since this review, the related literature dealing with local and central factors has increased by nearly one-third. Table 1 presents an updated version of a previously published table (39) and compiles the references that support or dispute local factor involvement for exertional ratings during physical exercise. From the tabular findings of his earlier review, Pandolf (39) cautions the reader that many of these hypothesized factors signalling local effort (mechanoreceptor and Golgi tendon organ activity, and sensations from muscle, skin, joints, and ligaments) would be nearly impossible to quantify truly. Much of the literature supporting the importance of blood lactate as a major cue in the perception of effort according to this earlier report is correlational in nature, which does not necessarily imply causality. Conclusions by Mihevic (33) in a recent review support these comments.

More recent studies (13,25,35,42,55) supply little further *direct* experimental evidence in support of local factor involvement (Table 1). Most of these studies were not designed to evaluate local factors, per se, but to draw conclusions concerning local cues from secondary observations. On the other hand, the recent experimentation disputing the importance of local factors appears to be somewhat more direct through design and stated purpose (30,44,46). Poulus et al. (44) and Robertson et al. (46) show that blood pH is not an underlying factor in the subjective feelings of fatigue or perception of effort, respectively. Mihevic (33) concludes from these findings that if blood lactate influences RPE, it is probably mediated through a pathway other than blood acidemia. In a study designed expressly to evaluate some of the proposed local factors and RPE, Löllgen et al. (30) failed to show any relationship among selected muscle metabolites (muscle and blood lactate, glycogen, NAD, and phosphagens), fiber composition, and perception of effort. These comments are not intended to cause disregard for the apparent importance of local

TABLE 1. Literature in support or dispute of local factors for exertional ratings.

Supports		Disputes	
Reference	**Variable measured or hypothesized**	**Reference**	**Variable measured or hypothesized**
Allen & Pandolf (1)	blood lactate	Kay & Shephard (27)	blood lactate
Borg & Noble (6)	local factors	Löllgen et al. (30)	muscle and blood lactate, muscle NAD, glycogen, ATP, CP, muscle fiber type
Cafarelli (7)*	IEMG		
Cafarelli et al. (9)*	local sensations	Poulus et al. (44)*	blood pH, acid-base balance
Cain (11)*	tendon, skin, joint, ligaments	Robertson et al. (46)*	blood lactate, pH and pCO_2
Cain & Stevens (12)*	mechanoreceptors & chemoreceptors	Sargeant & Davies (47)	blood lactate
Campbell et al. (13)*	peripheral factors	Stamford & Noble (50)*	blood lactate
Docktor & Sharkey (15)	vanilmandelic acid		
Edwards et al. (16)	blood lactate		
Ekblom & Goldbarg (17)	blood lactate		
Ekblom et al. (18)	leg and joint sensation		
Frankenhaeuser et al. (19)	catecholamine excretion		
Gamberale (20)	blood lactate		
Henriksson et al. (23)	mechanoreceptors, Golgi tendon organ activity		
Horstman et al. (25)	local factors		
Löllgen et al. (31)	pedalling rate & resistance		
Noble et al. (35)	muscle soreness and stiffness		
Noble et al. (36)	local muscular discomfort		
Pandolf et al. (42)	feelings from working muscles and joints		
Pandolf (38)	local proprioceptive factors		
Pandolf et al. (40)	local factors dominate cycling		
Pandolf et al. (41)	anaerobic metabolites		
Pandolf & Noble (43)	sensations from muscles, joints, tendons		
Stamford & Noble (50)*	muscle temperature, muscle lactate, EMG, proprioception, Golgi tendon organs		
Stevens & Krimsley (51)*	mechanoreceptor & chemoreceptor sensitivity		
Weiser et al. (52)*	leg fatigue cluster		
Weiser & Stamper (53)*	leg fatigue		
Winsmann & Goldman (54)	local factor involvement		
Young et al. (55)	blood lactate, local factors		

* Did not use Borg Scale.

TABLE 2. Literature in support or dispute of central factors for exertional ratings.

Supports		Disputes	
Reference	Variable measured or hypothesized	Reference	Variable measured or hypothesized
Bar-Or et al. (2)	HR	Allen & Pandolf (1)	HR, $\dot{V}E$, RR, V_T
Borg & Noble (6)	central factors	Cafarelli (8)*	$\dot{V}O_2$, central component
Cafarelli (7)*	$\dot{V}O_2$	Cafarelli & Noble (10)	$\dot{V}E$
Cafarelli et al. (9)*	central sensations	Davies & Sargeant (14)	HR
Edwards et al. (16)	HR, $\dot{V}O_2$, RR, $\dot{V}E$	Ekblom & Goldbarg (17)	HR
Ekblom & Goldbarg (17)	pulmonary ventilation and circulation	Gamberale & Holmér (21)	HR
Ekblom et al. (18)	tachycardia, dyspnea	Henriksson et al. (23)	HR, $\dot{V}O_2$
Gamberale (20)	HR, $\dot{V}O_2$	Kamon et al. (26)	HR
Gerben et al. (22)	hypoxia	Löllgen et al. (30)	$\dot{V}E$, $\dot{V}O_2$, HR
Henriksson et al. (23)	baroreceptors & chemoreceptors	Michael & Eckardt (32)*	$\dot{V}E$
Horstman et al. (24)	ventilatory differences, dyspnea	Noble et al. (35)	HR, $\dot{V}E$
Horstman et al. (25)	central factors	Noble et al. (36)	HR
Kamon et al. (26)	$\dot{V}E$, RR	Pandolf et al. (42)	HR, $\dot{V}O_2$
Kay & Shephard (27)	HR	Pandolf (38)	HR, $\dot{V}O_2$
Michael & Eckardt (32)*	HR	Pandolf et al. (41)	HR
Morgan et al. (34)	$\dot{V}E$	Pandolf & Noble (43)	HR, $\dot{V}O_2$
Noble et al. (37)	$\dot{V}E$, RR	Sidney & Shephard (48)	HR
Pandolf (38)	central factors	Stamford & Noble (50)*	$\dot{V}E$
Pandolf et al. (40)	central factors and treadmill walking	Young et al. (55)	HR, $\dot{V}O_2$
Pandolf et al. (41)	$\dot{V}E$		
Sargeant & Davies (47)	$\dot{V}E$, $\dot{V}O_2$, HR, relative aerobic stress		
Skinner et al. (49)	HR, proportion of aerobic capacity		
Weiser et al. (52)*	cardiopulmonary systems		
Weiser & Stamper (53)*	cardiopulmonary fatigue		
Winsmann & Goldman (54)	HR		
Young et al. (55)	$\dot{V}E/\dot{V}O_2$, respiratory effort		

* Did not use Borg Scale.

muscular cues in effort sensation, but to encourage more carefully designed studies to evaluate these local factors systematically.

Table 2, an updated version of an earlier table (39), presents the related literature in support or dispute of central factor involvement in the perception of effort during exercise. In his earlier tabular review, Pandolf (39) concluded that although there appears to be a greater amount of literature supporting rather than disputing central factor involvement, much of this support is correlational in nature. When many of these proposed cardiopulmonary cues (heart rate [HR], oxygen uptake [$\dot{V}O_2$], pulmonary ventilation [$\dot{V}E$], respiratory rate [RR]) were experimentally manipulated, they were not shown to be primary factors in the perception of effort. Of the more recent studies used to update the earlier tabular form (see Table 2), twice as many references provide findings to dispute (8,14,30,35,39,55) rather than support (24,25,55) the importance of central factors. Cafarelli (8) found no correspondence between effort sensations and $\dot{V}O_2$ when the peripheral signal to the effort sense was held constant. Using intravenous injections of atropine or practolol to alter autonomic nervous system activity, Davies and Sargeant (14) concluded that HR, per se, has little influence on RPE and is not a primary factor fundamental to effort sensation. From these and other findings, Mihevic (33) concluded that it is unlikely that HR and $\dot{V}O_2$ are directly sensed. On the other hand, Young et al. (55) utilized acute and chronic hypoxic exposure to environmentally manipulate normal physiological responses to exercise and to provide compelling evidence for the association between respiratory effort, as represented by the ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$), and central effort. These authors also provided findings that further show that HR and $\dot{V}O_2$ are not primary cues for the central factor. The recent literature coupled with the more dated references would seem to cast further doubt on the relative importance of central cues on the perception of effort. Indeed, as Mihevic (33) recently suggested, the literature does not support that central cues are primary sources in effort sensation during exercise.

EXPERIMENTAL OBSERVATIONS FROM STUDIES EMPLOYING DIFFERENTIATED RPE

The experimental findings from many of the studies cited in the earlier tabular review (Tables 1 and 2) helped lead to the development of an experimental model for studying local and central factors (Figure 1). The proposed experimental model (39, 40) suggests that the undifferentiated RPE from the category rating scale by Borg (4) probably is associated with the "superordinate" level of subjective reporting and represents overall body responsiveness that results from the integration of various sensory cues having different perceptual weightings. At the superordinate level of subjective reporting, undifferentiated RPE is not closely related to the underlying physiological substrata. The present model suggests that the interrela-

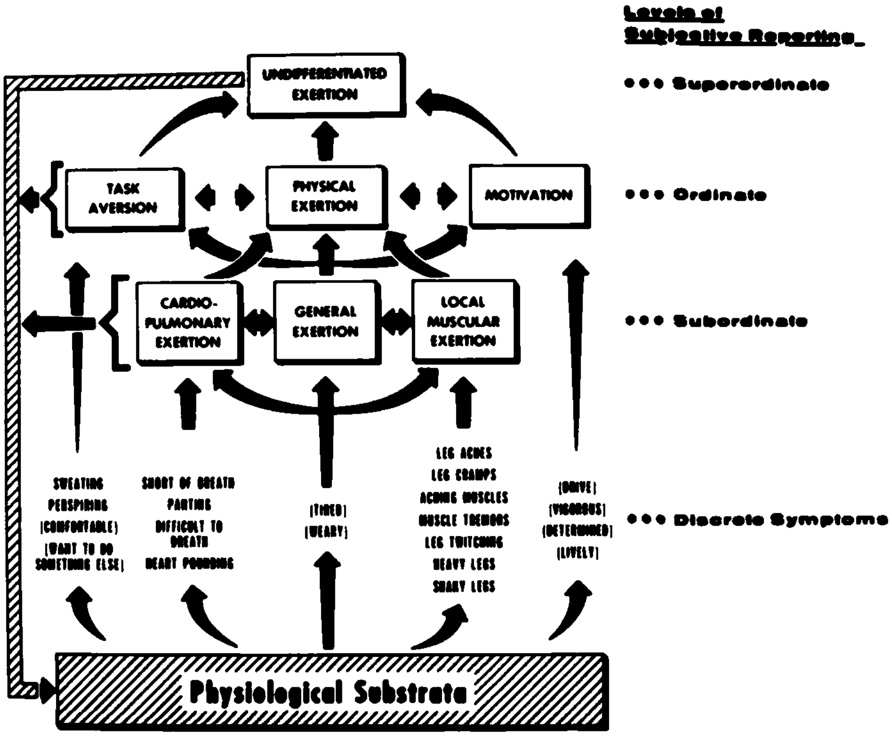

Figure 1—An experimental model that describes the levels of subjective reporting applicable to different types of physical exercise and presents a basis for differentiated ratings of perceived exertion. Reprinted with permission of the publisher from a study by Pandolf (39).

tionships between perceptual ratings and particular physiological responses during physical exercise can be more closely defined and compared utilizing "subordinate" differentiated ratings that appear to be in close proximity to the level of the "discrete symptoms." This model encourages comparisons between local (local muscular exertion) and central (cardiopulmonary exertion) factors with further contrasts to the general or overall exertion.

The remaining portion of this section reports experimental observations for studies actually employing differentiated RPE. Table 3 presents differentiated perceptual responses for three pedalling rates at a constant power output (840 kpm/min) as published by Robertson et al. (45). Ratings of perceived exertion were elicited with a nine-point category rating scale. The overall rating of perceived exertion was significantly lower than the rating for the legs (local) and higher than that from the chest (central) at each pedalling speed. These authors concluded that local signals from the legs dominated the sensory process with central signals being less pronounced. The mean of the ratings for the legs and chest was slightly but significantly higher than the overall rating at each pedalling speed. It is important to note that these findings, which were derived from a nine-point scale, are similar in terms of rank order of ratings to studies utilizing the 15-point Borg scale.

Table 4 shows the findings of Horstman et al. (24) depicting local (legs) and central (respiration) ratings of perceived exertion elicited while running or walking to self-imposed exhaustion at 80% $\dot{V}O_{2max}$ on a treadmill. It can be seen that the central or respiratory RPE was significantly lower during walking than running. While this study was not designed to quantitatively discriminate the degree of exertion perceived for the legs from that perceived for respiration, these differences are obviously small for running, but become of substantial magnitude for both groups (I and II) during walking with the local rating being dominant.

Another study by Pandolf et al. (40) employed differentiated RPE during level and grade walking at equivalent energy expenditures. Again, as seen in Table 5, local muscular factors appear to dominate the exertional perception. However, for this particular study this is only a trend; none of these perceptual differences were statistically significant ($P>0.05$).

In a more recent study, differentiated RPE for eccentric muscular exercise were utilized to help discern which effort sensations dominated the exertional perception (29). Also, this study investigated whether exercise training employing eccentric muscle contractions would lead to significant alterations in differentiated RPE. Six male volunteers trained (range of exercise intensities = 252-316 W) with eccentric contraction exercise for a 5-wk period (12-15 sessions, 60 min each) at 60 rpm on a specially designed cycle ergometer for which the pedal axle is driven in a reverse direction from normal cycling (concentric exercise) by an electric motor (29).

TABLE 3. Perceptual responses for three pedalling rates at a constant power output (840 kpm/min).

Perceived Exertion Rating	Pedalling Rate					
	40 rpm		60 rpm		80 rpm	
	M	SD	M	SD	M	SD
Legs	5.68[a]	1.22	5.02[b]	1.21	4.87[b]	1.35
Over-all	4.98[b]	1.10	4.38[c]	1.11	4.33[c]	1.31
Chest	4.38[c]	1.28	3.96[d]	1.19	3.94[d]	1.30
Mean Legs + Chest	5.04[a]	1.13	4.51[a]	1.07	4.47[a]	1.22
Over-all	4.98[b]	1.10	4.38[b]	1.11	4.33[b]	1.31

Means with different superscripts are significantly ($P<0.05$) different above the rule. *Below the rule means within a particular pedalling rate with different superscripts are* significantly ($P<0.05$) different. Reprinted with permission of the publisher from the *study by* Robertson *et al.* (45).

TABLE 4. Means and standard errors for endurance time and selected perceptual and biochemical variables for group I (80R and 80W) and group II (80W).

Variable	Group I (N = 26)		Group II (N = 28)
	80R	80W	80W
Endurance Time (min)	22.8 (2.1)	24.1 (2.2)	18.0 (1.8)†
RPE (legs)	17.5 (0.5)	17.9 (0.5)	17.0 (0.6)
RPE (respiration)	17.7 (0.4)	16.6 (0.4)*	15.0 (0.4)*
Lactate (mM)	9.2 (0.8)	8.8 (0.8)	7.3 (0.6)
Epinephrine (μg/L)	0.07 (0.01)	0.08 (0.02)	0.09 (0.02)
Norepinephrine (μg/L)	1.20 (0.17)	1.34 (0.17)	1.13 (0.11)

* Significantly ($P<0.05$) lower than 80 Run (group I).
† Significantly ($P<0.05$) lower than 80 Walk (group I).
Reprinted with permission of the publisher from the study by Horstman et al. (24).

TABLE 5. Differentiated ratings of perceived exertion (RPE) during predicted hard work* for level and grade walking at equivalent energy costs (M ± SE).

	0% Grade	10% Grade
Walking Speed (km/hr)	5.98 ± 0.15	3.03 ± 0.17
Energy Cost (kcal/hr)	399 ± 11.1	417 ± 9.8
HR (bts/min)	109 ± 4.1	111 ± 4.1
Local Ratings of Perceived Exertion	9.3 ± 0.6	9.0 ± 0.7
Central Ratings of Perceived Exertion	8.7 ± 0.4	8.6 ± 0.6
Over-all Ratings of Perceived Exertion	9.1 ± 0.6	8.7 ± 0.7

* Predicted according to Givoni-Goldman equation.
No significant differences at $P<0.05$ (N = 7). Reprinted with permission of the publisher from the study by Pandolf et al. (40).

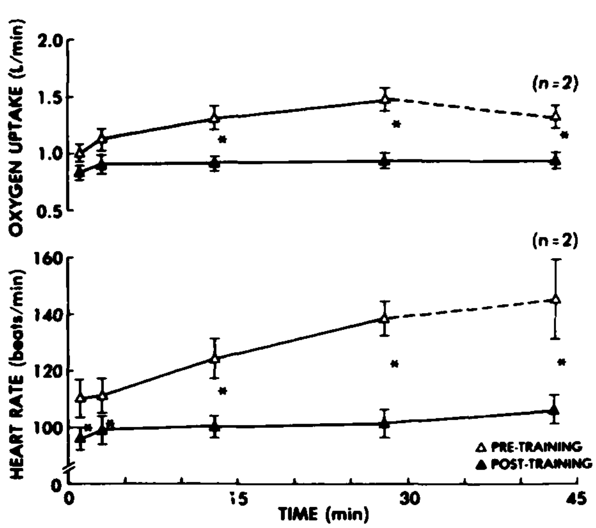

Figure 2—Mean values (±SE) for oxygen uptake and heart rate both pre- and post-training while performing eccentric exercise (asterisk indicates significant differences at 0.05 level of confidence). Reprinted with permission of publisher from Knuttgen et al. (29).

TABLE 6. Differentiated ratings of perceived exertion evaluated pre- and post-training using eccentric muscle contractions (Mean ± SE)*.

Ratings of Perceived Exertion		Time 10 min	25 min	40 min	
Pre-Training	Local RPE	11.5 (±1.0)	14.2 (±0.8)	13.0 (±1.0)	N = 2
	Central RPE	9.5 (±0.8)	11.3 (±0.8)	12.0 (±0.0)	N = 2
	Overall RPE	10.7 (±0.9)	13.2 (±0.7)	12.5 (±0.5)	N = 2
Post-Training	Local RPE	9.3 (±0.9)	10.3 (±1.1)	10.8 (±1.2)	
	Central RPE	8.3 (±0.7)	9.2 (±0.7)	9.7 (±1.0)	
	Overall RPE	8.8 (±0.8)	9.7 (±0.8)	10.0 (±1.0)	

TIME	10 min	25 min	
pre	10.6	12.9	→$P<0.01$
post	8.8	9.7	→$P<0.01$
	↓ $P<0.01$	↓ $P<0.01$	
	$cd_{.01}$ = 0.8		

Local RPE		Central RPE		Overall RPE
11.3	←($P<0.05$)	9.6	($P<0.05$)→	10.6
		$cd_{.05}$ = 0.8		

*N = 6 for each time period evaluation unless otherwise designated. Published previously in part by Knuttgen et al. (29).

Figure 2 shows the $\dot{V}O_2$ and HR values for pre- and post-eccentric training evaluations. In the pre-training experiments, both $\dot{V}O_2$ and HR demonstrate a continuous increase when all six subjects are included. Four of the subjects were unable to continue the exercise longer than 30 min (pre-training). A period of 2-3 d of extreme muscle soreness in the legs, beginning about 2 hr after these pre-training experiments, occurred for all subjects. The 5-wk training program resulted in a general decrease in both $\dot{V}O_2$ and HR. Values were significantly ($P<0.05$) lower for $\dot{V}O_2$ after 12 min and throughout the entire post-training evaluation for HR. Following the training period, all six subjects were easily able to complete a 45-min test bout at the same intensity, and all were able to maintain a constant rhythm without any obvious use of accessory musculature.

The average values for each of the differentiated RPE evaluated both pre- and post-training are depicted in Table 6. Statistical analysis was conducted only for time periods when the entire sample was complete. These findings illustrated that all ratings, both pre- and post-training, increased significantly ($P<0.01$) with time and that all ratings, regardless of time, decreased significantly with training. Local RPE was significantly ($P<0.05$) higher than central RPE; the overall RPE was significantly higher

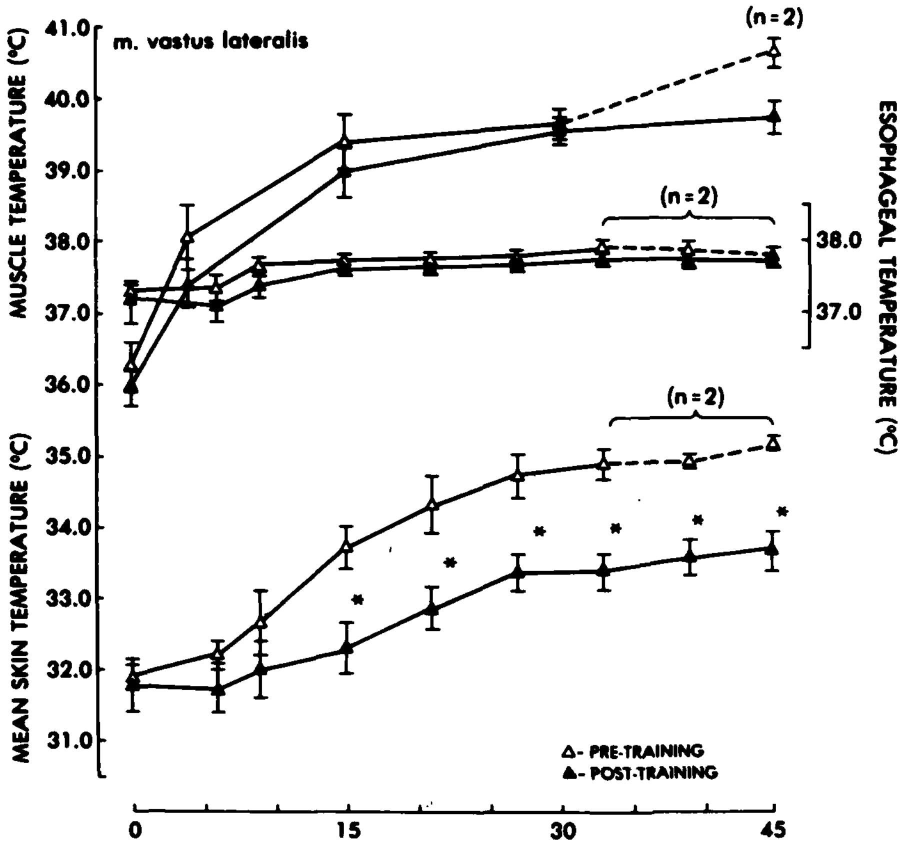

Figure 3—Mean values (±SE) for muscle temperature, esophageal temperature, and mean skin temperature both pre- and post-training while performing eccentric exercise. Reprinted with permission of publisher from Knuttgen et al. (29).

than the central RPE. These findings would lead one to conclude that the local RPE appears to be the dominant effort sensation for this type of exercise and also that this particular rating seems to be reduced most dramatically with eccentric muscular training.

Figure 3 illustrates the pattern of thermal responses during eccentric exercise both pre- and post-training. All of these responses have been implicated in previous publications as possible important cues in the setting of the exertional perception (26,37,41). Because muscle and esophageal temperatures did not differ with training while the perceptual ratings did, the importance of these cues in the effort sensations for this type of exercise can be questioned. Mean skin temperature (T_{sk}) tended to increase over the first 30 min of exercise both pre- and post-training. Values were significantly ($P<0.05$) lower for the post-training evaluation after 15 min with a difference in T_{sk} of about 1.5°C. One might infer that this difference in T_{sk} may be associated with differences in peripheral blood volume or blood flow after training. The lower T_{sk} after training may also be associated with the general reduction of all the differentiated ratings after training but may possibly be more closely related to the more dramatic reduction observed in the local RPE.

The observations from the last four studies would lead one to believe that local sensations from the exercising muscles and joints dominate the sensory process. In fact, Cafarelli et al. (9) investigated the relative magnitude of local and central components in the perception of effort and observed in no instance did central effort exceed local effort during exercise. In their study, central effort ranged in magnitude from 30-40% of local effort. However, very recent findings by Young et al. (55) may alter somewhat our understanding of the interrelationships between local and central effort sensations during exercise.

These experiments by Young et al. (55) involved exercise responses during altitude exposure. It is important to note for these experiments that mean $\dot{V}O_{2max}$ was 27% lower than sea level (SL) with both acute high altitude (AHA) and chronic (CHA) high altitude exposure. The particular findings presented concerned submaximal responses to an exercise intensity of 85% $\dot{V}O_{2max}$ for 30 min at SL and during both AHA and CHA exposure. Although the relative exercise intensities were the same, it should be remembered that at SL the average exercise intensity was 189 W while the intensity was significantly ($P<0.05$) lowered by about 50 W during both altitude exposures.

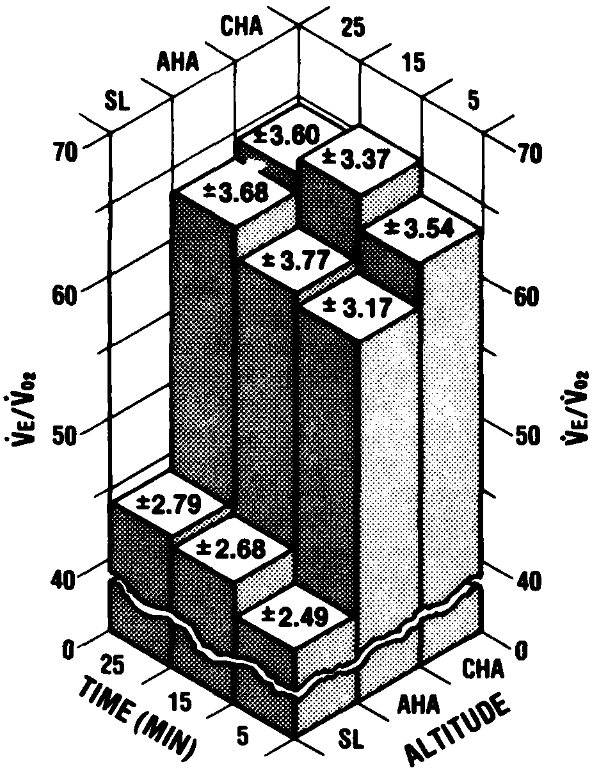

Figure 4—Mean values (± SE) for ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$) during exercise at sea level (SL) and during acute (AHA) and chronic (CHA) exposure to high altitude. Reprinted with permission of publisher from Young et al. (55).

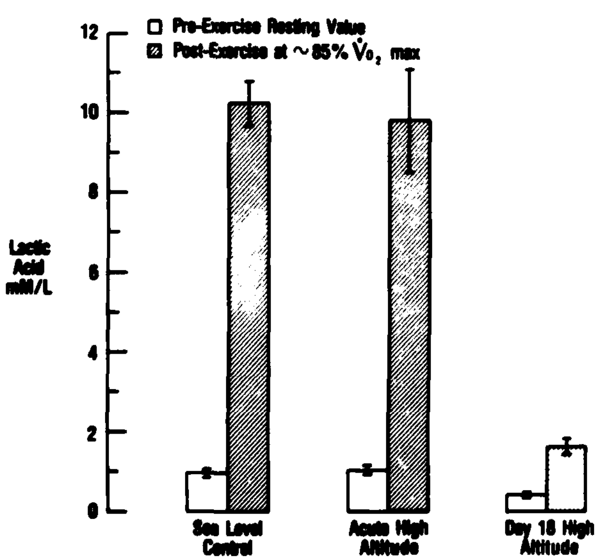

Figure 5—Mean blood lactate values (± SE) at rest and after submaximal exercise at sea level and high altitude. Reprinted with permission of publisher from Young et al. (55).

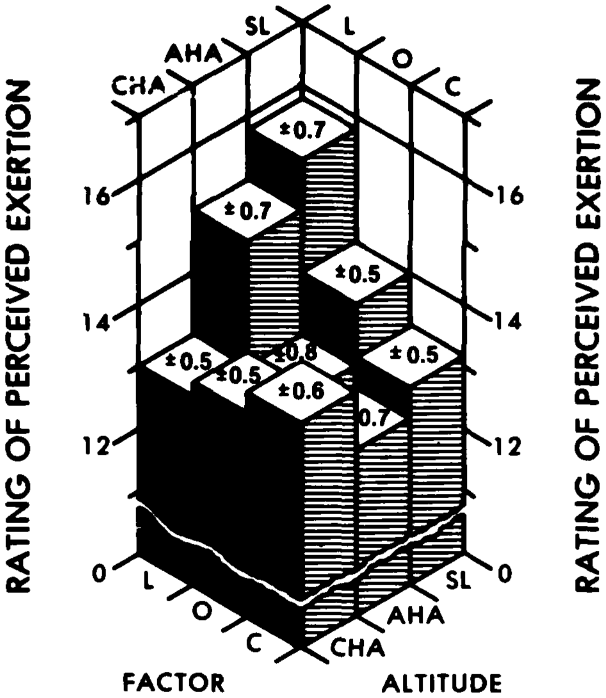

Figure 6—The effect of high altitude on local (L), central (C), and overall (O) RPE (sea level = SL; acute high altitude = AHA; chronic high altitude = CHA). Reprinted with permission of publisher from Young et al. (55).

As illustrated in Figure 4, the $\dot{V}E/\dot{V}O_2$ during acute and chronic high altitude exercise was not different ($P>0.05$), but each mean was significantly higher than at sea level. There was a significant increase in $\dot{V}E/\dot{V}O_2$ between minutes 5 and 15 of exercise with no additional change after 25 min. Thus, the increased $\dot{V}E/\dot{V}O_2$ seen during exercise at high altitude may be hypothesized as providing a dominant sensation (central factor) perceived, perhaps, as increased respiratory effort.

Somewhat in contrast, plasma lactate concentration during AHA exercise increased to the same degree as at SL, but after CHA exercise there was a significant ($P<0.05$) reduction in the degree of change in lactate concentration as depicted in Figure 5. From these findings, it may be hypothesized that the sensations provided by the large increase in blood lactate or local factor may have dominated the overall perception of effort during SL and AHA exercise.

The effect of altitude on the differentiated RPE is shown in Figure 6. During SL exercise, local RPE was significantly ($P<0.05$) greater than central RPE but neither differed significantly from the overall RPE. Although local RPE values during AHA exercise were greater than central and overall RPE, the differences were not significant. No significant differences were found between any of the three differentiated RPE during CHA exercise; however, central

RPE was the highest of the three ratings for most of the subjects. The local RPE during SL exercise did not differ from local RPE during AHA exercise but was significantly reduced after CHA exercise. Neither central nor overall RPE differed from corresponding SL values when exercise was performed at altitude (AHA or CHA).

These data would appear to suggest an apparent rearrangement in the relative order of magnitude of these three differentiated RPE. The very large reduction in the amount of lactate accumulation seen during exercise after CHA exposure may account for the reduced local RPE values seen during CHA. On the other hand, the ventilatory equivalent for oxygen ($\dot{V}E/\dot{V}O_2$) was significantly higher during both acute and chronic high altitude exercise compared to SL and would seem to imply greater central factor input at altitude. While $\dot{V}E/\dot{V}O_2$ was increased during AHA exercise, local feelings from the large increase in blood lactate may have dominated the overall perception of effort. Without these local sensations during CHA exercise, the increased $\dot{V}E/\dot{V}O_2$ may have provided the dominant effort sensations possibly perceived as increased respiratory or central effort. Young et al. concluded that "the key to whether these and other central factors may be sensed during exercise could involve the magnitude of the difference in the response among the particular conditions" (55, p. 228).

FUTURE DIRECTIONS FOR DIFFERENTIATED RPE RESEARCH

Further research should be directed to evaluate systematically local and central factors and other possible sensory inputs in an attempt to better understand the overall perception of effort during exercise. Mihevic (33) suggested that rather than considering a single primary cue, multiple sensory inputs (local and central factors) are processed in determining the overall RPE. While this statement appears valid, it may be more effective to study these proposed cues singularly rather than collectively at least initially to evaluate their importance more thoroughly. Nevertheless, the differentiated RPE model (39) allows for single or multiple evaluation of these suggested perceptual cues.

Another related area that has been neglected involves the effects of task aversion and motivation on the overall perception of effort. These two factors suggested to be at the "ordinate" level of subjective reporting (39) and others that alter an individual's mood state would certainly appear quite capable of altering the cognitive processing involved in determining the undifferentiated RPE. Better understanding of these factors should aid in our appreciation of how sensory information is processed in the perception of effort during physical exercise.

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The views, opinions, and/or findings contained in this report are those of the author and should not be construed as an official Department of the Army position, policy, or decision unless so designated by other official documentations.

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REFERENCES

1. ALLEN, P.D. and K.B. PANDOLF. Perceived exertion associated with breathing hyperoxic mixtures during submaximal work. *Med. Sci. Sports* 9:122-127, 1977.
2. BAR-OR, O., J.S. SKINNER, E.R. BUSKIRK, and G. BORG. Physiological and perceptual indicators of physical stress in 41- to 60-year-old men who vary in conditioning level and in body fat. *Med. Sci. Sports* 4:96-100, 1972.
3. BORG, G. Perceived exertion in relation to physical work load and pulse rate. *Kg. Fysiogr. Saellsk. Lund Foerh.* 31:105-115, 1961.
4. BORG, G. Perceived exertion as an indicator of somatic stress. *Scand. J. Rehabil. Med.* 2:92-98, 1970.
5. BORG, G.A.V. *Physical Performance and Perceived Exertion*. Lund, Sweden: Gleerup, 1962, pp. 1-64.
6. BORG, G.A.V. and B.J. NOBLE. Perceived exertion. In: *Exercise and Sport Sciences Reviews*, J.H. Wilmore (Ed.). New York: Academic Press, 1974, pp. 131-153.
7. CAFARELLI, E. Peripheral and central inputs to the effort sense during cycling exercise. *Eur. J. Appl. Physiol.* 37:181-189, 1977.
8. CAFARELLI, E. Effect of contraction frequency on effort sensations during cycling at a constant resistance. *Med. Sci. Sports* 10:270-275, 1978.
9. CAFARELLI, E., W.S. CAIN, and J.C. STEVENS. Effort of dynamic exercise: influence of load, duration, and task. *Ergonomics* 20:147-158, 1977.
10. CAFARELLI, E. and B.J. NOBLE. The effect of inspired carbon dioxide on subjective estimates of exertion during exercise. *Ergonomics* 19:581-589, 1976.
11. CAIN, W.S. Nature of perceived effort and fatigue: roles of strength and blood flow in muscle contractions. *J. Mot. Behav.* 5:33-47, 1973.
12. CAIN, W.S. and J.C. STEVENS. Effort in sustained and phasic handgrip contractions. *Am. J. Psychol.* 84:52-65, 1971.
13. CAMPBELL, E.J.M., R.H.T. EDWARDS, D.K. HILL, D.A. JONES, and M.K. SYKES. Perception of effort during partial curarization. *J. Physiol. (Lond.)* 263:186-187, 1976.
14. DAVIES, C.T.M. and A.J. SARGEANT. The effects of atropine and practolol on the perception of exertion during treadmill exercise. *Ergonomics* 22:1141-1146, 1979.
15. DOCKTOR, R. and B.J. SHARKEY. Note on some physiological and subjective reactions to exercise and training. *Percept. Mot. Skills* 32:233-234, 1971.
16. EDWARDS, R.H.T., A. MELCHER, C.M. HESSER, O. WIGERTZ, and L.G. EKELUND. Physiological correlates of perceived exertion in continuous and intermittent exercise with the same average power output. *Eur. J. Clin. Invest.* 2:108-114, 1972.
17. EKBLOM, B. and A.N. GOLDBARG. The influence of training and other factors on the subjective rating of perceived exertion. *Acta Physiol. Scand.* 83:399-406, 1971.
18. EKBLOM, B., O. LÖVGREN, M. ALDERIN, M. FRIDSTRÖM, and G. SÄTTERSTRÖM. Effect of short-term physical training on patients with rheumatoid arthritis I. *Scand. J. Rheumatol.* 4:80-86, 1975.
19. FRANKENHAEUSER, M., B. POST, B. NORDHEDEN, and H. SJOEBERG. Physiological and subjective reactions to different physical work loads. *Percept. Mot. Skills* 28:343-349, 1969.
20. GAMBERALE, F. Perceived exertion, heart rate, oxygen uptake and

blood lactate in different work operations. *Ergonomics* 15:545-554, 1972.

21. GAMBERALE, F. and I. HOLMER. Heart rate and perceived exertion in simulated work with high heat stress. In: *Physical Work and Effort*, G.A.V. Borg (Ed.). Oxford: Pergamon, 1977, pp. 323-332.
22. GERBEN, M.J., J.L. HOUSE, and F.R. WINSMANN. Self-paced ergometer performance: effects of pedal resistance, motivational contingency and inspired oxygen concentration. *Percept. Mot. Skills* 34:875-881, 1972.
23. HENRIKSSON, J., H.G. KNUTTGEN, and F. BONDE-PETERSEN. Perceived exertion during exercise with concentric and eccentric muscle contractions. *Ergonomics* 15:537-544, 1972.
24. HORSTMAN, D.H., W.P. MORGAN, A. CYMERMAN, and J. STOKES. Perception of effort during constant work to self-imposed exhaustion. *Percept. Mot. Skills* 48:1111-1126, 1979.
25. HORSTMAN, D.H., R. WEISKOFF, and S. ROBINSON. The nature of the perception of effort at sea level and high altitude. *Med. Sci. Sports* 11:150-154, 1979.
26. KAMON, E., K. PANDOLF, and E. CAFARELLI. The relationship between perceptual information and physiological responses to exercise in the heat. *J. Hum. Ergol.* 3:45-54, 1974.
27. KAY, C. and R.J. SHEPHARD. On muscle strength and the threshold of anaerobic work. *Int. Z. angew. Physiol.* 27:311-328, 1969.
28. KINSMAN, R.A. and P.C. WEISER. Subjective symptomatology during work and fatigue. In: *Psychological Aspects and Physiological Correlates of Work and Fatigue*, E. Simonson and P.C. Weiser (Eds.). Springfield, IL: Thomas, 1976, pp. 336-405.
29. KNUTTGEN, H.G., E.R. NADEL, K.B. PANDOLF, and J.F. PATTON. Effects of training with eccentric muscle contractions on exercise performance, energy expenditure, and body temperature. *Int. J. Sports Med.* 3:13-17, 1982.
30. LÖLLGEN, H., T. GRAHAM, and G. SJOGAARD. Muscle metabolites, force, and perceived exertion bicycling at varying pedal rates. *Med. Sci. Sports Exercise* 12:345-351, 1980.
31. LÖLLGEN, H., H.V. ULMER, R. GROSS, G. WILBERT, and G. NIEDING. Methodological aspects of perceived exertion rating and its relation to pedalling rate and rotating mass. *Eur. J. Appl. Physiol.* 34:205-215, 1975.
32. MICHAEL, E. and L. ECKARDT. The selection of hard work by trained and nontrained subjects. *Med. Sci. Sports* 4:107-110, 1972.
33. MIHEVIC, P.M. Sensory cues for perceived exertion: a review. *Med. Sci. Sports Exercise* 13:150-163, 1981.
34. MORGAN, W.P., K. HIROTA, G.A. WEITZ, and B. BALKE. Hypnotic perturbation of perceived exertion: ventilatory consequences. *Am. J. Clin. Hypn.* 189:182-190, 1976.
35. NOBLE, B.J., C.M. MARESH, T.G. ALLISON, and A. DRASH. Cardio-respiratory and perceptual recovery from a marathon run. *Med. Sci. Sports* 11:239-243, 1979.
36. NOBLE, B.J., K.F. METZ, K.B. PANDOLF, C.W. BELL, E. CAFARELLI, and W.E. SIME. Perceived exertion during walking and running II. *Med. Sci. Sports* 5:116-120, 1973.
37. NOBLE, B.J., K.F. METZ, K.B. PANDOLF, and E. CAFARELLI. Perceptual responses to exercise: a multiple regression study. *Med. Sci. Sports* 5:104-109, 1973.
38. PANDOLF, K.B. Psychological and physiological factors influencing perceived exertion. In: *Physical Work and Effort*, G.A.V. Borg (Ed.). Oxford: Pergamon, 1977, pp. 371-383.
39. PANDOLF, K.B. Influence of local and central factors in dominating rated perceived exertion during physical work. *Percept. Mot. Skills* 46:683-698, 1978.
40. PANDOLF, K.B., R.L. BURSE, and R.F. GOLDMAN. Differentiated ratings of perceived exertion during physical conditioning of older individuals using leg-weight loading. *Percept. Mot. Skills* 40:563-574, 1975.
41. PANDOLF, K.B., E. CAFARELLI, B.J. NOBLE, and K.F. METZ. Perceptual responses during prolonged work. *Percept. Mot. Skills* 35:975-985, 1972.
42. PANDOLF, K.B., E. KAMON, and B.J. NOBLE. Perceived exertion and physiological responses during negative and positive work in climbing a laddermill. *J. Sports Med. Phys. Fitness* 18:227-236, 1978.
43. PANDOLF, K.B. and B.J. NOBLE. The effect of pedalling speed and resistance changes on perceived exertion for equivalent power outputs on the bicycle ergometer. *Med. Sci. Sports* 5:132-136, 1973.
44. POULUS, A.J., H.J. DOCTER, and H.G. WESTRA. Acid-base balance and subjective feelings of fatigue during physical exercise. *Eur. J. Appl. Physiol.* 33:207-213, 1974.
45. ROBERTSON, R.J., R.L. GILLESPIE, J. MCCARTHY, and K.D. ROSE. Differentiated perceptions of exertion: part I. Mode of integration of regional signals. *Percept. Mot. Skills* 49:683-689, 1979.
46. ROBERTSON, R.J., R.L. GILLESPIE, J. MCCARTHY, and K.D. ROSE. Differentiated perceptions of exertion: part II. Relationship to local and central physiological responses. *Percept. Mot. Skills* 49:691-697, 1979.
47. SARGEANT, A.J. and C.T.M. DAVIES. Perceived exertion during rhythmic exercise involving different muscle masses. *J. Hum. Ergol.* 2:3-11, 1973.
48. SIDNEY, K.H. and R.J. SHEPHARD. Perception of exertion in the elderly, effects of aging, mode of exercise and physical training. *Percept. Mot. Skills* 44:999-1010, 1977.
49. SKINNER, J.S., R. HUTSLER, V. BERGSTEINOVA, and E.R. BUSKIRK. Perception of effort during different types of exercise and under different environmental conditions. *Med. Sci. Sports* 5:110-115, 1973.
50. STAMFORD, B.A. and B.J. NOBLE. Metabolic cost and perception of effort during bicycle ergometer work performance. *Med. Sci. Sports* 6:226-231, 1974.
51. STEVENS, J.C. and A.S. KRIMSLEY. Buildup of fatigue in static work: role of blood flow. In: *Physical Work and Effort*, G.A.V. Borg (Ed.). Oxford: Pergamon, 1977, pp. 145-155.
52. WEISER, P.C., R.A. KINSMAN, and D.A. STAMPER. Task specific symptomatology changes resulting from prolonged submaximal bicycle riding. *Med. Sci. Sports* 5:79-85, 1973.
53. WEISER, P.C. and D.A. STAMPER. Psychophysiological interactions leading to increased effort, leg fatigue, and respiratory distress during prolonged, strenuous bicycle riding. In: *Physical Work and Effort*, G.A.V. Borg (Ed.). Oxford: Pergamon, 1977, pp. 401-416.
54. WINSMANN, F.R. and R.F. GOLDMAN. Methods for evaluation of load-carriage systems. *Percept. Mot. Skills* 43:1211-1218, 1976.
55. YOUNG, A.J., A. CYMERMAN, and K.B. PANDOLF. Differentiated ratings of perceived exertion are influenced by high altitude exposure. *Med. Sci. Sports Exercise*, 14:223-228, 1982.

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