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Effort and dyspnoea during work of varying intensity and duration

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ABSTRACT: This study quantified the separate contributions of the intensity of exercise and its duration to muscular effort and dyspnoea during cycle ergometry. Six normal subjects estimated the perceived intensity (Borg scale 0–10) of peripheral muscular effort and dyspnoea during incremental exercise to their maximum work capacity (Wcap). On separate days, the same subjects exercised to endurance or 60 min at work rates rated for leg effort on the initial incremental test as: 2 ("slight", 33.1±1.45% Wcap) (mean±SE); 3 ("moderate", omission 83.6±3.87% Wcap). Perceived leg effort increased by a factor of 4.4 ($2^{2.13}$) with a doubling of work rate and by 1.3 ($2^{0.39}$) with a doubling of duration, as expressed by:

$$\text{Leg effort} = k \times \%\text{Wcap}^{2.13} \times \text{Time}^{0.39} \quad (r^2=0.87)$$

Perceived dyspnoea increased 5.3-fold with a doubling of work rate and by 1.4-fold with a doubling of duration:

$$\text{Dyspnoea} = k \times \%\text{Wcap}^{2.41} \times \text{Time}^{0.47} \quad (r^2=0.75)$$

Changes in work intensity, rather than duration, dominated symptom magnitudes such that in the performance of a given task, halving the intensity and doubling the duration of activity reduces the maximal intensity of muscular effort and dyspnoea to less than a third.
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Dyspnoea and muscular effort increase as the intensity of muscular work increases. In addition, increases in the duration of activity may further contribute to the magnitude of these sensations. Previous investigators have studied how sensory magnitudes vary with duration of exercise [1, 2], but generally only at a single work rate, thus precluding analysis of the interrelationships between work intensity, duration and symptoms. The aim of this study was to measure the changes in perceived leg effort and dyspnoea during exercise of different intensities and durations, and thus quantify the interaction of work intensity and duration as contributors to the magnitude of each sensation. This information is important because the intensity of peripheral muscle effort and dyspnoea commonly limits functional activity in both health and disease; minimizing these discomforts may be important in the regulation of muscular activity [3]. Furthermore, as the physiological response to prolonged activity may vary in extent and nature at different work rates, this study provides an opportunity to evaluate changes in sensory magnitudes under diverse physiological conditions and to clarify the interrelationships between contributing factors.

Methods

Subjects

Six normal male subjects aged from 28–42 yrs were studied. All gave informed consent, had normal spirometry, were nonsmokers, were familiar with sensory studies but were naive as to the purpose of the present study.

Apparatus

Subjects were exercised on a calibrated electrically braked cycle ergometer (Siemens Ergo Med 740, Siemens Electric Ltd, Pointe-Claire, Quebec, Canada).

Ventilation ($\dot{V}_E$), tidal volume (V_T), frequency of breathing (f_b), oxygen uptake ($\dot{V}_{O_2}$) and carbon dioxide output ($\dot{V}_{CO_2}$) were measured using a calibrated [4] automated universal exercise system (SensorMedics M.M.C. Horizon, Sensormedics Corporation, Anaheim, California, USA).

Procedure:

Care was taken to explain to each subject the specific sensations that they were required to estimate. For the legs, subjects were requested to estimate effort and not any other sensations arising within the muscle such as tension, displacement, impedance or pain. For dyspnoea, subjects were asked to estimate the intensity of any discomfort associated with the act of breathing without attempting to specify any particular sensory quality. Perceived leg effort and dyspnoea were measured using the Borg Scale [5]. The intensity of the perceived sensation of muscular effort and dyspnoea was matched to a number from 0–10; descriptive expressions were anchored to specific numbers as shown in figure 1. When using the scale, subjects were permitted to use fractions between integers.

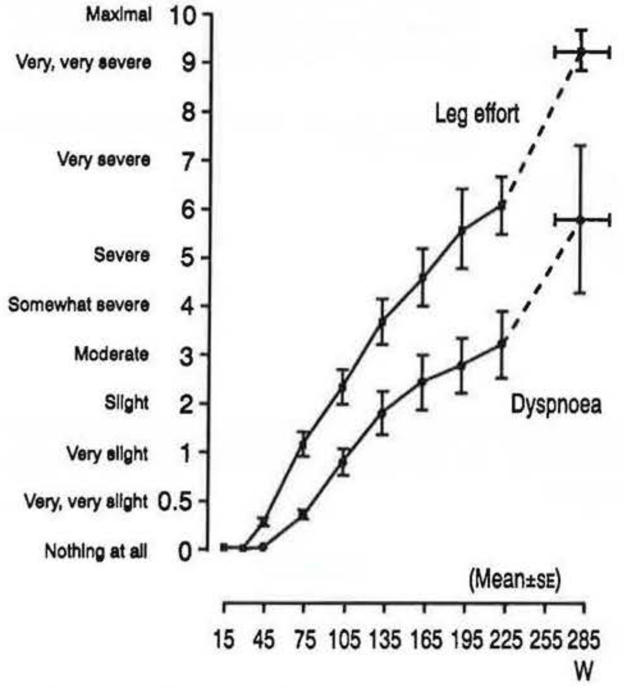

Fig. 1. – Leg effort (■) and dyspnoea (●) estimates during incremental exercise (mean±SEM). Solid lines join work rates at which values were available for all six subjects. Broken lines join the last work rate to which all six subjects contributed to the mean of the maximal value (symptom intensity and work rate) for all subjects.

Study stages

1. Incremental exercise. Subjects performed a progressive incremental exercise test, from loadless pedalling, in which power output was incremented by 15 W at the end of each minute to maximum work capacity (Wcap) [6] and rated the intensity of perceived leg effort and dyspnoea at the end of each minute.

2. Endurance exercise. On separate days, four endurance tests were performed at power outputs corresponding to a perceived intensity for leg effort of "slight" (Borg 2), "moderate" (Borg 3), "severe" (Borg 5), and "very severe" (Borg 7) determined during the incremental exercise test (table 1). They exercised to endurance or 60 min, whichever occurred first. Perceived leg effort and dyspnoea were rated at the end of each minute.

For the purpose of examining the relationship of the intensity and duration of respiratory muscle work to dyspnoea, work performed by the respiratory muscles was indirectly estimated using the equation of OTIS *et al.* [7]:

$$\text{Resp. work} = (5{,}000 \times f_b \times V_T^2) + (150 \times \dot{V}_E^2) + (3 \times \dot{V}_E^3)/100{,}000 \text{ kpm·min}^{-1}$$

Analysis of results

The relationship between symptom intensity and work rate during incremental exercise was calculated for each individual using regression analysis of the form:

$$\text{Symptom intensity} = k \times \%\text{Wcap}^n$$

where %Wcap is the intensity of exercise expressed as a percentage of maximum in the incremental exercise test, n is the exponent of the relationship, and k is a constant. Even though the linear relationship accounted for a similar proportion of the variance as the power function, it did not model the data as satisfactorily.

Using logarithmic transformation of all positive numbers, multiple regression was used to analyse the interaction of work intensity and duration to perceived leg effort and dyspnoea during endurance exercise for each individual to obtain an equation of the form:

$$\text{Symptom intensity} = k \times \%\text{Wcap}^n \times \text{Time}^m$$

where time is in minutes. Analysis of this relationship without log transformation of the data failed to account for as large a proportion of the variance in symptom intensities and is not reported.

The relationship of dyspnoea during prolonged exercise to the intensity and duration of respiratory muscle work was also determined to obtain an equation of the form:

$$\text{Dyspnoea} = k \times \%\text{Resp. work max}^n \times \text{Time}^m$$

where %Resp. work max is the intensity of respiratory muscle work expressed as a percentage of maximum in the incremental exercise test. It should be noted that the exponents in the above equations indicate the rate

Table 1. – Incremental exercise

	Leg effort						Dyspnoea		Work capacity	
Subjects no.	Threshold %Wcap	Slight %Wcap	Moderate %Wcap	Severe %Wcap	Very severe %Wcap	Max Borg	Threshold %Wcap	Max Borg	Watts	% Pred
1	10.3	31.4	45.1	70.6	96.1	8.0	36.6	5.0	255	97
2	18.0	35.1	45.6	66.7	87.7	10.0	27.0	8.0	285	112
3	24.0	36.4	45.5	65.2	83.3	10.0	37.1	9.0	330	131
4	12.1	33.3	43.9	64.9	87.8	9.0	21.9	7.0	285	123
5	16.4	35.7	42.9	59.5	78.6	10.0	20.8	4.5	210	91
6	9.5	27.0	34.9	52.4	68.3	10.0	66.2	1.0	315	135
Mean	15.0	33.1	43.0	63.2	83.6	9.5	34.9	5.8	280	115
±SD	5.53	3.36	4.10	6.39	9.49	0.84	16.86	2.89	43.2	18.0
±SEM	2.26	1.45	1.67	2.61	3.87	0.34	6.89	1.18	17.6	7.4

Work rates during incremental exercise (expressed as a percentage of maximum work capacity, (%Wcap) at which leg effort and dyspnoea became just noticable (threshold) and at which leg effort was rated as: "slight" (Borg 2); "moderate" (Borg 3); "severe" (Borg 5) and "very severe" (Borg 7). Maximum work rate in watts and expressed as a percentage of predicted (% pred) [15]. Maximum estimates for dyspnoea and leg effort at Wcap are also presented.

of change of symptoms associated with changes in the different factors, and not absolute symptom intensity.

We were unable to analyse interaction for dyspnoea in one subject (subject no. 6) who denied breathing discomfort during endurance exercise except at the later stages at the highest work intensity.

Linear regression analysis was performed to test for significant increases or decreases in physiological variables during the prolonged phase of exercise. The variable of interest (*e.g.* oxygen consumption) was regressed against time (expressed as percentage of time to endurance); values obtained early in the prolonged studies (before 6 min at the lower three work rates, before 4 min at the highest work rate) were excluded from the regression. Significant changes were judged to have occurred if the regression slope differed from zero ($p \le 0.05$). Intersubject variability was controlled for in the regression model by using dummy variables to identify each subject [8].

Results

Perceived muscular effort and dyspnoea during incremental exercise

Muscular effort became just noticeable at 43±8.1 W which amounted to 15.1±2.26% Wcap and increased to an intensity of 9.5±0.34 ("very, very severe") at 280±17.6 W (Wcap) which was above the predicted work capacity [9] for the group (table 1, fig. 1). All subjects indicated that exercise was limited by leg fatigue. The mean exponent and the coefficient of determination (r^2) for muscular effort expressed as a function of %Wcap were:

Leg Effort = k × %Wcap$^{1.58}$ (r^2=0.97; p=<0.0001; table 2)

Table 2. – Incremental exercise: relationship of symptom intensity to work rate

Subject no.	Leg effort k	Leg effort n	Leg effort r^2	Dyspnoea k	Dyspnoea n	Dyspnoea r^2
1	0.0315	1.20	0.96	0.0001	2.31	0.94
2	0.0037	1.70	0.94	0.0005	2.05	0.94
3	0.0006	2.14	0.98	0.00002	2.88	0.98
4	0.0174	1.34	0.96	0.0024	1.74	0.96
5	0.0047	1.67	0.98	0.0054	1.50	0.94
6	0.0090	1.48	0.98	0.00003	2.30	0.84
Mean		1.58	0.97		2.13	0.93
±SEM		0.140	0.0067		0.198	0.020

Individual and group mean values. k: constant; n: exponent; r^2: coefficient of determination. Form of relationship: symptom intensity (Borg units) = k × %Wcap^n.

Dyspnoea became noticeable at 101±24.1 W which amounted to 34.9±6.89% Wcap and increased to 5.8±1.18 ("severe") at Wcap (table 1, fig. 1). One subject rated dyspnoea 1 ("very slight") at maximal exercise. Dyspnoea was less than leg effort in all subjects at all times. The equation expressing dyspnoea as a function of %Wcap was:

Dyspnoea = k × %Wcap$^{2.13}$ (r^2 = 0.93; p<0.0001; table 2)

Perceived muscular effort and dyspnoea during prolonged exercise

Perceived muscular effort increased with the duration of activity at all four work rates (fig 2). The rate of increase was greatest at the highest work rate and least at the lowest work rate. Intensity and duration contributed to perceived effort in an interactive manner described by the following equation:

$$\text{Muscular effort} = k \times \%\text{Wcap}^{2.13} \times \text{Time}^{0.39}$$
$$(r^2=0.87;\ p<0.0001;\ \text{table 3})$$

The mean partial F associated with %Wcap was 576 ($p<0.0001$) and with time was 170 ($p<0.0001$). The proportion of the variance (r^2) accounted for by %Wcap alone was 0.59. Perceived dyspnoea increased with the duration of activity at all four work rates (fig. 3).

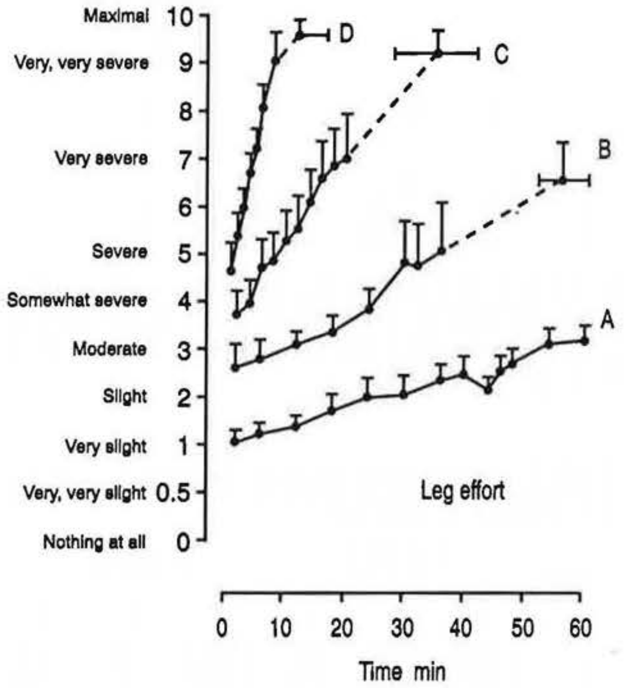

Fig. 2. – Leg effort estimates (mean±SEM) during endurance exercise at work rates corresponding to A: "mild"; B: "moderate"; C: "severe"; D: "very severe" leg effort as estimated during incremental exercise (see text, table 1). Solid lines join time intervals at which values were available for all six subjects. Broken lines join the last data point to which all six subjects contributed to the mean of the endurance value (symptom intensity and duration) for all subjects.

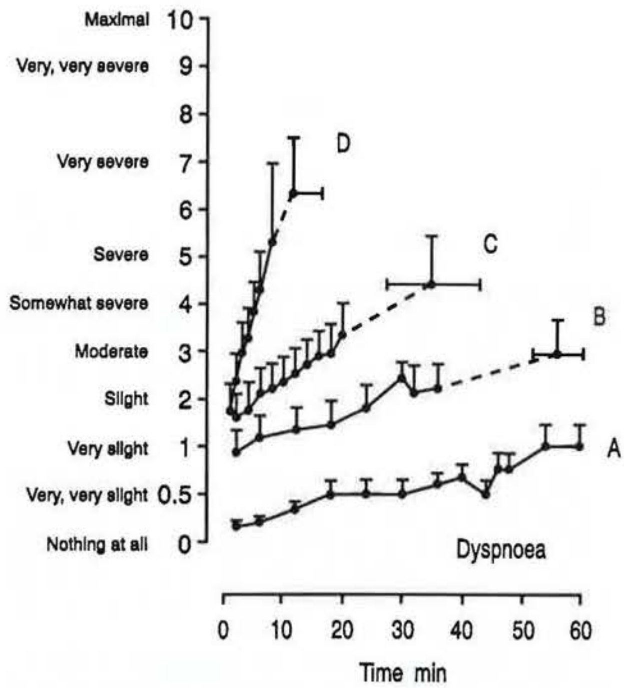

Fig. 3. – Dyspnoea estimates (mean±SEM) during endurance exercise at work rates corresponding to A: "mild"; B: "moderate"; C: "severe"; D: "very severe" leg effort as estimated during incremental exercise (see text, table 1). Solid lines join time intervals at which values were available for all six subjects. Broken lines join the last data point to which all six subjects contributed to the mean of the endurance value (symptom intensity and duration) for all subjects.

Table 3. – Endurance exercise: interactive relationship between work rate and duration as contributors to symptom intensity

Subject no.	Leg effort k	n	m	r^2	Dyspnoea k	n	m	r^2
1	2.9×10^{-3}	1.60	0.39	0.85	3.5×10^{-5}	2.33	0.41	0.83
2	3.0×10^{-4}	2.12	0.36	0.86	1.8×10^{1}	0.66	0.10	0.30
3	2.0×10^{-4}	2.25	0.33	0.90	1.4×10^{-4}	2.25	0.34	0.92
4	3.4×10^{-6}	2.97	0.73	0.88	1.7×10^{-8}	3.95	1.05	0.83
5	1.1×10^{-3}	1.98	0.31	0.85	9.7×10^{-6}	2.87	0.46	0.87
6	1.6×10^{-3}	1.88	0.22	0.89		NA		
Mean		2.13	0.39	0.87		2.41	0.47	0.75
±SEM		0.190	0.072	0.009		0.533	0.157	0.114

Individual and group mean values. k: constant; n: exponent for work rate; m: exponent for duration; r^2: coefficient of determination; NA: not available. Form of relationship: symptom intensity (Borg units) = k × %Wcap^n × Min^m. Interactive relationship could not be calculated for breathlessness for subject no. 6 (see text).

The increase was greatest at the highest work rate and least at the lowest work rate. Intensity and duration contributed to perceived dyspnoea in an interactive manner described by the following equation:

$$\text{Dyspnoea} = k \times \%\text{Wcap}^{2.41} \times \text{Time}^{0.47}$$
$(r^2=0.85;\ p<0.0001;$ table 3)

The mean partial F associated with %Wcap was 407 ($p<0.0001$) and with time was 135 ($p<0.0001$). The proportion of the variance accounted for by %Wcap alone was 0.48.

Physiological changes during prolonged exercise

Sequential measurements of gas exchange, ventilation and cardiac frequency were performed at each work rate. Regression analysis was performed to determine whether significant changes occurred during prolonged activity, after the onset of exercise (≥6 min at the lowest three work rates, ≥4 min at the highest work rate).

Work rate "slight" (33±1.5 %Wcap). Between 6 and 60 min, small but significant changes in gas exchanges occurred; oxygen consumption ($\dot{V}O_2$) increased from 1.47

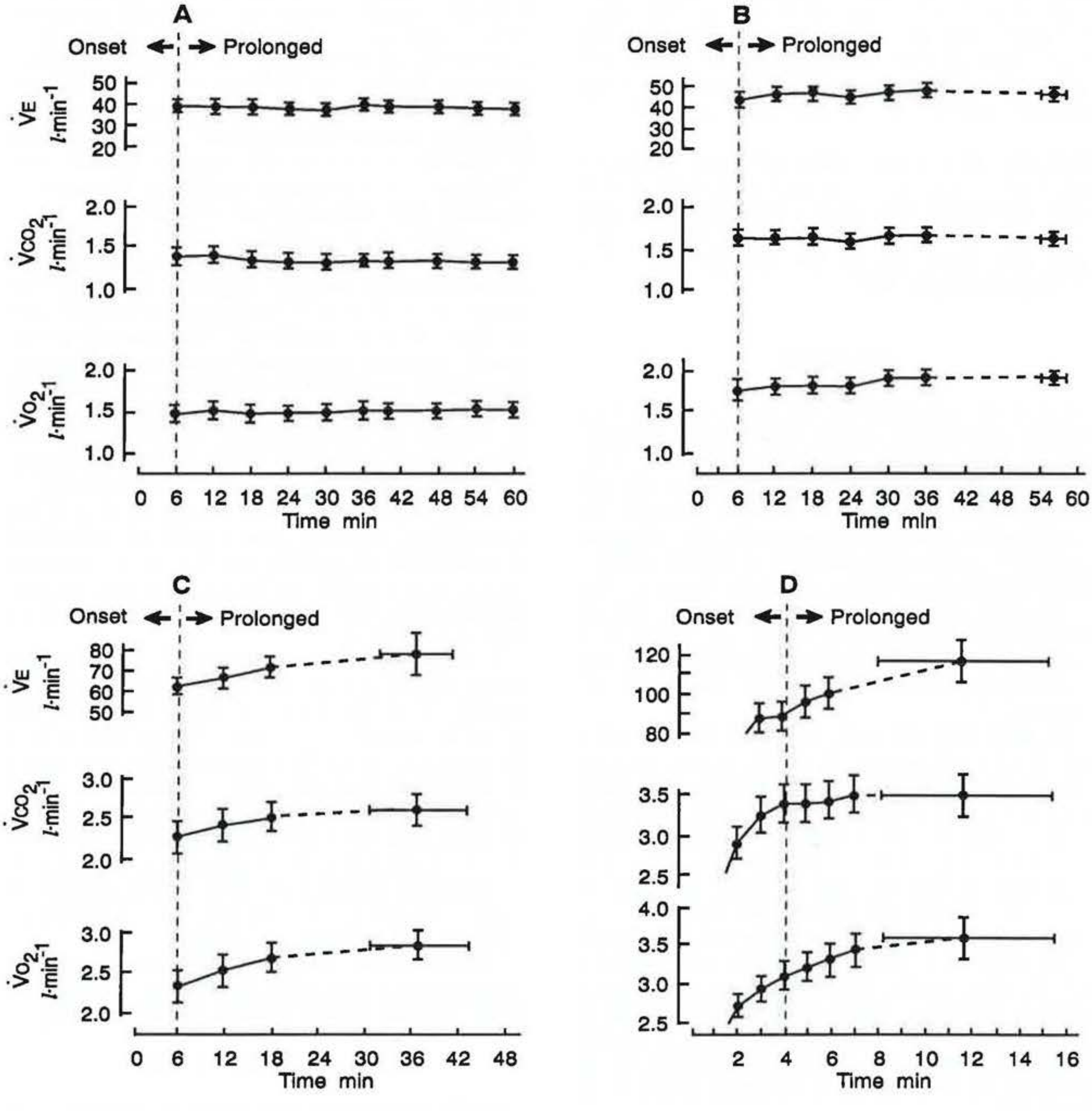

Fig. 4. – Physiological changes (mean±SEM) during endurance exercise at work rates corresponding to A: "mild"; B: "moderate"; C: " severe"; and D: "very severe" leg effort as estimated during incremental exercise (table 1). $\dot{V}E$: minute ventilation; $\dot{V}CO_2$: carbon dioxide output; $\dot{V}O_2$: oxygen uptake. Solid lines join time intervals at which values were available for all six subjects. Broken lines join the last data point to which all six subjects contributed to the mean of the endurance value for all subjects.

to 1.52 $l \cdot min^{-1}$ and carbon dioxide excretion ($\dot{V}CO_2$) decreased from 1.38 to 1.32 $l \cdot min^{-1}$ (fig. 4a). There was no significant change in ventilation ($\dot{V}E$) (p=0.08). Heart rate (HR) increased from 102 to 110 $beats \cdot min^{-1}$ ($p<0.0001$).

Work rate "moderate" (40±1.7 %Wcap). Between 6 and 56±4.0 min, $\dot{V}O_2$ increased from 1.76 to 1.93 $l \cdot min^{-1}$ (p=0.0001) while $\dot{V}CO_2$ did not change (p=0.94). $\dot{V}E$ increased from 44.1 to 46.8 $l \cdot min^{-1}$ (p=0.004) (fig. 4b). HR increased from 113 to 126 $beats \cdot min^{-1}$($p<0.0001$).

Work rate "severe" (63±2.6 %Wcap). Between 6 and 37±6.6 min, $\dot{V}O_2$ increased from 2.35 to 2.84 $l \cdot min^{-1}$ ($p<0.0001$); $\dot{V}CO_2$ increased to a lesser extent from 2.28 to 2.61 $l \cdot min^{-1}$ (p=0.01). $\dot{V}E$ increased from 60.4 to 87.9 $l \cdot min^{-1}$ ($p<0.0001$) during the same period (fig. 4c). HR increased from 135 to 155 $beats \cdot min^{-1}$, ($p<0.0001$).

Work rate "very severe" (84±3.9 %Wcap). Between 4 and 12±3.7 min, $\dot{V}O_2$ increased from 3.13 to 3.59 $l \cdot min^{-1}$ ($p<0.0001$); $\dot{V}CO_2$ did not change during the same period (p=0.3). $\dot{V}E$ increased from 100.7 to 131.8 $l \cdot min^{-1}$ ($p<0.0001$) (fig. 4d). HR increased from 156 to 171 $beats \cdot min^{-1}$ ($p<0.0001$).

Discussion

This study quantified the interaction between work intensity and duration as they contributed to dyspnoea and peripheral muscle effort during work of large muscle groups. The sense of muscular effort increased 4.4-fold with a doubling of exercise intensity and 1.3-fold with a doubling of exercise duration; dyspnoea increased 5.3-fold with a doubling of exercise intensity and 1.4-fold with a doubling of exercise duration. Thus, in the performance of a given total work, reducing power output and prolonging the duration of activity is extremely effective in reducing the maximal intensity of both peripheral skeletal muscle discomfort and dyspnoea.

The Borg scale was used to measure muscular effort and dyspnoea because it is simple to use, easy for subjects to understand and yields absolute values which allow direct comparison of estimates across individuals. Being a category scale it might be considered inferior to conventional ratio scaling methods (*e.g.* open magnitude estimation, cross modality matching or direct ratio scaling) for defining psychophysical relationships [10]. Because of the design and development of this scale [5], it retains interval and ratio properties and, therefore, mathematical manipulation of ratings is justified. Whether it validly preserves the psychophysical integrity of ratio scaling and properties of absolute magnitude as purported by Borg is uncertain, but the technique of cross modality matching attests to its utility [11].

Many distinct peripheral muscular and respiratory sensations can be identified and quantified. These include for the peripheral muscle, displacement [12], tension [12, 13] and effort [12, 13]; and correspondingly, for the respiratory system, volume [14], pressure [14] and breathing effort [15, 16]. In addition, deviation from the normal interrelationships between these sensations can also be distinguished; for example changes in impedance (tension/displacement [17, 18]) and muscle strength (tension/effort [19, 20]). It is apparent that the global quality of sensation arising in active muscle depends on the extent and balance of all of these sensory inputs.

Selection of the respiratory and peripheral muscle sensations used in this study was influenced by the multidimensional nature of muscular sensation, and the known difficulty that subjects may have in identifying specific sensory dimensions. The overall "discomfort associated with the act of breathing" was chosen in preference to a single specific respiratory muscular sensory dimension to avoid confusion. Also, no attempt was made to distinguish between "breathlessness" which may be used to describe a sense of the need to breathe, and "dyspnoea", a term usually applied to the sense of increased effort associated with breathing [21].

In contrast to the respiratory system, subjects were asked to estimate the intensity of a single specific peripheral muscle sensation - leg effort. Leg effort was chosen as it is readily identified by subjects and because effort is usually the dominant peripheral muscle sensation experienced during the performance of muscular work [20]. In addition, to supplement the main aim of the study (as discussed below), we wished to compare the psychophysical relationship between work performed and effort sensed by both the respiratory and peripheral muscles. As we believe dyspnoea is closely related to respiratory muscle effort [16], and we estimated respiratory muscle work, the relationship of dyspnoea to the intensity and duration of respiratory muscle work could be calculated. Similarly, the relationship of leg effort to the intensity and duration of leg work was determined.

It is uncertain whether interactions occur between sensations arising in respiratory and peripheral muscles, leading to an influence of one sensation on the perceived intensity of the other. The presence of such an interaction has not been formally studied and cannot be determined from this study. However, we found during previous studies in which subjects exercised at the same work rate while breathing against elastic and resistive loads, that severe dyspnoea was induced without associated change in leg effort. These observations suggest that quantitatively important interactions between leg effort and dyspnoea are unlikely.

Previous studies have shown that with single static handgrip contractions effort increased as an interactive power function of both intensity and duration [22]:

$$\text{Effort} = k \times \text{Force}^{1.7} \times \text{Time}^{0.7}$$

Similar relationships were found by Stubbing *et al.* [23] for single static inspiratory contractions, in which the perceived intensity of static inspiratory pressure increased as a function of pressure and duration:

$$\text{Perceived pressure} = k \times \text{Pressure}^{1.23} \times \text{Time}^{0.62}$$

With repeated peripheral muscle contractions over a short duration (240 s), CAFARELLI *et al.* [24] found that the interaction of intensity and duration of exercise was comparable but the rate of increase of effort as a function of time was less, as shown by the smaller exponent in the equation:

$$\text{Effort} = k \times \text{Intensity}^{1.4} \times \text{Time}^{0.27}$$

PANDOLF *et al.* [1] found that perceived exertion increased as a negatively accelerating function of duration over a 30 min exercise period on a cycle ergometer. During repeated inspiratory contractions against threshold loads, inspiratory effort increased faster with larger loads, suggesting a similar interactive relationship between the intensity and duration of respiratory muscle activity [25]. The results of the present study are consistent with these previous findings and extend our knowledge by quantifying the interaction between intensity and duration of dynamic muscular activity as contributors to dyspnoea and peripheral muscle effort during prolonged exercise.

The magnitude of dyspnoea and leg effort which would be associated with work of a given duration and intensity can be estimated from the results of this study (table 3). For example, after 30 min exercise at 50% Wcap, dyspnoea would be 2.8±0.40 and leg effort would be 5.2±0.51 on the Borg scale. The relationships outlined in this study facilitate quantification of the consequences of behavioural changes in work performance on associated symptom intensities. As exercise was not continued for longer than an hour in this study, the reliability of symptom predictions after this duration is uncertain.

In keeping with the work of others [26, 27], we found that $\dot{V}O_2$ increased during prolonged activity, the rate of increase being more marked as the intensity of work performed increased. The increase in $\dot{V}O_2$ may be due to greater reliance on fats as energy substrate [28], and a reduction in the efficiency of the exercising muscle with muscular recruitment. At all but the lowest work rate, ventilation also increased with duration, contributing to the increase in dyspnoea.

The circulatory response to prolonged exercise was similar to previously reported [1, 26, 29], with HR increasing progressively, particularly at the highest work rates. Previous investigators have consistently found that cardiac output is maintained during prolonged exercise of constant intensity [26, 29], the increase in heart rate being accompanied by a reduction in stroke volume. As exercise intensity and duration increase, perceived effort, dyspnoea and HR all increase but, as previously established by studies which directly manipulated HR during exercise, changes in HR are not independently sensed as contributors to effort [1, 30, 31].

Muscle fatigue probably underlies the observed increase in leg effort with increasing duration of activity. Effort continued to increase while the pedalling frequency and resistance remained constant. Power output and pattern of force development for the legs did not change at any work rate. In contrast, ventilatory demands increased with prolonged activity but this alone cannot account for all the increase in dyspnoea during prolonged activity, as dyspnoea increased at the lowest work rate despite $\dot{V}E$ remaining constant. Also, in a related study which will be published separately, we found that dyspnoea increased with duration independent of changes in breathing pattern, ventilation or respiratory pressures during prolonged exercise.

Fatigue of the respiratory muscles may have been an important contributor to dyspnoea. The fatiguing process is accelerated when muscle groups function at a higher proportion of their capacity, possibly explaining the increase in both sensations as work rate increased. Although a great deal is known about the physiology and biochemistry of muscular work, the relationship of these changes to sensory systems in general, and to perceived effort in particular, is less certain [32–34]. Under a number of specific experimental conditions, changes in ventilation, ventilatory equivalents for oxygen [2], acid-base conditions [34–37] and heart rate may correlate with peripheral muscle effort and dyspnoea, but no single factor, or combination of factors, is able to account consistently for sensory magnitudes under all circumstances. The effort required to drive a muscle increases as mechanical demands increase or as the ability of the muscle to meet those demands decreases. Several physiological factors may increase demands on the ventilatory muscle or may be associated with ventilatory and peripheral muscle fatigue, either of which may account for their relationship to perceived effort or dyspnoea under specific conditions. The responsiveness of the active muscle to central motor command may be sensitive to subtle changes in intramuscular homeostasis, requiring an augmented drive and effort to perform the same task. Possible mechanisms for this reduced responsiveness may include reflex afferent inhibition arising within the muscle [38], a reduced excitability of the muscle membrane [39] and/or a reduced contractile response to activation [40].

Dyspnoea and respiratory muscle work

Without attributing causality to the relationship, we contrasted the psychophysical relationship between dyspnoea and the power output of the respiratory muscle groups, and muscular effort and the power output of the leg muscles:

$$\text{Dyspnoea} = k \times \%\text{Resp. work max}^{0.74} \times \text{Time}^{0.25}$$
$$(r^2 = 0.66;\ p<0.0001;\ \text{table 4})$$

The mean partial F associated with %Resp. work max was 161 ($p<0.0001$) and with time was 28 ($p<0.0001$). The proportion of variance accounted for by %Resp Work max alone was 0.55. Dyspnoea increased 1.7-fold with a doubling of respiratory muscle work and 1.2-fold with a doubling of the duration of respiratory muscle activity. This contrasts with the

4.4-fold increase in perceived effort with a doubling of peripheral muscle work and 1.3-fold increase with a doubling of duration.

Table 4. – Endurance exercise: interactive relationship between respiratory work rate and duration as contributors to dyspnoea

Subject no.	k	n	m	r^2
1	0.066	0.86	0.22	0.79
2	1.64	0.29	0.058	0.57
3	0.29	0.71	0.28	0.78
4	0.053	0.89	0.51	0.61
5	0.074	0.93	0.20	0.57
6		NA		
Mean		0.736	0.25	0.66
±SEM		0.118	0.074	0.050

Individual and group mean values. k: constant; n: exponent for respiratory work rate; m: exponent for duration; r^2: coefficient of determination; NA: not available. Form of relationship: Dyspnoea (Borg units) = k × %Wresp.max^n Min^m. Interactive relationship could not be calculated for subject no. 6 (see text).

The reliability of the Otis equation to estimate the external work performed by the inspiratory muscles on the lung in exercising normal subjects has been established previously [41]. Respiratory work would need to have been grossly over or underestimated to significantly alter the exponent which describes its relationship to intensity of dyspnoea.

The relationship between changes in work output and perceived effort in peripheral skeletal muscle is substantially different to the relationship between changes in work output of the respiratory muscles and dyspnoea. Either the sensory stimulus giving rise to these sensory events is dissimilar or the way in which each muscle group operates in the performance of work is different. In the present study, the pattern of activity in the leg muscles was constant in terms of frequency, duty cycle, extent and velocity of contraction. Leg muscle tension varied with work rate but remained constant during each of the four episodes of prolonged activity. In contrast, subjects were free to adjust their pattern of respiratory muscle activity and to recruit additional ventilatory muscles. Either or both of these adaptations may account for the observed differences in the psychophysical relationship between effort and work rate for the two muscle groups.

The relationship between work performance and the discomfort associated with breathing and muscular effort is of practical concern in its own right. This study shows that the magnitude of dyspnoea and leg effort during sustained exercise is not simply the integral of intensity and duration. The same total work achieved over twice the duration is associated with less than one third the peak magnitude of dyspnoea and leg effort. Hence, in the performance of a given muscular task, minimizing the intensity by prolonging the duration of activity has a dramatic effect on reducing muscle effort and dyspnoea. Behavioural modification of the pattern of work performance, by reducing intensity and prolonging the duration of activity, may be the reason why patients with cardiorespiratory disease do not present until an advanced state of impairment.

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L'effort et la dyspnée au cours d'un travail d'intensité et de durée variables. M.C. Kearon, E. Summers, N.L. Jones, E.J.M. Campbell, K.J. Killian.

RÉSUMÉ: Cette étude a cherché à quantifier les contributions respectives de l'intensité de l'effort et de sa durée, à l'effort musculaire et à la dyspnée, au cours d'une cyclo-ergométrie. Six sujets normaux ont estimé l'intensité perçue d'efforts musculaires périphériques (échelle de Borg 0–10) et la dyspnée, au cours d'un effort progressif jusqu'à leur capacité d'effort maximum (Wcap). A des jours séparés, les mêmes sujets ont fait un exercice d'endurance ou de 60 minutes, à un taux de travail estimé pour l'effort des jambes au cours du test initial progressif comme 2 ("léger"; 33.1±1.45 %Wcap) (moyenne±SE), 3 ("modéré"; 43.0±1.45 %Wcap), 5 ("sévère"; 63.2±2.61 %Wcap), et 7 ("très sévère"; 83.6±3.87 %Wcap). L'effort des jambes perçu a augmenté selon un facteur de 4.4 ($2^{2.13}$) après un doublement du taux de travail, et selon un facteur de 1.3 ($2^{0.39}$) après un doublement de la durée, ce qui s'exprime par:

$$\text{Effort des jambes} = k \times \%\text{Wcap}^{2.13} \times \text{Temps}^{0.39} \quad (r^2=0.87).$$

La dyspnée perçue a augmenté de 5.3 fois après un doublement du taux de travail, et de 1.4 après un doublement de la durée:

$$\text{Dyspnée} = k \times \%\text{Wcap}^{2.41} \times \text{Temps}^{0.47} \quad (r^2=0.75).$$

Les modifications d'intensité du travail, plutôt que la durée, dominent l'ampleur des symptômes, en sorte que, dans l'exécution d'une tâche déterminée, diminuer l'intensité et doubler la durée de l'activité réduisent l'intensité maximale de l'effort musculaire et la dyspnée à moins d'un tiers.
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