Chapter 14

Subjective Symptomatology During Work and Fatigue

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THE CONCERN of this chapter centers around what has been called "subjective fatigue"—the feeling states experienced during the performance of work. Changes in these feeling states often may be related to work tolerance and performance. For example, individuals engaged in sports or any type of physical activity involving prolonged, strenuous exercise must continually determine their level of energy expenditure and the length of time they are willing to continue work. In general, the point at which a person quits may correspond to when he "feels very tired" or "worn out."

Welford (1965), however, has noted that the symptoms commonly associated with subjective fatigue have been viewed as difficult to measure adequately. Consequently, until recently they have been neglected by most investigators in favor of more directly observable physiological, neurological, or behavioral events. Indeed, a search of the literature in this area quickly reveals many inadequacies in methodology and a paucity of well directed and systematic investigations of subjective symptomatology during work. Fortunately, as will be seen, there are also some promising experimental approaches which have recently appeared in the literature.

It is certainly true that subjective symptoms cannot be measured directly. By definition, a symptom is a privately experienced event made public only when the experience is *reported* to an observer. The measurement of these symptoms is, therefore, necessarily indirect, depending on reliable self-report techniques. Furthermore, it is important to realize that the subjective symptoms most of us usually associate with fatigue *per se*, such as tiredness, lack of energy, or feeling worn out, probably encompass only a few of the many types of subjective symptoms that might be reported during work performance. Other subjective qualities as diverse as pain, thermal sensations, or boredom often occur during work. It is important to differentiate between these subjective qualities as Welford (1965) has pointed out. In recent years, there has been renewed effort to develop self-report techniques to measure such subjective qualities accompanying work performance.

It has frequently been assumed that subjective symptoms must inevitably

This chapter was supported in part by NIH Grants MH24222-01 and HL14985-02.

be related to work performance under any task condition. Some authors have suggested that the opposite is true, that is, that subjective symptoms are not related to work performance (e.g. Pierson, 1963a). As with many extreme positions in science, both statements are overgeneralizations. Frequently there have been work situations where no relationship between symptomatology and performance have been reported or would be expected. While this lack of relationship could result from the selection of the method of measurement or the specific quality measured, it may adequately reflect the real situation.

The objectives of this chapter are first to review and evaluate studies of the various subjective qualities reported during work, and second, to propose a model permitting a more appropriate conceptualization of subjective fatigue. The review section, comprising roughly the first three-fourths of the chapter, is not exhaustive but serves to exemplify the methods of measurement used and the subjective qualities studied. The reader is forewarned that the review often involves detailed discussion of individual studies since an adequate, critical overview of this area does not appear to exist. We hope the persistence of the interested reader will be rewarded by the novel conceptual organization of the area provided in the last quarter of the chapter.

THE MEASUREMENT OF SUBJECTIVE QUALITIES

Subjective symptoms represent one level of measurement during work performance in a matrix (the organism) which consists of a diversity of organizational levels. Questions should be asked about relationships within as well as between levels of biological organization during work performance: What *are* the subjective symptoms experienced during work? How do these differ between tasks? How do these change during the course of work? What are their relationships to physiological, and especially neurological, levels of organization? When are they related to work performance and work tolerance? When are they not related? None of these questions presume a specific answer, but the answers are bound to be informationally rich. If the first order of business in studies of subjective symptoms during work—measurement—is handled adequately, the answers to such questions as these will be interesting in their own right.

Scaling Techniques

There are a variety of solutions to the problem of *adequate* measurement that are available from the areas of psychophysics (e.g. see S. S. Stevens, 1957), psychological assessment (e.g. see Jackson and Messick, 1967), and, in particular, psychometric scaling (e.g. Guilford, 1954). Recent developments in scaling techniques have been reviewed by Cliff (1973) in an article containing over 200 references for the period 1968 to 1972 alone. The available scaling techniques have been used only recently in a *systematic* program of research in the area of work performance.

S. S. Stevens (1960) has discussed the numerical properties of various types of scales. Before proceeding further, it may be useful to review the characteristics of scales. A scale simply refers to the assignment of numbers to objects or events in order to differentiate between them. *Nominal* scales are the simplest means of numerical assignment providing only a substitute name for the purposes of identification. Social Security numbers, automobile license plates, and the numbers given to football players are all examples of nominal scaling. No information is provided about the magnitude of some quality of the objects to which numbers are assigned. The automobile with a license plate AL-4516 may either be a Volkswagen sedan or a Cadillac Eldorado according to nominal scaling.

In an *ordinal* scale, numbers are assigned according to the order of magnitude for some attribute which objects or events possess. For example, a compulsive psychometrician may ask his wife to rate how hungry she is on a 5-point scale before deciding on the restaurant for dinner. He may say "suppose a 5 is the hungriest you've ever been and 1 is the least hungry you've ever been. How hungry are you on a scale of 1 to 5?" If she's willing to put up with this nonsense, she may reply 4 indicating that she's very hungry, but not as "hungry as she's ever been." The scale thus allows a rough quantification of a subjective quality, hunger, and the psychometrician can use this information in making his choice of restaurants for dinner. In such an ordinal scale, however, there is no true zero point representing the complete absence of hunger, nor are the intervals on the scale necessarily equidistant. The difference between 4 and 5 or 1 and 2 on the "hunger scale" may both be 1 scale point, but may not represent equal differences in the magnitude of the subjective quality measured. Nevertheless, most applications of scaling techniques to measure subjective feelings during work performance have used rating scales with ordinal properties. As we will see, the shortcomings of ordinal scales, absence of a "true" zero point and equal intervals, can largely be overcome in most applications.

Interval scales possess all the attributes of ordinal scales, but the intervals between adjacent categories are equal. A thermometer is the most familiar interval scale with degrees indicating the magnitude of the difference between points on the scale. However, like ordinal scales, the interval scale lacks a true zero point. The zero on a Centigrade or Fahrenheit thermometer does *not* correspond to the "absence of heat." Interval scales can be constructed to measure subjective qualities, but require the use of rather lengthy psychometric techniques such as the method of equal appearing intervals (Thurstone and Chave, 1929; also see Niven, 1953; Guilford, 1950, 1954). In the measurement of subjective qualities during work performance, interval scaling is best exemplified by the studies of Pearson and Byars (1956) and of McNelly (1957), both of which will be discussed in some detail.

Only the *ratio* scales have a true zero point representing the absence of the attribute measured while also providing magnitude measurement by equal intervals in the units of measurement. Psychophysical techniques are used to obtain ratio scales for subjective qualities.

Most attempts to quantify subjective qualities during work have used *ordinal* rating scales. The inherent shortcomings of the ordinal scales can largely be overcome in most applications. The intervals between ordinal scale points often can be made to *appear* equidistant by careful selection of the verbal descriptions accompanying each scale point, physically representing the verbal descriptions at equal intervals, and by indicating equal intervals in the numbering of scale points, e.g. values of 0, 1, , 4. Furthermore, a zero point can be provided by anchoring the first category with "not present" indicating complete absence of the subjective quality. Such ordinal scales have often been treated statistically as if they were true equal-interval scales. Overall and Klett (1972) have noted that equal-appearing interval scales "have frequently been demonstrated to be linearly related to Thurstone type equal-interval scales except in the extreme categories." Such scales are among the simplest to construct and to use; therefore, they have enjoyed the widest application in studies of subjective fatigue to be discussed.

TYPES OF MEASUREMENT OF SUBJECTIVE QUALITIES

In this section the techniques available to measure subjective qualities during work performance will be reviewed and evaluated. Measurement has relied primarily on two general methodologies: (1) psychophysical techniques and (2) rating scales. Psychophysical techniques produce ratio scales which although more precise in describing relationships between stimulus levels and perceptions, are less useful in most work situations. Rating scales have enjoyed a wider application largely because of the ease with which the ordinal or interval scales may be used. Most recently, a third general methodology involving multivariate statistical procedures has been used to identify categories or dimensions of symptomatology related to work performance.

Psychophysical Studies

There has been renewed interest in the application of psychophysical techniques to relate subjective qualities to certain parameters of work performance (see Table 14-1). These techniques provide a *ratio scaling* that relates stimulus level to the perception of the stimulus. Application of psychophysics to the area of work performance provides rather precise answers to questions regarding how the perception of effort increases as physical activity increases.

Classical psychophysics has a long history extending back to the 19th century and the work of Weber (1834), Fechner (1877), and Plateau (1872). Detailed discussions of the development of psychophysics have been presented by S. S. Stevens (1957, 1960). Psychophysics involves the description of the relationship between *perceived* change in a physical stimulus, the psychological dimension, and change in the objective intensity or quality of the stimulus measured in physical units, the physical dimension. For many years, it was assumed that Fechner had accurately described the relationship between perception and levels of a physical stimulus as a logarithmic function:

$$\Psi = k \log \Phi \qquad (1)$$

where Ψ is the subjective unit of the psychological scale, k is a constant and Φ is the level of the physical stimulus.

Since the 1930's, however, under the influence of modern psychophysicists such as S. S. Stevens and Ekman, this relationship is generally agreed to be better approximated by a power function:

$$\Psi = k\,(\Phi)^m \qquad (2)$$

where m is an exponent defining the power function fitting the shape of the curve.

The value of the constant threshold, i.e. the minimum stimulus level which the individual can perceive may also be included in the power function as a constant:

$$\Psi = k\,(\Phi - a)^m \qquad (3)$$

where a is an additive constant included to bring the zero point of the physical scale in line with the zero of the psychological scale. Inclusion of this constant in the equation will generally result in a rescaling of stimulus values corresponding to the range of perception. According to S. S. Stevens (1960), it was Luce (1959) who noted that "the use of an additive constant to bring the zero of the physical scale into coincidence with the zero of the psychological scale is a proper generalization of the power law."

This power function has been found to be applicable to subjective judgments covering a wide range of stimulus modalities including brightness, pitch, loudness, taste, odor, and heaviness (S. S. Stevens, 1957) as well as the perception of force exerted during work performance (Borg, 1962; Schmale, Schmidtke, and Vukovich, 1963; and Bernyer, 1967), and fatigue (Bujas, Pavlina, Sremec, Vidaček, and Vodanović, 1966). An example of a power function relating perception of exertion ("Anstrengung") to load level expressed as percentage of maximum load is shown in Figure 14-1.

Various psychophysical methods are used to derive the power functions. These have been described in detail in numerous sources (e.g. see Stevens, 1957, 1960; and Ekman, 1958, 1959). It is beyond the scope of this chapter to discuss in detail the many issues and methods in the area of psychophysics. However, it may be worthwhile to describe two of the more useful psychophysical methods of ratio scaling: the *estimation* and *production* methods, both of which have been applied to the perception of force exerted during work.

In general, *estimation* methods require the subject either to estimate the relative magnitude (magnitude estimation) of physical stimuli by assigning numerical values (e.g. 105, 120, etc.) to a series of comparative stimuli in reference to a standard stimulus of a given numerical magnitude (e.g. 100); or, to estimate the percentage magnitude (ratio estimation) of the comparative stimuli in relation to the standard. The *production* methods, in contrast, require the subject to *produce* a stimulus that is either a multiple of (ratio production) or a specified magnitude (magnitude production) of a standard stimulus of given intensity. In work situations, the stimulus dimension in a psychophysical study might typically be work load (e.g. kpm/min. on ergometer tasks), weight lifted, and grade or walking speed on a treadmill. By these psychophysical methods, ratio units of perceptual values may be obtained based on the judgments associated with the sequence of comparative stimuli presented in relation to the standard stimuli used. The psychophysical relationship between perceptual values and values of the physical stimuli can frequently be described by equation 2 or 3 above. When this function is plotted on log-log coordinates, the exponent of the power function (m) defines the slope of a straight line, permitting direct comparisons between perception-stimulus relationships for different stimulus modalities. In general, a high exponent indicates that the perception of the stimulus changes rapidly with respect to changes in the physical stimulus; in contrast, a low exponent indicates that the perception changes relatively more slowly with respect to the physical dimension. For example, exponents of the power function for loudness have been found to be about .6 indicating that the perception of loudness grows slowly relative to changes in sound intensities. In contrast, the exponent for electric shock has been observed to be 3.5, indicating that perception changes rapidly with respect to shock intensity.

Table 14-I presents a summary of specific psychophysical studies relating to physical work, indicating the task and psychophysical method used, the subject population studied, the subjective quality measured, and the exponent of the power function obtained. In an initial study, Borg and Dahlstrom (1960) investigated perception of force exerted (pedal resistance) on a bicycle ergometer using four subjects. The ratio estimation technique

TABLE 14-I

PSYCHOPHYSICAL STUDIES DURING WORK PERFORMANCE

Subjective Quality	*Physical Modality*	*Task*	*Subjects*	*Exponent of Power Function*	*Studies*
Force exerted	Work load (kpm min)	Bicycle ergometer	Young males (n = 4)	1.6	See Borg (1962)
Force exerted	Work load (kpm min)	Bicycle ergometer	Young males (n = 12)	1.6	See Borg (1962)
Force exerted	Work load (kpm min)	Bicycle ergometer	Young male students (n = 12)	1.8	See Borg (1962)
Force exerted	Force of pressure (lbs)	A. Stationary foot pedal B. Hand grip	Young males and females (n = 12)	A. 1.65 B. 1.65	Eisler (1962)
Force exerted	Work load (kpm sec)	Arm and leg ergometer	Young males and females (n = 20)	1.4	Schmale, Schmidtke, and Vukovich (1963)
Force exerted	Work load (kpm sec)	Wrist-curling	Young males and females (n = 6)	1.9	Schmale, Schmidtke, and Vukovich (1963)
Force exerted	Weight (kp)	Weight-holding	Young males and females (n = 10)	3.1	Schmale, Schmidtke, and Vukovich (1963)
Force exerted	Weight (grams)	Lifting weights by manually pressing levers	Young males (n = 3)	1.8 to 2.5	Bernyer (1967)
Force exerted	Force of pressure (newtons)	Hand grip	Males (n = 18)	1.7	Stevens and Cain (1970); also see Stevens and Mack (1959) and Cain and Stevens (1971)
General feeling of fatigue	Duration of effort (secs)	Weight-holding	Males (n = 5)	1.5	Bujas, Pauling, Sremec, and Vidachek (1966)

was used with power levels measured in kpm/min. This study resulted in the power function with an exponent of 1.6 and having a high test-retest reliability (r = .95). In subsequent pilot work, Borg (1962) determined that length of the work period, varied systematically between 5 and 100 sec. affected the perception of force exerted: longer work periods resulted in higher perceived force exerted for the same task.

Subsequently, twelve male subjects were studied using the ratio production method. Five standard load levels, presented for five seconds, were used: 500, 700, 900, 1,000, and 1,300 kpm/min. On each trial, the subject was required to establish (i.e. produce) a load level equal to one half of the standard. The derived power function had an exponent identical to the earlier preliminary study. An estimate of test-retest reliability for this data was exceptionally high: r = .96. Perceived force exerted was also studied in a group of twenty-two male subjects using the ratio production method wherein one power level (800 kpm/min.) was halved 10 times by ascending (5 trials) or descending (5 trials) to the perceived mid-point. Calculations indicated that the resulting power function had an exponent between 1.39 and 1.73.

Using ratio estimation, as opposed to the production method described above, Borg (1962) derived the power function for perceived force exerted using twelve male subjects between 20 and 30 years of age. In this study, load-levels of 300, 600, 900, and 1,200 kpm/min. were presented in pairs, one immediately after another, for 20 seconds each. The task for the subject was to estimate the intensity of the lower load level of each pair as a percentage of the higher. Each trial was separated by a 30-second rest period. Six of the twelve pairs were in ascending order, and six in descending order; order of presentation was random. After completion of this experimental sequence, the same subjects were rerun with the pairs presented in ascending order, so that within each pair and across trials, higher stimulus intensities followed lower stimulus intensities. This latter condition was designed to correspond with the stimulus sequence often used in work tests. The obtained power functions had exponents of 1.8 and 1.2 for the random and ascending series, respectively. An ascending series thus appears to lead to a higher absolute threshold for force exerted (300 vs. 200 kpm/min.) and to a less rapid increase in perceived force exerted relative to load level. This effect upon the exponent of the power function has been labeled "hysteresis" (S. S. Stevens, 1957).

Borg's studies suggest that the exponent for perceived force exerted during cycling is 1.1 to 1.8, corresponding quite well to that obtained for other work modalities. For example, perceived force of handgrip was found to have an exponent of 1.7 (J. C. Stevens and Mack, 1959), perceived heaviness of lifted weights has been found to have an exponent of approximately 1.45

using both production and estimation techniques (S. S. Stevens and Galanter, 1957), and the perception of respiratory sensations—pressure, lung volume, and ventilatory volume—have been found to have exponents of 1.5, 1.3, and 1.9, respectively (Bakers and Tenney, 1970).

Eisler (1962) derived a ratio scaling of subjective force exerted for a mixed group of men and women using magnitude production and estimation techniques. The principal interest of this study was to evaluate the exponent of the power function for force exerted when large muscle groups were used. Additionally, Eisler inquired about the correspondence between the exponent for work involving large muscle groups, i.e. exerting a force in a horizontal direction against a foot pedal, and work involving small muscle groups, i.e. squeezing a handgrip. For the foot pedal task, the exponent of the power function for force exerted was found to be approximately 1.6, in excellent agreement with the findings of Borg (1962a) who had used the bicycle ergometer. To compare the exponents of the two work tasks, Eisler used two matching tasks: (a) the subject was required to squeeze a hand grip to match the force previously exerted against the foot pedal, and (b) vice versa. If the perception of force exerted changed with the physical force exerted in the same way for both hand grip and foot pedal tasks, the slope of a plot of force exerted for the hand grip vs. foot pedal matching tasks would equal unity. Results confirmed that, in fact, the slope of both lines (hand grip vs. foot pedal and foot pedal vs. hand grip) were unity. Thus, these results suggest that the perception of force exerted changes with the actual physical force exerted similarly for both large and small muscle groups, with power functions having exponents of approximately 1.6.

Schmale, Schmidtke, and Vukovich (1963) have summarized their own substantial psychophysical studies of work, reporting on a variety of tasks ranging from dynamic work (arm and leg bicycle ergometer tasks, and wrist curling) to static work (holding up a weight). For each of the dynamic work tasks, the production method was used to derive the power function. For the bicycle ergometer tasks, a linear relationship was found between "Anstrengung" (perceived exertion) for both leg and arm work. This linear relationship permitted derivation of a common power function for both arm and leg work relating "Anstrengung" to load level defined in percent of maximum load (P): Ψ = (P + 2.14)$^{1.4}$. The exponent agrees with that reported subsequently by Borg (1962) for dynamic work on the bicycle ergometer. For static work involving holding up weights suspended from the wrist, the power function relating "Anstrengung" to weight expressed as a percent of maximum weight that could be held (P) was: $\Psi = .000008\ (P + 42.1)^{3.1}$. A graph of this power function is presented in Figure 14-1. In summary, the exponent of the power function for dynamic

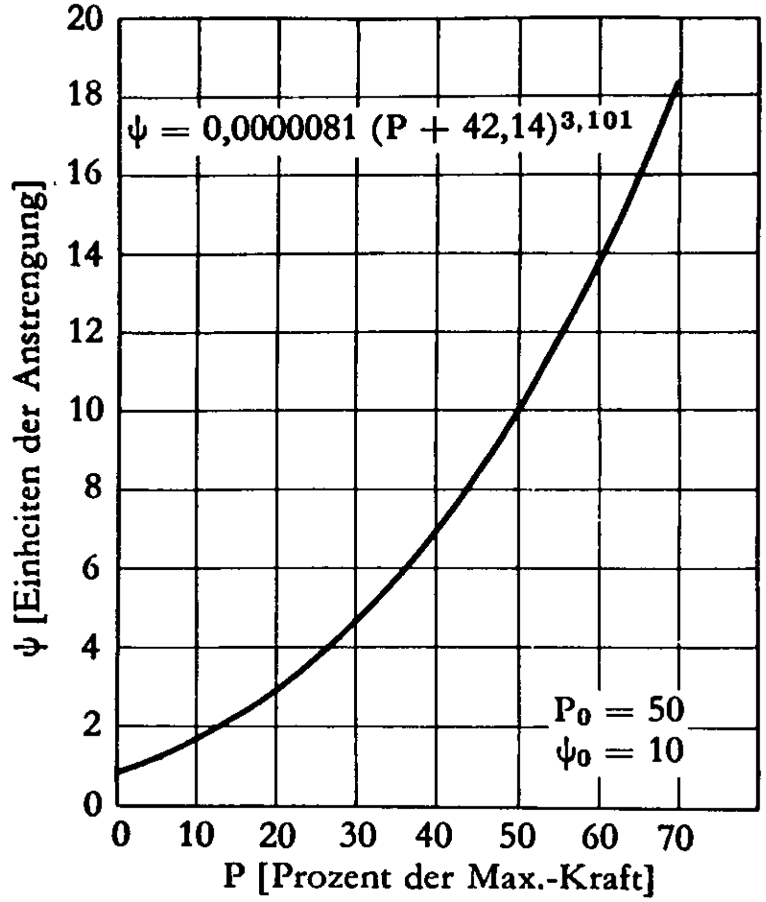

Figure 14-1. Power function relating "Anstrengung" (effort) to weight as a percentage of maximum strength. (From H. Schmale, H. Schmidtke, and A. Vukovich, "Untersuchungen über den Grad der subjektiv gegebenen Beanspruchung bei Körperlicher Arbeit, *Forschungsbericht des Landes Nordrhein-Westfalen*, Nr 1261, 1963).

work was between 1.4 to 1.9 whether the work involved arms, legs, or wrist curling. However, the exponent obtained for static work, 3.1, was considerably higher.

Bernyer (1967) has demonstrated that production methods (e.g. the method of bisections) may result in different mathematical functions for perceived heaviness of lifted weights depending on whether the test series presented was in ascending or descending order. For ascending order, a power function with exponents ranging from 1.8 to 2.5 describes the positively accelerated perception-stimulus relationship adequately; for a descending series, a negatively accelerated function is produced, apparently described more adequately by a Fechnerian log function, shown in equation 1 above. The actual relationship derived by psychophysical techniques has been shown to be substantially influenced by task requirements. Among the factors affecting the obtained psychophysical relationships are, as previously noted, the direction of the series presented (e.g. ascending or descending) and time-order errors related to order of presentation of the stimuli in a series (S. S. Stevens, 1957).

Hosman (1967) studied the time-course for the "feeling of exhaustion" in 5 subjects during three prolonged static work tasks. Using cross-modality matching against white noise, 9 of the 15 total responses showed a linear growth function. In 2 trials the increase was negatively accelerated, while in only 4 trials did the time-course show a positive acceleration. However, since the subjective response was reported as an average of 10 sessions at each task, the linear response might partially represent a timing bias that could have developed after several sessions (see p. 370). More detailed and sophisticated psychophysical analysis of the time course for fatigue during prolonged static work has been reported by J. C. Stevens and Cain.

J. C. Stevens and Cain (1970) explored the more complex interaction that the effects of force and duration have upon perceived force of handgrip using 18 male subjects. In an initial study, magnitude estimation was used to obtain a ratio scaling of perceived force relative to handgrip squeezes at forces between 22 and 220 newtons (5 to 50 lbs) for durations of 4 to 60 secs. Power functions were derived separately for force and duration. For force, the exponent was 1.4. However, they noted that because of the tendency for subjects to attenuate the range of numbers used in magnitude estimation (i.e., regression bias: see S. S. Stevens and Greenbaum, 1966), the value of the exponent was depressed and actually closer to 1.7. The latter is also the exponent found experimentally in the earlier study by J. C. Stevens and Mack (1959). Perceived effort also increased with duration, having an exponent of 0.57 (i.e., 0.70 when adjusted for regression bias). One equation could then describe the combination of force and duration which "produces the same terminal perceived force, Ψ_e: $\Psi_e = K\Phi^{1.7}t^{.7}$ where Φ represents force in newtons, t is time in seconds, and K is the constant level of perceived force at the limit of endurance. Rearrangement of this equation yields a simplified, one-exponent equation: $\Psi_e = K\Phi^{2.43}t$ which is independent of regression bias, being obtainable from either the biased or unbiased independent estimates for force and duration. Based on these

findings, they suggested that subjects instructed to maintain a constant perceived effort would demonstrate diminishing force exerted over time, a result obtained earlier by Eason (1959).

In a subsequent study, Cain and J. C. Stevens (1971) explored these implications using a unique constant effort task. First, for a group of 12 male subjects, the earlier magnitude estimation study was replicated for phasic squeezes at seven forces between 88 and 429 newtons (19.8 to 96.4 lbs). The obtained power function had an exponent within the expected range. Next, for each of the forces, the subjects were asked to maintain their *effort* on the handgrip task *constant* for 2.5 min. Results indicated that actual force exerted typically dropped off rapidly for the first 20 secs, with a much slower decline in force thereafter. A single exception to this generality was for the lowest force squeeze, 88 newtons (19.8 lbs) for which a consistent, slow decline was observed throughout the 2.5 min duration. A two-exponent equation could describe the initially rapid, then slower decline in force across time. On the basis of these results, it was predicted that "two different constant-effort contractions may arouse the same degree of fatigue when the areas under their respective force versus duration curves are equal." A subsequent study impressively supported this prediction.

Since two components were involved in the force-duration curves of Cain and J. C. Stevens (1971) for the constant-effort contractions, a fast then slow decline, it was suggested that two separate physiological processes may be involved in the perception of effort: "(the fast) one—representing activity of mechanoreceptors in the tendons or the skin, and the (slow) term the activity of receptors sensitive to noxious metabolites produced by muscular activity." At least one alternative explanation may be proposed: the fast decline in force may have been due to derecruitment of glycolytic, fast twitch fibers in favor of less rapidly fatiguing oxidative, slow twitch fibers.

Their subsequent studies of surface electromyography (Cain and J. C. Stevens, 1973) indicated the EMG activity in the forearm initially did decrease rapidly similar to force in constant-effort handgrip tasks but tended to asymptote at a point where force was still declining. Their two-process model could also be explained by the alternative explanation noted above. In summary, in a series of elegant psychophysical studies on constant-effort tasks, J. C. Stevens and Cain attempted to relate perceived effort to physiological processes and acknowledged that perceived effort is founded on more than a single underlying physiological process.

In the psychophysical studies described above, perception of force exerted or "Anstrengung" (exertion) was related to stimulus intensity for fixed, brief work periods. Bujas, Paulina, Sremec, Vidacek, and Vodanovic (1966) noted that the research of J. C. Stevens and Mack (1959) and Borg (1962), and presumably Schmale, et al. (1963) and Bernyer (1967), do not present psychophysical power functions relating the perception of "fatigue" to *duration* of effort. They pointed out that brief effort or momentary exertion, used in the above studies, may not lead to "fatigue" although the effort expended may be relatively high. Bujas, et al. present information about the psychophysical relationship for the feeling of fatigue *per se* during periods differing in the duration of static work. Using well-trained subjects a steady tension was exerted by holding a 7.17 kg weight with the arm upright and the elbow supported. Durations of 30, 60, 90, 120, 150, and 180 sec. were used and the psychophysical function relating the perception of fatigue to duration of effort was derived using the magnitude estimation method. Fatigue ratings were obtained 30 and 60 sec. after termination of each trial. The subjects were told to include feelings of "tightness, numbness, increase in muscle sensitivity through pain, weight" and so on in their judgments of "fatigue." The obtained power function for the overall group was $\Psi = .0048\ (\Phi - 30'')^{1.54}$ for the mid-range of the curve relating perception of fatigue to task duration. In a subsequent experiment, the identical procedure was repeated while integrated EMG amplitude from four muscle groups of the arm was recorded. A power function for the mid-range of the curve relating integrated EMG levels to task duration was almost identical to the psychophysical function: $\Sigma EMG = .0051\ (\Phi - 30'')^{1.51}$ indicating impressively high correspondence between the growth of fatigue in static work and EMG activity. It is also of interest that the exponent of the power function for both fatigue and EMG activity in this study falls within the range of exponents observed for force exerted in the studies described above.

These psychophysical studies provide important information about the relationships between perception of effort and load levels during various types of work performance. In general, for positive (i.e. concentric) work, the exponents of the power functions for force exerted and fatigue in a variety of situations fall within a limited range (1.4 to 1.9), indicating that the perceptions increase at a moderate rate relative to changes in the physical work stimulus. An interesting contrast existed for the exponent (3.1) of the weight-holding task of Schmale, et al. (1963) which may be related to the negative (eccentric) nature of the task. However, psychophysical techniques are currently limited in regard to application for the evaluation of subjective fatigue on a longitudinal basis. With the exception of Bujas, et al. (1966), most of these studies relate a subjective quality (e.g. perception of intensity) to the actual intensity of an *external* physical stimulus. Subjective fatigue can be conceived as arising from a different source: specifically, the cues defining subjective fatigue may derive from the *internal* physiological processes activated by work. There is thus no easy way to identify *intensity* of the "physical" stimulus when in fact

precise *origins* of these physiological cues are not well understood. Presently, there is no clear way to derive the power function describing such relationships. Furthermore, none of the available psychophysical techniques are readily applicable to measurement of subjective qualities during work performance on an ongoing basis. Future applications of psychophysical methods may prove to overcome these difficulties, but changes in methodology will be required.

Alternative scaling techniques discussed in the following sections have been applied more frequently to the measurement of subjective qualities or symptoms during work primarily because of their applicability to prolonged work situations. These techniques may be roughly grouped into (1) nondimensional, single point measures, (2) unidimensional rating scale techniques, and (3) multidimensional rating scale techniques.

Nondimensional, Single Point Measures

In Table 11-II, studies using nondimensional, single point measurement of subjective qualities in work are shown. These studies have employed the simplest methods of measurement which generally require a single verbal report during work performance. Most often an attempt is made to identify factors displacing the "fatigue" point toward or away from the initiation of work. Inspection of the table reveals little consistency between the studies in regard to the subjective qualities measured (tiredness and undifferentiated fatigue), tasks used, or subject populations selected. It is worth noting that just such inconsistency has hampered the development of a meaningful overview of research concerning subjective fatigue.

In a study by McGrath, Wittkower, and Cleghorn (1954), the undifferentiated (i.e. global) feeling of fatigue was regarded as an all-or-none event, characteristic of single point measurement. Specifically, ratings of various factors which were regarded as "causing fatigue" during long distance flights were obtained from aircraft crews. The crews studied consisted of Canadian pilots, co-pilots, navigators, and radio officers who flew DC 6's in the Tokyo Airlift. The three legs of the flight were 10 to 18 hours each separated by 48-hour layovers. Group discussions and individual interviews were used to identify factors which the crewmen believed to cause fatigue. The specific factors chosen for inclusion in a questionnaire were identified during these preliminary group discussions and interviews. Each of the thirty-four factors were arranged on a 4-point ordinal scale to permit rating from "no importance" (1) in causing fatigue to "great importance" (4). However, the quantitative data available from the questionnaire was not summarized in the report. Conclusions were based principally on the nonquantitative information derived from the interviews and group discussions.

TABLE 14-II
NONDIMENSIONAL MEASUREMENT OF SUBJECTIVE FATIGUE

Subjective Quality Measured	*Task*	*Subjects*	*Studies*
"Undifferentiated fatigue"	Airplane flights	Male aircraft crews (n = 100)	McGrath, Wittkower, and Cleghorn (1954)
"Undifferentiated fatigue"	Reaction time task	Male medical students (n = 26) Female P.E. students (n = 15)	Pierson (1963), Pierson and Lockhart (1964)
Tiredness	Manual and office work	Male manual and office workers (n = 379)	Griffith, Kerr, Mayo, and Topal (1950)
Tiredness	Isometric weight lifting	Female psychiatric patients (n = 42)	Hemphill, Hall, and Crookes (1952)

Members of the crews tended to report boredom, but only minimal fatigue, during the first six hours of a flight. From six to 10 hours, the crewmen reported becoming tired, sleepy, and irritable. Causes of fatigue were grouped into three categories: (1) *General Factors*, such as length of flight, delayed flights and false starts, details prior to takeoff, reliability of radio communications and navigational aids, bad weather, monotony and boredom of familiar routes, number of intermediate stops, and drinking the night before the flight; (2) *Specific Factors*, associated with problems peculiar to the DC 6 aircraft (including noise and vibration, design of the flight deck and instrument panels, and uncomfortably fitting oxygen masks), and problems peculiar to the route (including post-flight conditions, recreational facilities at stopover points, and irregular hours); and (3) *Personal Factors*, such as inexperience and tension within the crew, relative burden of responsibility, relationships with higher authorities, and domestic worries.

In this study, no information was obtained to quantify fatigue or performance during the course of flights. The authors were well aware of this basic limitation in their study. They note that the "method used in this investigation might be criticized on the grounds that information gathered was of a purely subjective nature and was given in retrospect." Continuing to discuss these limitations, they clearly indicate the two ingredients minimally necessary to conduct research evaluating the role of subjective fatigue longitudinally during work performance: (1) An adequate *measure of subjective fatigue* for which "no satisfactory objective tests [had] as yet been designed" and (2) *Performance measures* to evaluate "the subject's performance under normal operating [or working] conditions."

Pierson (1963a) attempted to relate the occurrence of "fatigue" in twenty-six male medical students to performance on a reaction time task using an apparatus described by Pierson and Rasch (1959). On each trial, an auditory preparatory signal was given approximately one second before presentation of a light stimulus which cued the response. Each subject was required to release a telegraph key and move their hand 11 in. forward through a light beam when the light stimulus appeared. Reaction time (RT) was measured as the latency between presentation of the light and the release of the key, while movement time (MT) was measured from the release of the key to the breaking of the light beam. Trials were presented at intervals of approximately 10 seconds with the task continuing until the subject indicated that he could no longer proceed. During the task, the subject was required to indicate when he "believed his responses were becoming slower." The trial on which this report was given was defined as the "fatigue" point. Subjects were also asked to indicate the point at which they became bored with the task.

A significant relationship (r = .47) was found between RT latency and the trial on which the "fatigue" report was given. This relationship means that slower RT's tended to be associated with later fatigue points, while early fatigue points were more often concomitant with faster RT's. More importantly, no differences in RT or MT were found between five baseline trials, selected near the beginning of the task, five trials following the fatigue point, and the last five trials preceding voluntary termination. Furthermore, no relationship (r = .02) was found between the "fatigue" trial and total trials performed before voluntary termination. Pierson (1963b) reported that measures of unspecified isometric strength for these same subjects were found to be unrelated either to RT and MT decrement or the trial defined as the fatigue point. He concluded that "subjective impressions of performance bear little relationship to actual performance" and that the "subjective experience of fatigue is not a valid criterion for the ability to perform speed or endurance type muscular work."

In regard to Pierson's conclusions, it should be noted first that a study subsequently reported by Pierson and Rich (1967) found a steady O_2 consumption during this task. Performance of the task required only slightly greater O_2 uptake than baseline measures obtained while the subjects were sitting quietly (330 ml/min. vs. 280 ml/min.). Therefore, generalization of these results to "speed or endurance type muscular work" appears unjustified. At best, the results may be generalized to sedentary type tasks. Additionally, RT and MT performance decrement was measured as the slowest block of five trials within a sequence averaging 174 trials for the group of subjects. In tasks of this kind, random variations in performance across trials would be expected due to momentary fluctuations in motivation, concentration, and so on. As the measure of performance decrement, selection of the slowest block of five trials may therefore reflect nothing more than random changes in performance. In fact, since there was no systematic trend toward deteriorating performance across trials, as the data indicates, it is hardly conceivable that "the subjective experience of fatigue" would be related to RT or MT decrements in this study. In a word, Pierson's conclusions seem unfounded.

A subsequent study (Pierson and Lockhart, 1964) did qualify the earlier conclusions of Pierson (1963a). Using fifteen female physical education majors with a mean age of 19.6 years, an attempt to replicate the earlier study was made. This time, the principal finding was a *significant* relationship (r = .59) between the trial on which "fatigue" was reported and the total number of trials performed. The "fatigue" point for male medical students had been found to be clearly unrelated to endurance (r = .02). One might suggest that these conflicting findings may be explained by differences in motivation and cooperation with task requirements. For example, those

medical students who reported "boredom" (7 of 26) did so at a mean trial of 70.4 while those female subjects reporting boredom (4 of 15) did not do so until trial 102.4 even though females quit earlier (an average of 171 total trials for the males vs. 151 for the females). The male subjects evidently quit performing for reasons unrelated to "fatigue," while the female subjects seemed to be more highly motivated, quitting for reasons more related to "fatigue." All other findings in this study were generally consistent with Pierson (1963a). Obviously, there are problems related to replicability as the contrasting principal findings between the studies indicate, and specifically require qualification of the earlier conclusions concerning the relationship between subjective report of fatigue and performance factors.

A study by Griffith, Kerr, Mayo, and Topal (1950) is another example of a single point measurement technique. They employed a simple "tear ballot" used previously by Kerr (1943) to determine the hour during each half of an eight-hour shift when manual workers, foremen, and office workers reported feeling "most rested" or "most tired." To indicate the hour of each half-shift, the subjects simply tore the appropriate corner off the ballot. Data for the study were reduced to percentages reporting "most tired" and "most rested" during each four-hour period. Findings were remarkably uniform for all types of work and are schematized in Figure 14-2. There was a tendency for workers to report feeling "most tired" during the first and fourth hour of the morning and the last hour of the afternoon. Manual workers more than 36 years old reported feeling "most tired" more often during the last hour of the morning and afternoon periods than did younger manual workers. Information about the consistency of this technique is sketchy, although it is reported that "repeat-test reliability coefficients for small groups ranged from .69 to .92." No information was available concerning validity of the self-report since no other measures of work performance were obtained. Information provided by this study is limited, since only a single point of "most tired" was reported, it was impossible to evaluate relative *levels* of fatigue on an hourly basis across the work shifts. By focusing on *percentages* of workers reporting "most tired," an erroneous conclusion was also drawn, i.e. "Older workers report significantly greater variation of such feelings ('most tired' and 'most rested') than do employees under the age of 36." This conclusion may be correct for workers as a whole, but since the relative *degree* of tiredness was not measured, no conclusion can be made concerning the variability in tiredness reported by workers in different age groups.

Hemphill, Hall, and Crookes (1952) also used a single point measurement technique within a simple weight holding task. Using the middle finger of the right hand, female psychiatric patients classified as endoge-

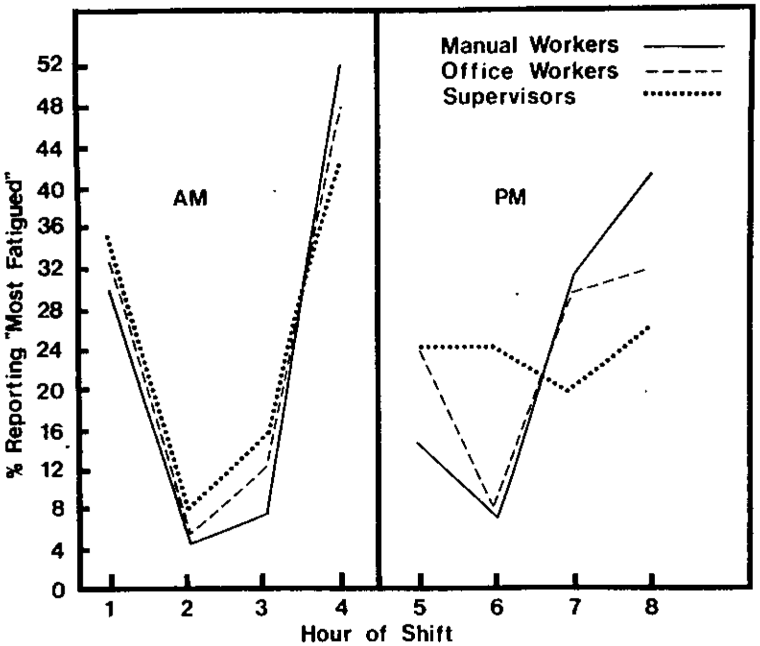

Figure 14-2. Percentage of workers reporting feeling "most fatigued" during the morning (AM) and afternoon (PM) halves of an eight-hour shift (From J. W. Griffith, et al. "Changes in Subjective Fatigue and Readiness for Work During the Eight-Hour Shift." *Journal of Applied Psychology, 34*:163, 1950).

nous depressives and anxiety neurotics were instructed to lift a small weight (2 kg) for as long as possible. They were asked to report when they "began to feel tired." The results indicated that the "endogenous depressive" patients reported feeling tired more rapidly and quit sooner after reporting tiredness than patients classified as anxiety neurotics. The results suggest that endogenous depressive patients, who are characteristically "fatigued" and with minimal energy reserves, became tired more readily during static work. Anxiety neurotics, on the other hand, are frequently characterized by an agitated, aroused kind of depression which may actually serve to reduce the degree of tiredness during activity or static work.

Single point, nondimensional measures of fatigue are open to criticism. "Fatigue" is conceptualized in these studies as an all-or-none event: either the individual is experiencing a certain "degree" of fatigue, or he is not.

It is hard to defend such a notion, either conceptually or psychometrically. First, experience suggests that, in general, one can report a variety of intensities of subjective qualities—one has, at different times, felt fresh, somewhat tired or extremely worn out. It would seem more logical that the symptoms would increase quantitatively, in some fashion, the longer one performs work. Measurement should be designed to quantify at least ordinal levels of the subjective experience.

Second, from the standpoint of measurement, good psychometrics also suggests that some arrangement be made to measure quantitative *levels* of fatigue. Without this possibility, the relationship between subjective fatigue and work decrement or endurance cannot be clearly specified. It takes at least three points to define a function, and theoretically a subjective event varying in intensity such as subjective fatigue, can be measured on more than three points. Additionally, reliability is known to increase, up to some limit, as the range of scores increases. Single point measures can thus be expected to be less reliable than multi-point, or dimensional, measures of subjective fatigue.

Unidimensional Rating Scales

Studies using unidimensional rating scales to evaluate subjective qualities during work are summarized in Table 14-III. An example of an early study attempting to dimensionally quantify a single subjective quality, i.e. "feeling tone," is provided by Foltz, Jung, and Cisler (1944). They had seven male subjects ride a bicycle ergometer at 1235 kpm/min. while pedalling at 54 rpm's until unable to maintain the required level of performance. This work of about 2.8 L. min. Vo_2 would be approximately 85 percent max Vo_2 of nearly 3.3 L. min. for an "average" young male. All subjects rode twice daily with the rides separated by a 10-minute rest period until a total of 378 rides were obtained over 27 days. Ratings of "feeling tone" were obtained *before* each ride using a 15-point rating scale ranging from "the worse I have ever felt in my life" (1) to "the best I have ever felt in my life" (15) while the midpoint (8) required the response "the way I usually feel." Ride duration was the measure of performance and ranged from 2 to 22 min. The study was designed to test the hypothesis that work performance is influenced by how an individual feels before beginning work. Results indicated that the relationship between ride duration and prework "feeling tone" was negligible and, in fact, slightly opposite from predicted. The authors suggested that work performance was unrelated to prework subjective feeling states.

The approach used by Foltz, et al. represents one of the early systematic efforts to relate a subjective quality (prework "feeling tone") to performance in a laboratory work situation. However, this study again exemplifies

TABLE 11-III

RATING SCALES IN THE MEASUREMENT OF SUBJECTIVE FATIGUE

Subjective Quality Measured	Scale Point Range	Task	Subjects	Studies
"Feeling tone"	15	Bicycle ergometer	Healthy males	Foltz, Jung, and Cisler (1944)
"Undifferentiated fatigue"	4	Housework	Healthy females: housewives	Gross and Bartley (1951)
"Undifferentiated fatigue"	9	Bicycle ergometer: normal conditions	Healthy males	Nunney (1963)
Tiredness	5	Mental work. Verbal and qualitative	Healthy males	Poffenberger (1928)
Tiredness	20	Psychomotor tasks: drug states	Healthy males: US Air Force enlisted men	Pearson and Byars (1956); Pearson (1957)
Tiredness	20	Prolonged aircraft flights	Healthy males: aircraft crews	Buckley and Hartman (1969); Hartman, et al. (1974a, b)
Tiredness	9	Psychomotor task	Males and females: college students	McNelly (1957)
Tiredness	5	Factory workers	Healthy males: butchers	Bujas, Sremeg, and Vidachek (1965)
Tiredness	10	Portages	Healthy males	Strauss and Carlock (1966)
Tiredness	7	Bicycle ergometer	Healthy males	Heuting and Sarphati (1966)
Tiredness	13.5	Psychomotor task: visual threshold	Healthy males: college students	Walster and Aronson (1967)
Perceived effort	15	Bicycle ergometer: normal conditions	Healthy males	Borg (1961a); Borg (1962); Borg and Linderholm (1967); Frankenhauser, Post, Nordhader, and Sjolberg (1969); Kay, and Shephard (1969); Bar-Or, et al. (1972); Skinner, et al. (1969; 1973b); Morgan (1973)
Perceived effort	15	Bicycle ergometer: normal conditions	Male cardiac patients	Borg, and Linderholm (1970)
Perceived effort	15	Bicycle ergometer: hypoxic conditions	Healthy males	Gerben, House, and Winsman (1972) Weiser, et al. (unpublished observation)
Perceived effort	15	Bicycle ergometer: dynamic weight lifting: wheelbarrow pushing	Healthy males	Gamberale (1972)
Perceived effort	15	Bicycle ergometer: concentric and eccentric work	Healthy males and females	Henrikson, Knuttgen, and Bonde-Petersen (1972)
Perceived effort	15	Treadmill walking and running	Healthy males	Noble, et al. (1973)
Perceived effort expended	5	Treadmill walking	Healthy males	Lloyd and McClaskey (1971)
Perceived effort expended	5 and 10	Isometric contraction: hand dynamometer	Healthy males	Caldwell and Smith (1967); Caldwell (1967)
Pain intensity	5	Isometric contraction: hand dynamometer and arm pull	Healthy males	Caldwell and Smith (1966); Caldwell (1967); Menzer, Smith, and Caldwell (1969); Lloyd, Voor, and Thieman (1970); Lloyd (1971); Lloyd (1972)
Discomfort	4	Bicycle ergometer	Healthy males	Gagge, Stolwijk, and Saltin (1969)
Thermal sensation	7			

the caution required in design and interpretation of research in this area. First, no attempt was made to equate work levels for the individual subjects. While information was not presented regarding individual differences in such factors as max V_{O_2} or heart rate response to specific work levels, almost surely there were differences in working capacity between the individual subjects. These individual differences in working capacity, while not well known at that time (Simonson and Enzer, 1942), would greatly influence ride duration. Failure to equate work levels during exercise, however, would lead to a substantial attenuation of the relationship between "feeling tone" before work and subsequent work performance.

Second, it would appear that performance data for all 378 rides and subjective ratings for the seven subjects were grouped across subjects to obtain the correlation between ride duration and prework "feeling tone." Grouping data in this way violates an assumption of independence of the pairs of observations for correlational analysis and could further attenuate any potential relationship in the data. Therefore, on the basis of this study, little can be concluded regarding the relationship between pre-work "feeling tone" and subsequent work output due to these inherent design and methodological problems. In addition, since subjective symptomatology *during* work, or produced by work, was not measured, the implications for the area of subjective fatigue are limited. However, studies of this sort could lead the unsuspecting reviewer to conclude that "research has indicated" that subjective symptoms are unrelated to work performance.

In contrast to Foltz, et al., the remaining studies described in this section measure subjective qualities *during* work performance. These have focused upon five types of subjective qualities during work: undifferentiated fatigue, tiredness, effort, pain, and thermal discomfort.

Undifferentiated Fatigue

A study by Gross and Bartley (1951) provides an example of the use of a simple rating scale to measure undifferentiated fatigue. A four-point rating scale (Great, Moderate, Little, None) was employed. A group of twenty women rated their level of fatigue at 30 minute intervals at the beginning and throughout a two-hour period of housework. Records were maintained concerning the quality and quantity of work performed. Those reporting the most fatigue cleaned fewer rooms than those moderately fatigued, but more than those reporting little or no fatigue. The women reporting the most fatigue also received the lowest ratings for quality of housework performed. Additionally, it was found that the rating of fatigue for some women tended to peak at the middle of the work period even though there was no intervening rest. The latter observation was regarded as support for the notion that subjective fatigue is not consistently

related to the amount of energy expended. Examination of the individual protocols suggests that some subjects may have been timing the work period, reporting less fatigue as the end of the period neared. In contrast, most reported increased fatigue toward the end of the work period. This is an occasional observation when work periods are of a fixed duration, and appears related to expectations about the length of a dull, nonrewarding task. Walster and Aronson (1967; see p. 365) found an increase in fatigue reports toward completion of a monotonous task of fixed duration. Additionally, Gross and Bartley noted that there was a "lack of distinction in the minds of the subjects between localized muscle discomfort from stooping, etc., and the overall personal experimental (sic) state we identify as fatigue." Recently, a task specific category of subjective qualities experienced during work, including those related to localized muscle discomfort, have been identified statistically within a larger set of fatigue symptoms (Weiser, Kinsman and Stamper, 1973).

Nunney (1963) used a nine-point rating scale to evaluate subjective fatigue in eighty male college students. The testing program encompassed six test sessions of five min. given on alternate days. The subjects were divided into five groups: A control group; two groups who bicycled on an ergometer, either with no load or a seven-lb load; and two groups who ran on a treadmill at 6 mph, either on a 0 percent or on a 25 percent grade. The rating scale ranged from No Fatigue (1) to Extreme Fatigue (9) and was given 15 sec. after cessation of work. Pulse rate was measured before, at the end of the work task, and after 10 min. of recovery. If the mean testing pulse rate was 80 bpm (the actual value was not reported), then the mean pulse rate was 91 and 137 bpm for the 0 and seven-lb bicycle work tasks and 141 and 181 bpm for the 0 percent and 25 percent treadmill work. This indicates that the work loads were progressively heavier, with the two middle tasks nearly the same and the heaviest nearly 100 percent max V_{O_2}. We note that Nunney, similar to Foltz, et al. (1941) did not control for individual differences in the ability to do aerobic work as measured by max V_{O_2}. The fatigue scale scores at the end of work were 1, 4, 4, and 6 for the respective work loads. The *group means* for pulse rate changes and fatigue scale scores correlated highly ($r = .99$), suggesting that for tasks demanding a larger circulatory adaptation there is a corresponding increase in subjective fatigue. Intratask variability was large for fatigue scale scores, but these scores were not significantly correlated to pulse rate changes. Considering the relationships between pulse rate and subjective fatigue ratings for a single work load on a task, the correlations were low (r's ranging from −.03 to +.37). These low correlations would be expected when the range of work loads relative to max V_{O_2} within tasks are attenuated relative to the range represented across all tasks and work loads. While

Nunney concludes "that physiological changes are not directly related to fatigue," his data actually support a direct relationship between fatigue measures and work as indicated by heart rate changes when there is a sufficiently high range in work loads.

Tiredness

As early as 1928, Poffenberger reported the use of a simple rating scale to evaluate the feeling of tiredness during prolonged *mental* work. Ten subjects performed up to fourteen consecutive trials on each of four tasks: continuous addition, sentence completion, judging of written compositions and various independent forms of a rather lengthy intelligence test. In the case of the composition judging, 10 specimen compositions were rated on each trial. For the other tasks, each trial required 20 to 30 minutes of continuous performance. Performance was measured on each trial, and ratings of tiredness were obtained using a seven-point *ordinal* scale, given immediately before the first trial and after each trial of a task. The rating scale ranged from "extremely good" (1) to "extremely tired" (7) with a midpoint defined as "medium" (4). Results indicated that the mean rating of tiredness increased across trials in a fairly linear manner for all tasks, although overall performance remained (1) unchanged—for sentence completion or composition judging, (2) improved—for intelligence testing, or (3) deteriorated—for addition. Due to improvement in the tasks resulting from practice, the relationship between mental work and the feeling of tiredness may have been masked for all of the tasks except addition. Presumably, addition is a highly learned task, the performance of which would not be expected to improve with additional practice. Thus, the relationship between the subjective quality "tiredness" and performance would be most clearly manifest for the addition task. Subjects showing the greatest performance decrement for each task reported a large increase in tiredness; those showing the least performance decrement reported substantially less tiredness across trials. Poffenberger's results thus indicate a fairly clear relationship between "tiredness" and performance in prolonged mental work.

Pearson and Byars (1956) and Pearson (1957) reported the development of a 10-item unidimensional scale measuring the subjective quality of tiredness. Their *interval* scale represents the most thorough effort to devise a measure of subjective fatigue as a unidimensional feeling of tiredness. Procedures for scale construction recommended by Edwards and Kilpatrick (1948) were followed. The problem was to select a set of adjectives that could be arranged in a continuum, with *equidistant* adjacent items, so that the subject could report his level of tiredness by pinpointing a position along this continuum. An initial set of 500 adjectives were selected. All ambiguous items were eliminated, and the remaining ninety-two items were scaled using Thurstone's method of equal appearing intervals (see Guilford, 1954). Briefly, independent judges sorted each item into nine categories ranging from extreme well being (1) to extreme fatigue (9). All forty-eight items showing low interjudge agreement were eliminated. The forty-four remaining items were arranged in a checklist and provided with choices of "better than," "same as," or "worse than" allowing an individual to place himself on a continuum of subjective tiredness. A developmental study involving a lengthy psychomotor task (Multidimensional Pursuit Test; Hauty and Payne, 1956) was used to further eliminate those items with low validity and internal consistency. Finally, two equivalent forms (A and B) of the checklist were constructed. The item composition of one form (Form A) of the checklist is shown below:

Item	*Order No.*
1. Like I'm bursting with energy	(2)
2. Extremely peppy	(6)
3. Very lively	(12)
4. Very refreshed	(9)
5. Quite fresh	(4)
6. Somewhat fresh	(7)
7. Slightly tired	(1)
8. Slightly pooped	(5)
9. Fairly well pooped	(11)
10. Petered out	(8)
11. Very tired	(13)
12. Extremely tired	(3)
13. Ready to drop	(10)

In application, the items were arranged in a random order as indicated in the right-hand column. The colloquial content of the checklist ("petered out," "ready to drop," "fairly well pooped") is apparent.

A validation study using the same psychomotor task showed that equivalent forms of the checklist intercorrelated highly ($r = .92$) both for 100 experimentally fatigued and for 100 control subjects. The scores for experimentally fatigued subjects were significantly increased from pre- to post-task. Additionally, the checklist clearly differentiated between experimentally fatigued and control subjects. Subsequently, the checklist was shown to differentiate between subjects given analeptic (5 mg of dextro-amphetamine sulfate) and depressant (.65 mg hyoscine hydrobromide mixed with 50 mg of diphenhydramine hydrochloride) drugs in a single-blind study. As a unidimensional measure of tiredness, Pearson's interval scale is unsurpassed since it was constructed systematically according to sound psychometric principles.

Unfortunately, application of the checklist beyond the original validating studies has been limited although the authors suggest that its applicability should be general. Its widest application has been to evaluate changes in fatigue during aeromedical studies by Hartman and his coworkers. In a study by Buckley and Hartman (1969), Pearson's checklist was used to evaluate changes in subjective tiredness during a 32-hour transatlantic helicopter flight. The flight was accompanied by loss of usual sleeping patterns, decreased food intake, continuous vibration, and flicker illumination common to rotary wing aircraft. Ratings on tiredness showed an almost linear increase throughout the flight, with an interesting recovery spurt during fly-by in a Paris airshow even though no rest periods intervened. During this fly-by, which occurred at the end of the flight, tiredness ratings decreased to a point reported 14 to 16 hours earlier. Such a recovery phenomenon may occur in tasks of fixed duration in which there is high expectation of personal reward upon successful completion. Such a phenomenon may be related to the Hullian goal-gradient (Hull, 1943; 1952). Similar application of this scale have been made to the study of the in-flight fatigue of FB-111 crews (Hartman, Hale and Johnson, 1974) and C5 jet transport crews (Hartman, Hale, Harris, and Stanford, 1974).

McNelly (1954) also used Thurstone scaling techniques to develop a 9-point rating scale of tiredness. Again, an attempt was made to construct an *interval* scale with adjacent scale points of equidistance. One form of McNelly's scale is shown below:

Item	*Mean Scale Point*
About to fall over	1.1
Fagged	2.2
Let down	3.2
A little tired	3.8
Average	5.0
Fairly well	5.9
In gear	7.0
Very good	7.9
Terrific	8.9

Preliminary Thurstone scaling was performed on 123 adjective items or phrases by 10 judges. The judges sorted each item into categories according to increasing degree of tiredness, establishing a preliminary mean scale point value for each item. Sixty (60) adjective items or phrases with the least variability were retained, and rescaled by the same judges. The second scaling had a high correlation (r = .95) with the first scaling. Of these 60 items, two groups of nine items each were selected on the basis of (1) having low variability and (2) being approximately one scale point apart. The mean scale values for one set of nine items are shown above.

The validity of the scale was tested on eighty male and female undergraduates using a block turning task with heavy (11 ounces) or light (.4 ounces) blocks either with massed practice (without rest) or spaced practice (rest after each trial). Each trial consisted of turning twenty blocks as rapidly as possible. The interval scale was administered before and after

1,000 trials. As expected, spaced practice produced both less work decrement and lower "tiredness" scores than did massed practice. Ratings of tiredness showed a significant change pre- to post-work, although the relationship between the subjective ratings and work decrement was quite low (r = .30). While McNelly's scale has frequently been cited, to the best of our knowledge it has not been used in any other studies reported in the literature. Its validity in other work situations is essentially unknown. Similar to the Pearson and Byars' scale (1956; Pearson, 1957) the composition of McNelly's scale includes colloquial items (e.g. fagged, in gear, etc.) which appear to be unique in regard to culture, time, and geographic location.

Bujas, Sremeg, and Vidachek (1965) comprehensively investigated the relationships between the subjective quality of tiredness and other variables in 115 butchers from the same factory after an eight-hour work shift. A five-point scale was used to obtain ratings of tiredness. The scale ranged from "Generally I am not tired" (1) to "I feel very tired" (5). Only 4.4 percent of the workers reported that they were generally *not* tired after work, while 26.5, 49.6, 12.4, and 7.1 percent reported feeling "slightly," "moderately," "quite," or "very" tired, respectively. Ratings of tiredness were independent of estimates of the workers productivity made by the foremen and plant supervisors. However, the authors note that productivity ratings tended to be uniformly high for all workers so that no discrimination in productivity was achieved by the supervisors' ratings. It is interesting to note that the tired workers reported having less satisfaction with their work, sleeping less well at night, less appetite, generally feeling less healthy, and more often being in a worse mood at and away from work than their less tired co-workers. This study is similar in many ways to that of McGrath, et al. (1954) in that the emphasis was upon identification of factors *contributing* to the subjective feelings of tiredness or fatigue that occur during occupational activities.

Strauss and Carlock (1966) measured subjective tiredness during portages with various loads using an 11-point rating scale developed by Psychometric Affiliates (1954). This rating scale ranged from "worn out, too tired to do anything" (1) to "not tired at all, fresh enough to start a full day" (11). Ten male subjects ranging in age from 18 to 35 years carried weights of 10 to 34 lbs during three walks over a two-mile course performed at two-hour intervals. Two portage modalities were used for each weight condition: comfortable, i.e. weights carried on the back, and uncomfortable, i.e. weights carried by hand. Performance on a battery of perceptual and psychomotor tests and ratings of tiredness were obtained before and after each portage. Walking time did not differ between light and heavy portages and was found to be unrelated to tiredness scores. However, the most uncomfortable portage modality was associated with reports of more tiredness. Task performance was significantly related to ratings of tiredness for each of the tests administered, with correlations ranging from −.62 (for perceptual speed and accuracy) to −.89 (for locating and marking identical pairs of names within a list).

Heuting and Sarphati (1966) noted that subjective ratings obtained during work performance could be subject to Tichener's "stimulus error." Specifically, the *load* levels on an ergometer may be presented in such a way as to provide the subjects with *external* information capable of altering their judgments about subjective tiredness. Thus, a subject given information about the load level at which he is performing will be apt to base his subjective rating of tiredness, in part, on that external information. Heuting and Sarphati had their subjects perform on a bicycle ergometer for 11 minutes on 13 successive days. The terminal load level for each daily session was selected as one of seven equal increments between 1050 and 1950 kpm/min. For each session, the initial work load was 45 kpm/min; it was increased by 10 percent of the final load level for each minute thereafter. Previous studies (Heuting, 1964; Heuting and Visser, 1960) indicated that the work load appeared to increase equally for each of these graded work schedules. Thus, estimates of tiredness could be obtained that were less affected by external information. Tiredness was rated in three ways: (1) during each minute of work the subjects positioned a potentiometer pointer along a blank scale to a location between horizontal and vertical corresponding to their level of tiredness; (2) immediately post-work the subjects adjusted the volume of a white noise source to match their level of tiredness; and (3) immediately post-work, the subjects indicated their level of tiredness on a seven-point scale ranging from "feeling fit, rested" (1) to "feeling extremely tired, exhausted" (7).

Average correlations between the terminal work load and post-work tiredness ratings ranged from .71, for the pointer, to .49 for both the white noise and seven-point rating scale. *Individual* correlations generally ranged from .54 to .93. The regression lines between work load and individual post-work ratings of tiredness were clearly linear. The study indicates the feasibility of measuring subjective status during work performance by rating scale techniques. Additionally, the potentiometer method showed the highest post-work relationship to work level. This result may have been due to the subjects' familiarity with this rating technique since it was used more frequently than the other two methods. Thus, there is the suggestion that *experience* with the rating technique may improve the relationship between subjective status and work load.

Janssen and Docter (1973) explored the change in fatigue during static work and recovery using Heuting's method (1968) of "fatigue" assessment. They had six well-trained male subjects exert pulls with the forearm at 25, 35, and 45 percent of their voluntary maximal capacity for intervals of 2.5 min., followed by 2 min. of recovery. Fatigue measures were obtained at rest and at 30 sec. intervals throughout the static work task and recovery. An essentially linear growth of fatigue was observed, more rapid for the higher work loads, with the expected steeper decline during recovery. Reproducibility was very high, and similar results were obtained for the left and right arm. Predictably, heart rate changes in this static work task were less impressively related to the course of work and recovery than the fatigue ratings (see Chap. 11 "Physiology of Work Capacity and Fatigue"). The impressive linearity may have been partially a result of timing during this relatively brief, fixed duration task.

While Heuting and Sarphati (1966) noted that external information about the work load level during exercise could influence reports of subjective tiredness, they did not directly test the effects of such external information on subjective reports. A more direct test of the effects of task information on subjective report was made by Walster and Aronson (1967). They reasoned that reports of tiredness would depend on time perceived to be remaining in the task: after the same duration on a task, a report of "very tired" would be incompatible with information that considerably more time is required. In contrast, such a report would be more compatible with information that the task is near completion. Two groups of 10 subjects were told that they would be required to complete either three (short expectancy) or five (long expectancy) trials during the study. Each trial involved two tasks: (1) marking X's on graph paper squares at the rate of one/second for 10 minutes, and (2) obtaining the visual threshold to white light which required approximately 10 additional minutes. Ratings of tiredness were obtained on each trial after the X-marking task. A rating scale ranging from "as fresh as I have ever been" (1) to "as tired as I have ever been" (13.5) was used. Only data from the first three trials were used in making the comparison between groups. Results indicated that the subjects in the three-trial condition reported a sudden increase in tiredness on trial three, while subjects in the five-trial condition did not report a corresponding increase. These results support the notion that information about task duration can influence subjective report. As yet, there have been no studies testing this effect for tasks involving physical work. This could be done by manipulating external information about such variables as load level and task duration. It would also be of interest to explore the possibility that motivational factors would differentially affect the subjective reports near the end of the task.

Subjective reports of fatigue may well be affected by the relationship between external (e.g. apparent task duration) and internal physiological cues as described by Snyder, Schulz, and Jones (1974). Briefly, their hypothesis was that when an internal standard of subjective fatigue is lacking, individuals believing that they have worked longer durations demonstrate more behavioral fatigue than those believing they have worked shorter durations, even though both groups work equally long. However, when clear, physiological cues are present, the effect of *apparent* duration may well be reversed since it conflicts with the predominant internal standard. A study using brief psychomotor tasks appeared to support this hypothesis. Studies such as these deriving from attribution theory (see Jones, Kanouse, Kelley, Nisbett, Valins, and Weiner, 1972) could contribute substantively to subjective fatigue and its behavioral correlates. Unfortunately, very little has yet been accomplished in this regard, and more adequate subjective rating techniques need to be employed together with improved physiological measures and work performance tasks.

Exertion

During work performance, rating scale techniques have been used to evaluate *perceived effort* by Borg (1962) and his co-workers while *perceived effort expended* has been studied by Lloyd and McClaskey (1971). Both will be discussed below.

EFFORT. In a recent review, Borg (1973) has traced the development of a rating scale of perceived effort (RPE) specifically designed for use during bicycle ergometer work. Initially (Borg, 1962) the scale consisted of 21 points with odd points, 3 through 19, anchored by verbal phrases: 3, extremely light; 5, very light; 7, light; 9, fairly light; 11, neither light nor laborious; 13, fairly laborious; 15, laborious; 17, very laborious; and 19, extremely laborious. On the basis of several initial studies, the scale was revised to include 15 points, 6 through 20, as follows:

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

The scale was presented in quarto fashion, with equal intervals between adjacent scale points, so that the full scale could be seen by the subject when making his ratings of perceived effort. The RPE scale is currently "so constructed that the heart rate (HR) of a normal, healthy middle-aged man can be predicted if the RPE value is multiplied by 10; thus RPE × 10 = HR" (Borg, 1971). Borg cautions, however, that this equation should not be taken too literally since deviations from the equation result from "difficulties in rating, lack of motivation, and disease." Specific circumstances in which the relationship between HR and RPE can be altered will be discussed below.

The load level giving a heart rate of 170 beats/min. can be obtained to define the Physical Working Capacity$_{170}$ (PWC$_{170}$; Wahlung, 1948). At a work level corresponding to PWC$_{170}$, an RPE of 16.5 was obtained and defined as PWC$_R$ (Borg, 1962a). The correlation between PWC$_{170}$ and PWC$_R$ was .61 indicating that, in general, the higher the work load for PWC$_{170}$, the higher the PWC$_R$. For an overall work test, RPE tended to grow as a negatively accelerated function of the work load. The correlation between HR and RPE across several work loads was .85, indicating exceptionally high validity. The high validity suggests that the reliability of the rating scale would also be high since, as a general rule, validity cannot exceed the square root of reliability (Cronbach, 1960). This is to be expected since the linear work load-heart rate relationship for individuals has been shown to be highly reliable (Rowell, 1969).

In a validation study, PWC$_R$ and PWC$_{170}$ were compared to wage rates among forestry workers (Borg, 1962a). The PWC$_{170}$ correlated at a low level ($r = .24$) to wage rates, while PWC$_R$, the subjective estimate, was considerably higher ($r = .54$). Borg suggests that the PWC$_R$ takes into account motivational components not inherent to PWC$_{170}$ but which affect on-the-job performance considerably.

Gamberale (1972) has compared RPE on other tasks with that obtained during bicycling. He noted that the RPE scale was constructed to reflect heart rate (HR) increments of 10 beats between successive scale points. According to this basis, a rating of seven on the RPE scale ("Very, very light") would correspond approximately to a heart rate of 70 beats/min. Twelve male subjects (20 to 35 years of age) performed three tasks: (1) bicycling at work loads of 300, 600, and 900 kpm/min; (2) repetitive lifting of 1.35, 3.35, and 5.35 kg weights 25 cm above a shoulder height starting point; and (3) pushing a wheel barrow loaded with 36, 66, and 96 kg at 100 m/min. In general, these tasks have different muscle mass requirements. The bicycle ergometer task may be characterized as dynamic work requiring a large muscle mass, while the weightlifting involved work using a small muscle mass. The wheel barrow task was a combination of static work (load on the arms) and dynamic work (walking).

The range in heart rates and RPE ratings was greatest for the bicycle ergometer task (approximately from 100 to 185 beats/min), and least for the wheel barrow task (from 100 to 130 beats/min). The weight lifting produced an intermediate heart rate response (from 110 to 140 beats/min). Mean RPE and HR values were linearly related for all tasks with the RPE close to 1/10 of HR. However, RPE correlated most highly with HR for the bicycle ergometer task (r = .94), least for the wheel barrow task (r = .42), and at an intermediate level for the weight lifting task (r = .64). In general, instructions to rate the overall perception of effort, as opposed to rate specifically the perception of efforts in arms or legs, resulted in a higher relationship between the mean HR and RPE. Nevertheless, differences were observed in the relationships between RPE and HR with specific and overall instructions. As might be expected, for the weight lifting task, specific instructions resulted in a closer relationship between RPE and HR. This suggests that caution should be observed when instructing subjects to employ the RPE scale for different tasks.

Gamberale noted that "it proved beyond the scope and the possibility of the present investigation to provide a satisfactory estimate of the level of correlation between heart rate and RPE." On a statistical basis, assuming equivalent variability in the measure of RPE and heart rate, it could be expected that a reduction in range of heart rate, as in the wheel barrow and weight lifting task, would lead to an attentuation of the correlation between heart rate and ratings on the RPE scale. It would be worthwhile to evaluate the relationship between RPE and heart rate on tasks differing in the degree of dynamic work and muscle mass involvement while employing equivalently sizeable ranges in heart rates produced across levels of each task.

As will be discussed (see p. 391), within the past decade a substantial international literature has become available concerning the systematic measurement of a specific subjective quality, perceived effort, in carefully controlled work conditions (also see Table 14-III).

Effort Expended. Another aspect of subjective effort is the perceived amount of total available effort expended during work performance. In a study by Lloyd and McClaskey (1971), eighteen male subjects with an average age of approximately 21 years rated perceived effort expended during performance on a motor-driven treadmill using a unique five-point scale. The rating technique had been developed earlier by Caldwell (1967) for use on an isometric handgrip task (see p. 370). Each subject was asked to respond when he perceived that successive 1/5's of his total available effort had been expended. The first response during work (1) was defined as the point where 1/5 of his total available effort had been expended; the response (5) defined the point at which he had expended *all* of his effort. Thus, the rating procedure can be described as a self-paced technique in that ratings were volunteered by the subject rather than requested at selected points by the experimenter. By prior agreement, performance terminated when the subject called out "5". During the task, all subjects walked on the treadmill at 0 percent grade at 75 percent of their maximum walking speed. Maximum walking speed was determined by noting the points at which the subject broke into a jog during three preliminary trials with increasing treadmill speed and the point at which he started walking after jogging during subsequent deceleration. Eight daily walks at 75 percent maximum walking speed were obtained for each subject during which he called out the points indicating when successive 1/5's of his total available effort had been expended. All subjects were instructed to continue walking as long as possible.

As shown in Figure 14-3, results indicated a highly linear relationship between subjective judgments of the amount of effort expended and mean time on the task. Endurance times tended to increase through the third session, and showed a slight decrease on subsequent sessions. This increase in walk duration may have been due to the effects of practice. The degree of linearity between subjective ratings and mean task time generally increased across the eight sessions, with the last five sessions showing remarkable linearity. In view of these results, Lloyd and McClaskey suggest that subjects "have both the capacity to attend to psychological and physiological cues and to report, on a psychological continuum, their judgments of increasing difficulty of the task or their diminishing capacity to perform."

While the degree of linearity in the relationship between perceived ef-

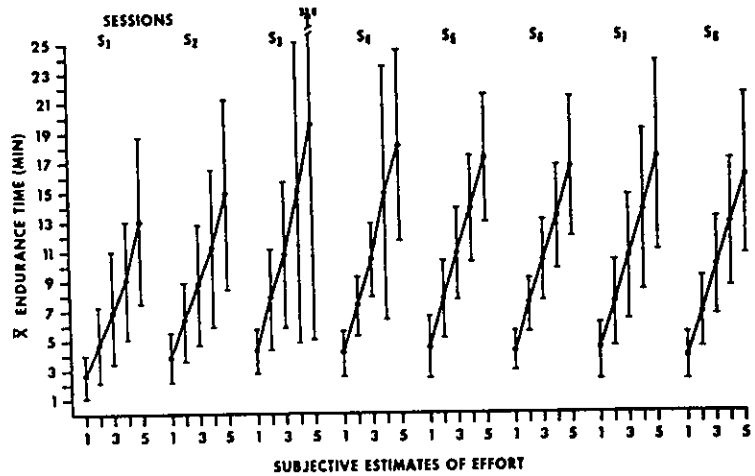

Figure 14-3. Subjective estimates of effort related to mean endurance time during treadmill performance (From A. J. Lloyd, and E. B. McClaskey, "Subjective Assessment of Effort in Dynamic Work," *Journal of Motor Behavior, 3:49*, 1971).

fort expended and task time is impressive, the study raises several interesting questions. First, considerable variability was represented in the data. Standard deviations shown in Figure 14-3 indicate a very broad range of endurance times. In addition, average endurance times (approximately 13 to 19 min.) seem short for such a treadmill task. Were the subjects really performing near the limits of their endurance capacities? In fact, Lloyd and McClaskey note that on session three, which had the greatest variability, two subjects were able to walk 41 and 69 minutes. This raises the possibility that having subjects perform at a given percentage of maximum walking speed might not effectively place each subject at the same relative work load. In other words, 75 percent maximum walking speed may be a physiologically "empty" variable for normalizing endurance capacity compared to maximum aerobic power or other physiological variables such as heart rate. Unfortunately, no data is available in the literature examining the relationship between percent maximum walking speed and measures of endurance capacity. Second, to what degree would the observed linearity found for the subjects as a group exist for individual subjects? No data is presented in this regard. Third, to what degree does this task represent an exercise in timing? The possibility of a timing artifact can be raised almost everytime the self-paced rating technique is used. While the authors clearly regard the data as a demonstration that perceived effort expended is being measured, it is quite possible that each subject was simply *timing* successive fifths of the total duration he was *willing* to spend on the task. Stevens (1957) has discussed categorical and magnitude estimation of time durations which humans can learn to do quite well. No doubt perceived effort expended was being measured in some way, but it is difficult to separate the degree to which effort expended contributed to these results apart from judgments of elapsed time. Additional comment will be offered in the following section regarding timing artifacts in the self-paced rating techniques.

Pain

Pain is another subjective quality experienced during work performance. Caldwell (1967) and Caldwell and Smith (1967) have found a linear relationship between time on an isometric task and ratings of both pain intensity and perceived effort expended. In both of these studies, the subject was required to hold a hand dynamometer at submaximal levels until it became necessary, in the subject's own judgment, to stop. Subjects were required to indicate when pain intensity attained values of 1 to 5 in the same self-paced fashion as that used by Lloyd and McClaskey (1971) for ratings of perceived effort expended. Under these conditions, ratings of pain intensity could be influenced by the subjects' ability to time successive intervals, as has been discussed. If, with practice, a subject could call out successive ratings of pain intensity at intervals matched on the time dimension, the relationship between ratings of pain intensity and time on the isometric task would attain a spurious linearity. As noted above, this is a problem also relevant to the interpretation of the Lloyd and McClaskey (1971) study.

Menzer, Smith, and Caldwell (1969) addressed the problem of the possible timing artifact directly. In this study, using the same isometric task, pain ratings by the self-paced technique were compared to those obtained by an irregular report technique adapted from Beecher (1966) and Smith, Egbert, Markowitz, Mosteller, and Beecher (1966). As in previous studies, the subjects were required to sustain a submaximal handgrip, either 25 or 40 percent of maximum, until they judged it necessary to stop. One group of subjects used the self-paced technique calling out the numbers "1" through "5" as these subjective intensities were reached, terminating performance at the highest rating of pain intensity, "5." A second group of subjects were required to select a rating of from "1" to "5" at the request of the experimenter made at random, irregular intervals during the task. All subjects were practiced on *both* rating procedures *before* the experiment began. Their notion was straightforward: if timing of the intervals accounted for the linearity observed in previous studies, the irregular report ratings would be expected to be less linear than the self-paced technique. The results, however, clearly indicated that for subjects practiced on both techniques, the self-paced and irregular ratings produced equally linear relationships with time on the isometric task for average values of perceived pain for the group as a whole.

Nevertheless, these results do not eliminate the possibility that self-paced ratings of perceived *effort expended* used by Lloyd and McClaskey (1971) contained a timing artifact. In the latter study, each rating scale point referred to the estimated proportion of total available effort expended. This may be worthwhile reviewing in some detail. A rating of "1" meant that 1/5 of the subject's total effort was expended; when the subject called out "5" this meant, by definition, that *all* his available effort was expended and he stopped performing the treadmill task. Such a procedure is virtually identical to having the subject state when he is one-fifth through the task, two-fifths through the task, and so on, making the successive ratings highly dependent on the subject's ability to estimate and match successive intervals.

In an excellent study by Lloyd, Voor, and Thieman (1970) ratings of pain were obtained during an isometric hand dynamometer task of either 25 or 50 percent of maximum grip strength. During each of two trials, the forty male subjects reported their ratings of pain intensity using the self-paced technique. The two trials were separated by a rest period of 15 minutes. The results of the study are depicted in Figure 14-4, showing the re-

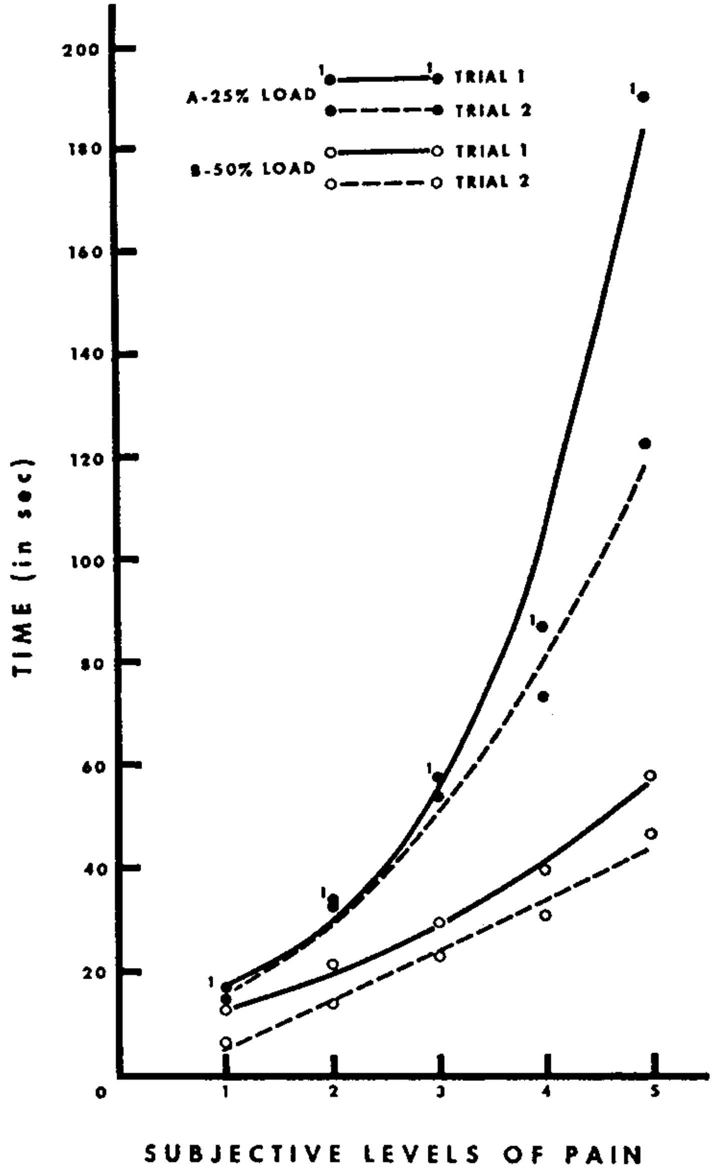

Figure 14-4. Subjective estimates of pain related to endurance time during isometric hand dynamometer tasks (From A. J. Lloyd, J. H. Voor, and T. J. Thieman, "Subjective and Electromyographic Assessment of Isometric Muscle Contractions," *Ergonomics, 13*: 685, 1970).

lationship between pain intensity ratings and average time on the isometric task. From the figure, it can be seen that ratings of pain increased regularly across time on the task, in a generally quadratic fashion, particularly for the 25 percent load level. Ratings for the 50 percent load level were much more linear for both trials. It is interesting that Trial 2 was more linear in appearance than Trial 1 for *both* load levels, although the decrease in average task duration for the 25 percent load level on Trial 2 was more pronounced. A decrease in the average task duration for the 25 percent load level may reflect a learned timing effect inherent to the self-paced ratings of pain. This effect due to timing of successive intervals, was not observed by Menzer, Smith, and Caldwell (1969), an apparent paradox which may be resolved by the fact that the latter's subjects were already *well practiced before* the experimental trials began.

Thus, even for self-paced ratings of pain, the issue of a timing artifact does not appear resolved. Examining the two functions for the 25 percent load level, the successive intervals in Trial 1 were approximately 16, 18, 24, 27, and 105 sec. while for Trial 2 the intervals between ratings were somewhat more equal, approximately 13, 19, 21, 21, and 50 sec. Since Menzer, Smith, and Caldwell (1969) note that their subjects were given practice on both self-paced and irregular rating procedures before the experimental trials were initiated, interval timing may have been learned during practice with the self-paced procedure and *transferred* to the irregular rating procedure during the experimental sessions. Whether this transfer phenomenon does happen or not is an empirical question which should be resolved by further research. Also, the Menzer, et al. subjects had a much lower average task duration than Lloyd, et al. (approximately 65-96 sec. vs. 120-190 sec.) for the same 25 percent load level. This suggests that, in general, the briefer the task duration, the more equal the intervals will be between successive self-paced ratings of pain. Perhaps this difference exists since it is easier to divide a short interval into equal subdivisions than a longer one. While these comments have been offered critically to evaluate the self-paced rating technique, the ability to time work duration could turn out to be an actual phenomenon representing an important parameter used to "pace" work performance.

Thermal Discomfort

Gagge, Stolwijk, and Saltin (1969) used rating scales to relate thermal sensation and discomfort to the level of work being performed. Four male subjects rode at work loads of 25, 50, and 75 percent max Vo_2 on a bicycle ergometer under conditions of different ambient temperature (10°, 20°, and 30°C). A four-point scale of discomfort was used ranging from "comfortable" (1) to "very uncomfortable" (4). Thermal sensation was measured on a seven-point scale ranging from cold (1) to hot (7). Physiological measurements including rectal, muscle (quadriceps), and average skin temperature were also obtained along with measures of sweat loss and heat conductance. Each subject rode for periods of 40 min. at each work level and ambient temperature. Results indicated that at the start of exercise changes in both thermal and comfort sensations were related to the rise in mean body temperature. However, after 30 to 40 min. of exercise, the sensation of "warm discomfort" (obtained by deleting ratings of slightly cool or below) related most highly to skin sweating ($r = .66$), although relatively high relationships were also found for skin conductance ($r = .56$), rectal temperature ($r = .55$), and metabolic rate ($r = .53$). When one highly trained subject was excluded from the data, the correlation between skin sweating increased substantially (to $r = .84$). Thermal sensations, from cold to hot (as opposed to "warm discomfort") were principally related to ambient air temperature ($r = .72$) and skin temperature ($r = .73$). The lower boundary for a comfort zone during steady exercise appeared to be determined by exercise levels and ambient temperatures at which there was no sweating. The upper boundary for the comfort zone during steady exercise was found to be associated with "skin sweat rate equivalent to an evaporative heat loss of 150 kcal/m^2/hour or approximately 65 percent wetness of the skin" provided "the percentage of maximum oxygen uptake [does not] exceed 50 percent." This study illustrates the power of subjective qualities, combined with measurement of appropriate physiological parameters, in adding to an understanding of the adaptive responses to work performance.

By confining attention to one subjective quality, many of the above studies have yielded considerable valuable insights regarding the nature of individual subjective symptoms during work performance. However, subjective symptomatology during work, as Bartley and Chute (1947) have noted, is probably more *complex* than a single subjective quality is able to encompass. During work performance a variety of categories of subjective symptoms may be experienced, each of which may be related to work performance in some way. By focusing on only one subjective quality, the essential complexity of the range in subjective qualities is ignored. Attempts to dimensionally quantify a number of subjective qualities during work will be described in the following section.

Multidimensional Analysis of Subjective Qualities

By now it should be clear that a variety of subjective qualities have been measured preceding or during work performance. These have included "feeling tone" (Foltz, et al., 1944), undifferentiated fatigue (Nunney, 1963; Pierson, 1963a; Bujas, et al., 1966), tiredness (Poffenberger, 1928; Griffith, et al., 1950; Pearson and Byars, 1956; McNelly, 1957), perceived

force exerted (Borg and Dahlstrom, 1960; Eisler, 1962; Schmale, Schmidtke, and Vukovich, 1963; Bernyer, 1967), perceived effort (Borg, 1962a; Gamberale, 1972), perceived effort expended (Caldwell, 1967; Lloyd and McClaskey, 1971), pain intensity (Caldwell and Smith, 1967; Caldwell, 1967; Menzer, et al., 1969; Lloyd, et al., 1970), and thermal discomfort (Gagge, et al., 1969) [See Tables 14-I through 14-III]. Since a variety of subjective qualities occur and can be measured during work performance, another approach might begin by first inquiring what the categories of subjective symptoms are and how they are interrelated during work performance. Studies such as these may also aid in the conceptual organization of the melange of different subjective qualities measured during work.

The rationale for the application of multidimensional techniques to work performance derives from the reasoning that work produces changes in a variety of subjective qualities (symptoms). As noted by Bartley and Chute (1947), certain of these subjective symptoms occurring during work should be considered conceptually discrete from others. Prolonged exercise may produce subjective symptoms such as boredom or an aversion to the physical activity which may also be significantly related to work tolerance. Therefore, subjective symptomatology may be conceived as a set of conceptually clear, discrete symptoms which increase together during work performance (Kinsman, Weiser, and Stamper, 1973). Multidimensional analysis, such as factor analysis or key cluster analysis, provide means to identify sets of symptoms that group together to form such symptom categories. Table 14-IV presents an outline of studies relevant to the multidimensional analysis of subjective symptomatology during work performance and fatigue.

Although Wotzka and Grandjean (1968) did not specifically use multidimensional techniques, they did give a battery of ten 7-point rating scales as well as measured critical flicker fusion (CFF) and two tapping tests to sixty-eight air traffic controllers throughout their work day. They found a common trend between the mean values of the self-rating of "refreshed-tired" and CFF, grid tapping, and ordinary tapping tests. The ratings and performances were high during the day and low during the night. Regardless of the actual starting hour, the mean values of the self-rating scales, "strong-weak," "refreshed-tired," "vigorous-exhausted," and "awake-sleep" gradually changed concurrently toward the direction of fatigue. After the time that these ratings exceeded the neutral point (4), between the 5th and 7th hour of work, there was also a rapid drop in the mean values for CFF, tapping, and grid tapping. Since there are significant correlations (from $r = .26$ to $.32$) between the changes in "refreshed-tired" scores, CFF, and grid tapping, Wotzka and Grandjean suggested that subjects with a marked decrease of CFF or grid tapping performance also had a greater deviation toward being

TABLE 14-IV
MULTIDIMENSIONAL STUDIES OF SUBJECTIVE QUALITIES DURING WORK

Subjective Dimensions	*Development*	*Task*	*Subjects*	*Studies*
....	Key cluster analysis	Various tests of mental work	? (n=49)	Bujas, Petz, Krkovic, and Sorokin (1960)
Nervous; drowsy; and exhaustion	Factor analysis	Reporting a fatiguing situation	College students (n=150)	Wolf (1967)
High activation, 12 factors; moderate activation, 9 factors; low activation, 5 factors (see text)	Factor analysis	Reporting a situation	College students (n=315)	Wijting, Wollack, and Smith (1970)
Physical; mental and neuro-sensory	....	....	....	Industrial Fatigue Research Committee of the Japanese Association of Industrial Health (1954)
Drowsiness and dullness; difficulty in concentration; and projection of physical disintegration	Factor analysis	Various jobs	Workers (n=9,575)	Saito, Kogi, and Kashiwagi (1970)
Motivation; task aversion; fatigue (general and leg)	Key cluster analysis	Bicycle ergometer (56% max VO_2)	Young males (n=63)	Kinsman, Weiser, and Stamper (1973) Weiser, Kinsman, and Stamper (1973)

"tired." On the basis of this finding, they hypothesized that the changes in these measures indicate a *common* state that Wotzka and Grandjean would label "fatigue." Their contribution to conceptualizing fatigue lies in the acknowledgement that a variety of subjective and behavioral measures, rather than any single variable, show change during prolonged work.

As early as 1960, Bujas, Petz, Krkovic, and Sorokin had reported application of multidimensional techniques (i.e. key cluster analysis) to evaluate relationships between individual mental tests (e.g. tests of reasoning, perception, numerical ability, etc.) under normal control conditions and "fatigue" induced by a 24-hour period of sleeplessness followed by a 10 kilometer walk. While subjective symptoms were not measured in this study, Bujas, et al. did find that following induced "fatigue," the *relationships* between various psychological tests were altered. They suggest that fatigue may be understood as a disintegration or disorganization of the psychological and physiological processes that existed during *nonfatigued* performance of work. Examples of these changes in the adaptative responses to work during fatigue have been discussed in detail in Chapter 1. The multidimensional approach to subjective symptomatology during work is implicit in this study since pattern-like changes in discrete subjective symptom categories may be inferred to occur along with alterations in other psychophysiological processes.

Using a varimax factor analysis, Wolf (1967) identified three fatigue categories within a set of thirty adjectives given to a group of 150 subjects in the preliminary study. The subjects were instructed to check those adjectives associated with an imagined "fatiguing situation." The selection of the situation was left up to the subject. No details were provided concerning how the original set of adjectives were originally selected or arranged within the checklist for rating. The three categories identified were labeled *Exhaustion* (Physically Tired, Aching Muscles, Exhausted, Easily Distracted, No Energy and Perspiring); *Drowsy* (Mentally Sluggish, Want to Fall Asleep, Lazy, Drowsy, Feel Sleepy, and Tired; and *Nervous* (Tense, Jumpy, Keyed Up, Head Tightness, Feel Dizzy, and Irritable).

A speed of tapping task of one minute duration, and two pursuit-rotor tracking tasks given for five, 30-second trials, were used to test the validity of these categories. Validation data was limited since no decrement in performance was observed for 35 to 65 percent of the subjects on the tasks. Thus, the tasks, which were brief and easily accomplished, seemed inadequate to induce a significant level of fatigue. In fact, the relationships between performance decrement across trials, for those showing a decrement, and scores on each of the fatigue categories were found to be negligible.

Wolf also measured subjective effort immediately after task performance by the inclusion of two unspecified "effort" items rated as being either present, indeterminate, or absent. He noted that some of the subjects who reported a feeling of increased effort also reported higher post-task scores on the three fatigue categories. On this basis, he suggested that "fatigue is a product of *motivation,* not task" [author's italics]. This assumes that the categories are sufficiently generalizable to alternative work situations; however, the tasks on which he based his conclusions, as noted above, appeared inadequate to induce fatigue. In addition, it was also assumed that reports of effort are indicative of motivational level. Subjective effort has already been discussed above as one subjective quality commonly *experienced* during work, and having relationships to work capacity and endurance. Subjective effort should not be assumed *also* to be a measure of *motivational* level. The value of Wolf's study lies largely in the identification of subjective qualities reported to be experienced during imaginary fatiguing situations which group on a *connotative* basis (i.e. share a common meaning).

In a subsequent study by Wijting, Wollack and Smith (1970), Wolf's findings were substantiated and extended in regard to the factorial organization of subjective qualities: three hundred and fifteen subjects were asked to indicate which of 132 selected subjective qualities printed on a checklist were experienced during *imaginal* states of "high activation" (e.g. "being awakened by a loud noise"), "moderate activation" (e.g. "playing a card game"), or "low activation" (e.g. "sunbathing"). Varimax factor analysis of the checklist protocols identified twelve, nine, and five subjective factors for the high, moderate, and low imaginal states of activation, respectively. For imaginal "high activation," Wolf's *Exhaustion* factor was essentially replicated, while his *Nervous* and *Drowsy* factors emerged in the "low activation" condition. More interestingly, a *General Fatigue* factor, consisting of twenty-four subjective items, emerged for the imaginal "moderate activation" condition. The General Fatigue factor consisted of subjective items such as "drowsy," "tired," "dull," "slow," "physically tired," "sluggish," "no energy," and so on. No validation data is presented in which measures of subjective symptoms were obtained in actual situations. Neither Wolf (1967) nor Wijting, et al. (1970) have used their subjective symptom factors to measure fatigue in real or adequately fatiguing work situations.

As early as 1949, Kirihara urged that subjective factors be studied in investigations directly dealing with industrial fatigue in Japan. Subsequently, under the auspices of the Japanese Industrial Fatigue Research Committee (1954), 30 symptoms of subjective fatigue were listed in an "Inventory for the Subjective Symptoms of Fatigue." The initial inventory included three symptom categories labeled Physical, Mental, and Neurosensory Fatigue arranged in a checklist so that an individual could indicate the presence or absence of each symptom. The initial inventory was formulated on a conceptual, rather than empirical grouping, of items within the symptom categories. During the period 1965 to 1967, the items of this inventory were used to develop a Fatigue Scale by factor analytic techniques (Kogi, et al., 1970). This Fatigue Scale is shown in Table 14-V. It consists of three factors: *Drowsiness, Difficulty in Concentration,* and *Projection of Physical Disintegration,* the latter similar to the *Nervous* factor of Wolf (1967). A description of the empirical approach leading to the derivation of the 1967 Fatigue Scale is presented by Saito, Kogi, and Kashiwagi (1970). They empirically derived the factorial structure using protocols of 9,575 workers occupied in eighteen different industrial jobs. Scores for the three fatigue factors showed increasing frequency of report during the course of work for most occupations, although certain differences occurred between occupations in the manner with which the symptoms grouped empirically.

Kogi, Saito, and Mitsuibashi (1970) validated the fatigue scale shown in Table 14-V using protocols for railway yard workers (n = 309), iron foundry workers (n = 181), and railroad engine drivers (n = 365) before, during, and after an eight-hour work shift. The factorial structure of the inventory *changed* pre- to post-work, and differed between industrial jobs, suggesting that the appropriate fatigue scale to be used might be tailored to the characteristics of each job situation. For example, clerical workers may not complain of the *same* physical symptoms as workers in an iron foundry who are engaged in a more highly physical occupation. There were clear differences in the frequency of reported symptoms for the jobs in the Kogi, et al. study: most iron workers reported feeling thirsty post work (82%), having

TABLE 14-V

1967 FATIGUE SCALE OF THE INDUSTRIAL FATIGUE RESEARCH COMMITTEE OF JAPAN

Drowsiness	*Difficulty in Concentrating*	*Bodily Complaints*
1. Feel heavy in the head*	11. Difficulty thinking*	21. Headache*
2. Feel tired in the whole body*	12. Become weary while talking	22. Stiffness in the shoulders
3. Tired legs*	13. Irritable	23. Low back pain
4. Yawning*	14. Unable to concentrate*	24. Constrained in breathing
5. Feel confused*	15. No interest in things	25. Thirsty
6. Become drowsy*	16. Apt to forget things*	26. Husky voice*
7. Eye strain*	17. Apt to make mistakes	27. Dizzy
8. Become rigid or clumsy when moving	18. Anxious about things	28. Eyelid spasms*
9. Feel unsteady while standing	19. Unable to maintain a straight posture*	29. Limb tremors*
10. Want to lie down*	20. No energy*	30. Feel ill*

* Symptom items validated within the symptom categories of the 1967 Fatigue Scale by K. Kogi, et al., "Validity of Three Components of Subjective Fatigue Feelings," *Journal of Science of Labour,* 46:251, 1970; and Y. Saito, et al., "Factors Underlying Subjective Feelings of Fatigue," *Journal of Science of Labour*, 46:205, 1970.

heavy legs (91%), and being generally tired (67%); in contrast, engine drivers, engaged in a physically less demanding job, reported only infrequently experiencing these symptoms post work (27%, 28%, and 24% for thirsty, heavy legs, and general tiredness, respectively). Such differences affect the derived factorial structure of the fatigue scale. Thus, specific symptoms and symptom categories may not apply in the evaluation of "fatigue" in certain work situations.

Additionally, the derivation of the symptom factors of this fatigue scale has been based on the *frequency* with which groups of workers check the occurrence of the symptoms during or post work. Yoshitake (1969, 1971) has found that the reported *frequency* of symptoms on the 1967 Fatigue Scale have a "high correlation" between ratings of *severity* of undifferentiated fatigue for office workers.

Recently, the multidimensional analysis of subjective symptomatology has been applied to a standard work situation on the bicycle ergometer in controlled laboratory conditions (Kinsman, Weiser, and Stamper, 1973). In this study, four stages were involved in the development of a Physical Activity Questionnaire (PAQ) designed to describe *categories* of subjective symptoms experienced as a result of prolonged bicycle riding. First, a wide range of adjective items, potentially descriptive of subjective changes experienced from rest to the end of prolonged physical work were selected for inclusion in an Initial Adjective Checklist (IAC). These items, shown

TABLE 14-VI

ITEMS PRESENTED IN THE INITIAL ADJECTIVE LIST*

1. Perspiring	22. Determined	43. Happy
2. Short of Breath	23. Comfortable	44. Headache
3. Muscle Tremors	24. Leg Cramps	45. Pleased
4. Test Attention	25. Working Hard	46. Distracted
5. Weak	26. Hard to Breathe	47. Head Tightening
6. Easy to Think	27. Easy to Concentrate	48. Nauseated
7. Physically Tired	28. Leg Twitching	49. Meter Attention
8. Leg Aches	29. Drive	50. Jumpy
9. Lively	30. Heart Pounding	51. Dizzy
10. Weary	31. Refreshed	52. Listless
11. Out of Gas	32. Tired	53. Satisfied
12. Rather Quit	33. Weak Legs	54. Depressed
13. Aching Muscles	34. Drained	55. Abdominal Cramps
14. Lazy	35. Do Something Else	56. Tense
15. Bored	36. Shaky Legs	57. Irritable
16. Sore from Sitting	37. Hard to Keep Going	58. Backache
17. Heavy Legs	38. Vigorous	59. Angry
18. Numb	39. Dry Mouth	60. Fidgety
19. Easygoing	40. Panting	61. Active
20. Worn Out	41. Sweating	62. Worried
21. Thirsty	42. Fed Up	63. Drowsy

* Items 1 to 41 inclusive were retained for the Modified Adjective List (From Kinsman, Weiser, and Stamper, 1973).

TABLE 14-VII

PHYSICAL ACTIVITY QUESTIONNAIRE DERIVED BY KEY CLUSTER ANALYSIS*

Item No.†	*Symptom Category*‡					
1	C2	Perspiring severely	Perspiring badly	Perspiring some	Perspiring a little	Not perspiring at all
2	C1	Severely short of breath	Quite short of breath	Some shortness of breath	A little short of breath	Not at all short of breath
9	C3	Very lively	A little lively	About as lively as usual	Less lively than usual	Not at all lively
13	C1	Severely aching muscles	Badly aching muscles	Muscles aching some	Muscles aching a little	No aching muscles at all
20	C1	Severely worn out	Badly worn out	Worn out some	A little worn out	Not at all worn out
22	C3	Very determined	A little determined	About usual determination	Less determined than usual	Not at all determined
23	C2	Very comfortable	A little comfortable	About usual comfort	Less comfortable than usual	Not at all comfortable
26	C1	Very hard to breathe	Quite hard to breathe	Some difficulty in breathing	A little difficulty in breathing	Not at all difficult to breathe
29	C3	A lot of drive	A little drive	About average drive	Less drive than usual	No drive at all
30	C1	Severe heart pounding	Bad heart pounding	Some heart pounding	A little heart pounding	No heart pounding at all
33	C1	Severely weak legs	Quite weak legs	Some leg weakness	A little leg weakness	No leg weakness at all
34	C1	Severely drained	Quite drained	Drained some	A little drained	Not drained at all
35	C2	Want to do something else very much	Want to do something else a little	Want to do something else as much as usual	Want to do something else less than usual	Do not want to do something else at all
36	C1	Severely shaky legs	Quite shaky legs	Some leg shakiness	A little leg shakiness	No leg shakiness at all
38	C3	Very vigorous	A little vigorous	About usual vigor	Less vigorous than usual	Not at all vigorous
39	C1	A severely dry mouth	A badly dry mouth	Some dryness in the mouth	A little dryness in the mouth	No dryness in the mouth at all
40	C1	Panting severely	Panting badly	Panting some	Panting a little	Not panting at all
41	C2	Severely sweating	Badly sweating	Some sweating	A little sweating	Not sweating at all

* According to order of appearance in the standard form of the Initial Adjective List. (From Kinsman, Weiser and Stamper, 1973).
† Items 9, 22, 23, 29, and 38 were scaled from 1 (absent) to 5 (severe) while the remainder were scaled from 5 (severe) to 1 (absent).
‡ C1 = Fatigue; C2 = Task Aversion; C3 = Motivation.

in Table 14-VI, were assembled from previously reported measures of fatigue (Pearson and Byars, 1956; Wolf, 1967), the General High Altitude Questionnaire (Evans, 1966; Stamper, Kinsman, and Evans, 1970; Stamper, Sterner, and Kinsman, 1971), as well as additional items suggested by the research team. Second, each descriptive item was arranged along a five-point ordinal scale of severity by using appropriate modifiers according to procedures adapted from Nowlis and Nowlis (1956). Examples of the scaled items as they appeared in the six-page IAC are shown in Table 14-VII. In practice, the subject could rate the level of his subjective experience by circling the applicable descriptive phrase defining a point along the five-point scale for each item. Third, sixty-four subjects, on two occasions at least three days apart, rode the bicycle ergometer at a work load approximating 56 percent max $\dot{V}o_2$. Before each ride, subjects were given explicit instructions to continue pedalling until they became so discomforted that it was necessary to stop. Immediately before Ride 1, the IAC was completed twice to provide experience with the use of the instrument. The end-of-ride IAC was completed while sitting on the bicycle ergometer, with instructions to describe the subjective experiences while riding just before terminating the ride. Identical pre- and end-of-ride IAC administrations were given for Ride 2. Fourth, those items that were either redundant in meaning or showed less than a 10 percent mean change from pre- to the end-of-ride for both rides were eliminated. For the remaining forty-one items which comprised the Modified Adjective Checklist (MAC), the mean pre- to end-of-ride increase ranged from 10 to 84 percent.

Key cluster analysis (Tryon and Bailey, 1970) was then performed on the end-of-ride MAC protocols to empirically identify nonredundant categories of items describing unique aspects of subjective change. In brief, these categories were empirically grouped by key cluster analysis according to the following three criteria: (1) high collinearity between items within a category, i.e. the items within a category shared a similar pattern of correlation across all other items of the MAC, (2) maximum independence between all categories, and (3) maximum accountability by the smallest number of categories of the total variability within the score space. These empirically derived categories may be regarded as subscales whose scores are obtained by adding individual member item values.

Accordingly, it was assured that only those items reasonably expected to show change were studied. Furthermore, key cluster analysis was performed on only those items actually showing change on an empirical basis, thereby building validity into the selection procedure. Finally, analyses were performed on the end-of-ride scores, thereby identifying symptom categories that group together near the end-point of work tolerance.

Three symptom categories common to both rides, were identified and la-

beled on a conceptual basis: *Fatigue* (panting, short of breath, worn out, drained, legs weak, heart pounding, difficult to breathe, shaky legs, aching muscles, and dry mouth); *Task Aversion* (sweating, perspiring, uncomfortable, want to do something else); and *Motivation* (drive, vigorous, determined, lively). In Figure 14-5, the geometrical organization of these categories is shown on a Spherical Analysis (SPAN) diagram for the Ride 2 data. In the SPAN diagram, the loci of the categories (clusters) are shaded and located on the surface of a three-dimensional sphere. The boxes labeled I, II and III are the termini of *orthogonal,* i.e. independent, axes which are located by the factoring process and pass through the origin of the sphere to form the orthogonal factor structure. Similar to coordinates on a map, the orthogonal structure primarily serves as a frame of reference to locate the *oblique* categories, the shaded areas labeled C1, C2 and C3. The oblique structure represented in the diagram depicts the actual relationships between the categories. For a detailed discussion of the SPAN diagram, see Tryon and Bailey (1970).

While all symptom categories form distinct groupings, Fatigue appears to be the most dense and tightly packed, indicating that the relationships between items within this category are high. In fact, internal consistency reliabilities were generally high for all categories ranging from .94 for Fatigue to .77 for Motivation. The symptom categories were quite independent from one another: intercorrelations among the category scores ranged from .34 to .17 for Ride 2. Since two rides were performed, it was possible to evaluate stability of the *amount* of *change* from pre- to end-of-ride for the categories. Stability measures were respectably high for Fatigue and Task Aversion ($r = .83$ and $.65$); however, the Motivation category had a low stability of change ($r = .38$). Individual category scores changed significantly from pre- to end-of-ride for both rides: 95, 58, and 11 percent for Ride 1 and 105, 80, and 21 percent for Ride 2 for Fatigue, Task Aversion and Motivation.

The *Fatigue* category appears to be composed of those subjective symptoms describing *bodily feeling states* associated with prolonged exercise (Kinsman, Weiser, and Stamper, 1973). In a subsequent study (Weiser, et al., 1973) two subcategories of *Fatigue* were identified and labeled General Fatigue (worn out, weary, tired, out of energy) and Leg Fatigue (leg aches, leg cramps, muscle aches, muscle tremors, leg twitch, heavy legs, shaky legs). Only a moderate relationship existed between these two subcategories ($r = .58$) indicating a maximum of 34 percent overlap in the common variability of both Fatigue components. The symptom items of General Fatigue group largely on a connotative basis and agree in composition with the comparable categories previously identified by Wolf (1967) and Wijting, et al. (1970) as discussed above. The composition also agrees with

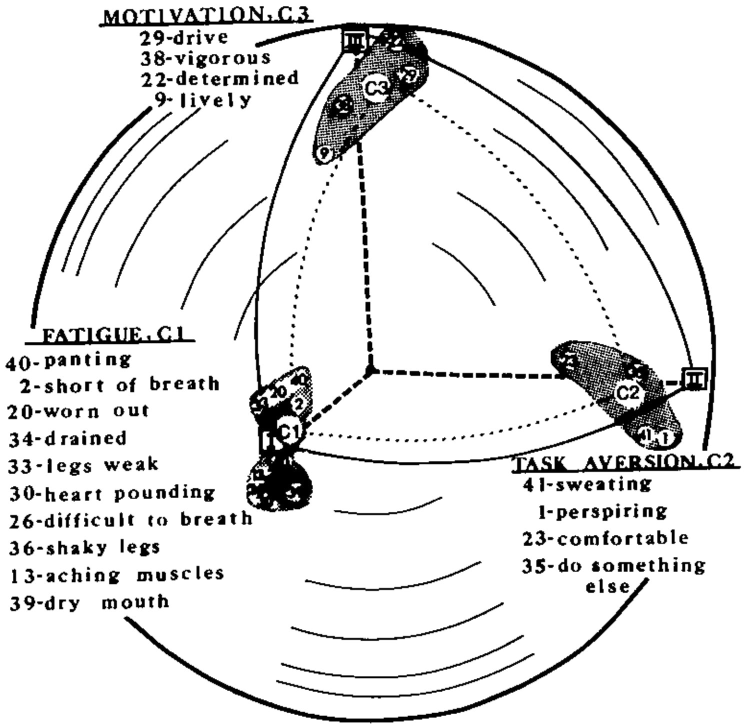

Figure 14-5. Spherical Analysis (SPAN) diagram showing the organization and structure of three symptom categories identified at the end of bicycle ergometry work. For explanation, see text (From R. A. Kinsman, P. C. Weiser, and D. A. Stamper, "Multidimensional Analysis of Subjective Sympotomatology During Prolonged Strenuous Exercise." *Ergonomics, 16*:211, 1973).

comparable categories identified by Kinsman, Luparello, et al. (1973) in studies of asthma symptomatology, and Stamper, et al. (1970, 1971) in studies of the symptomatology of acute mountain sickness. Thus, it seems to represent a truly *general* type of subjective fatigue, common to different tasks, environmental conditions, and pathology. On the other hand, Leg Fatigue is a symptom subcategory apparently *specific* to tasks that are highly leg dependent such as bicycle riding. A variety of physiological changes occurring during bicycling (e.g. increased input from muscle spindles and Golgi tendon organs) feed back to higher nervous centers as internal physi-

ological cues which may contribute to the self-report of the Leg Fatigue symptoms. A group of cardiopulmonary symptoms within the overall Fatigue symptom cluster (short of breath, panting, difficult to breathe, and heart pounding) also appeared as a distinguishable subcategory more closely associated with Leg Fatigue than with General Fatigue (Weiser, et al., 1973).

Task Aversion, the second symptom cluster, appears to measure a general level of *discomfort* and a disinclination to continue the task (Kinsman, Weiser and Stamper, 1973). The inclusion of the doublet symptom set, "perspiring" and "sweating" in conjunction with the level of discomfort ("comfort") appears reasonable in view of the study by Gagge, et al. (1969) which indicated that the sensation of thermal *discomfort* during bicycling was principally related to sweating.

Motivation, although conceptually clear, has a low stability as noted above and shows a relatively minimal change during exercise as compared to *Fatigue* (and its subcategories) or to *Task Aversion.* This does not necessarily minimize the value of the *Motivation* category but suggests that motivational level may fluctuate on a daily basis, while being relatively *constant* throughout a single work session.

Finally, it should be noted that ride durations varied substantially in this study, ranging from 1½ min. to 98 min. In spite of this extraordinary range, the test-retest reliability between Rides 1 and 2 was high: r = .80. This range occurred even though subjects performed at 55.6 ± 2.8 percent estimated max $\dot{V}o_2$. Thus, other factors in addition to aerobic capacity are obviously required to account for differences in work tolerance during strenuous exercise. One of these may be the relative heart rate increment during exercise. In general, subjects having a high heart rate increment early in the exercise period chose to discontinue riding sooner than subjects with lower heart rate increments (Weiser, Stamper, Kinsman, and Hannon, 1971). Motivational factors, personality differences and performance expectations deriving from prior athletic or work history, may also be importantly involved. There needs to be more information in this regard since these factors may also influence subjective report.

In summary, results of these studies indicate that a complex set of symptoms are experienced during physical work. Nonetheless, these symptoms may be organized meaningfully (i.e. empirically and conceptually) into categories. Dimensional analysis of subjective symptomatology during work may clarify the meaning of terms such as subjective fatigue. This approach also implies that differences may exist between identifiable types of individuals in regard to their *pattern* of changes across various categories of subjective symptomatology. For example, during a given task, one type of individual may tend to terminate work in response to an increase in the subjective symptoms labeled Fatigue, while another type may quit because of flagging motivation together with a rising aversion to the task associated with increased discomfort. It is also likely that the relevant symptom *categories* may differ between tasks, just as the patterns of symptomatology may differ between individuals. Thus, these studies suggest that while the use of simple unidimensional scales of a single subjective quality may provide useful information, they may well be limited in regard to the representative richness of the subjective experience during work. Without adequate caution, complex patterning of subjective changes could obscure any direct relationships between a single subjective quality, work tolerance, and the underlying substrata of physiological factors.

OBSERVATIONS ON THE ROLE OF SYMPTOMATOLOGY DURING WORK AND FATIGUE

Subjective fatigue has often been discussed as if it were a simple self-explanatory concept. However, the research applications reviewed have frequently either avoided the use of a global report of undifferentiated fatigue in favor of discrete, objectively definable subjective qualities, or have used reports of undifferentiated fatigue to relatively little advantage.

In our estimation only one study (Bujas, et al., 1966) has used reports of undifferentiated fatigue in which clear relationships have been shown between the subjective rating and physiological parameters, i.e. EMG activity during work. In this study the subjects were clearly informed about the composite, discrete subjective qualities that should enter into their judgments of fatigue during an isometric weight-holding task. Specifically, they were told to attend to feelings of "tightness, numbness," and to an "increase in muscle sensitivity to pain, weight, and so on" in their judgments of fatigue.

Herein lies a clue that may help to define what is meant by a report of undifferentiated fatigue. Specifically, undifferentiated fatigue might best be regarded as a superordinate feeling state into which is focused a set of discrete subjective qualities arising during work. The composite subjective qualities focused into such a superordinate report will depend on a variety of factors such as the nature of the task. This is why a person doing prolonged *mental* arithmetic can finally describe himself as feeling fatigued, just as a bicycle rider, performing strenuous *physical* work, can do likewise. But the meaning of the report of "fatigue" in terms of the underlying discrete symptoms and physiological factors involved is necessarily quite different for the two tasks. Thus, the report of undifferentiated fatigue might best be regarded as a superordinate subjective state into which is funneled discrete subjective symptoms.

The above provides a starting point for a conceptualization of subjective fatigue. The following will serve as a summary statement for this chapter. Specifically, three ingredients will be involved in this conceptualization: (1) the report of subjective symptomatology, including undifferentiated fatigue, categories of symptoms, and discrete symptoms; (2) the physiological substrata which is importantly altered during work; and (3) the relationship between physiological factors and symptomatology during work.

Subjective Symptomatology

The full range of individual subjective qualities studied during work is extensive enough to provide some difficulty in developing an organizational schema. In the order presented earlier in this chapter, these include force exerted, undifferentiated fatigue, tiredness, perceived effort and effort expended, pain intensity, thermal discomfort, and thermal sensations. At least one study (Foltz, Jung, and Cisler, 1944) obtained pre-work reports of a vague state called "feeling tone." At this time, the available multidimensional studies of subjective qualities are few but demonstrate that wide ranges of discrete symptoms can be organized meaningfully into more limited, but conceptually clear categories. Of these multidimensional studies, at the time of this writing, only two have identified categories of symptoms using a controlled laboratory situation and a standard work task, i.e. the bicycle ergometer (Kinsman, Weiser, and Stamper, 1973; Weiser, Kinsman, and Stamper, 1973). These studies provide an opportunity for some comparisons between unidimensional and multidimensional studies employing bicycle ergometry. Additionally, as noted earlier, they help to clarify the meaning of subjective fatigue.

In general, the connotatively similar subjective qualities of "weak," "worn out," "no energy," "tired," "weary," "exhausted," and "fatigued" tend to cluster in a wide variety of situations including imaginal states of activation or fatigue (Wolf, 1967; Wijting, et al., 1970), exposure to high terrestial altitude (Stamper et al., 1970; Stamper, et al., 1971), acute asthmatic attacks (Kinsman, Luparello, et al., 1973; Kinsman, O'Banion, et al., 1973) and during bicycle work (Kinsman, Weiser, and Stamper, 1973; Weiser, Kinsman, and Stamper, 1973). Together, they can be described as composite items of a subordinate category which we have labeled General Fatigue (Weiser, Kinsman, and Stamper, 1973).

But what is meant by such a category labeled General Fatigue? One way of answering this question is to locate its position within the larger set of subjective symptoms experienced during work. Figure 14-6 presents a pyramidal schema, including General Fatigue, which comprises several levels of subjective report during bicycle riding. This schema is an outgrowth of the multidimensional studies of symptomatology during prolonged bicycle riding (Kinsman, Weiser, and Stamper, 1973; Weiser, Kinsman, and Stamper,

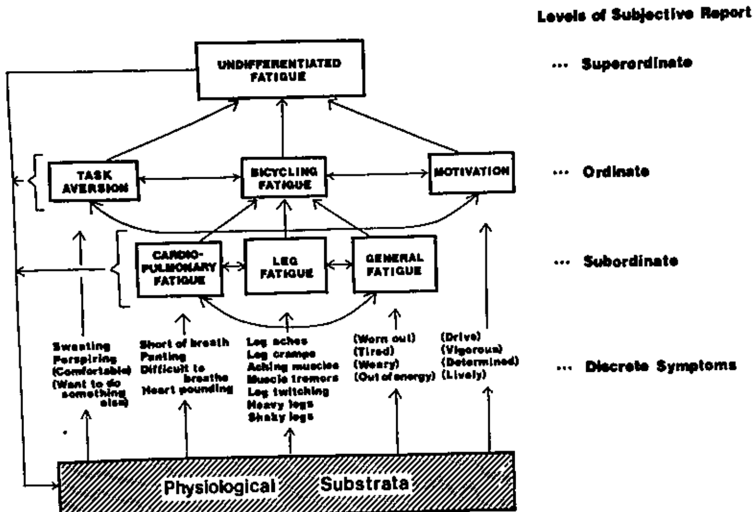

Figure 14-6. Pyramidal schema describing levels of subjective report during bicycle ergometer work. For explanation, see text.

1973). The basic framework would be applicable to the performance of *any* task although the specific symptoms and symptom categories may changes substantially between tasks.

In Figure 14-6, the levels of subjective report are labeled in the right hand margin. At the most basic level, the assumption is made that discrete symptoms have their genesis in known or as yet unidentified physiological changes occurring during work, i.e. within the Physiological Substrata.[1] On a statistical basis, these discrete symptoms have been shown to organize into meaningful groups. At the lowest level of organization, these groupings of discrete symptoms have been labeled Subordinate. The Subordinate level of organization includes three component subcategories; i.e. Cardiopulmonary, Leg, and General Fatigue, of a Bicycling Fatigue category shown in the middle level labeled Ordinate. Also at the Ordinate level are two additional categories of symptoms labeled Task Aversion and Motivation each comprised of a set of discrete symptoms. In turn, the symptom categories at the Ordinate level funnel into the highest level of subjective report. At

1. In Figure 14-6, the discrete symptoms indicated in parentheses are not clearly a simple, *direct* function of changes in the physiological substrata.

this superordinate level occur such global reports as Undifferentiated Fatigue.

In general, the arrows between and within levels represent relationships between symptom categories which may be defined empirically. First, the *vertical* arrows indicate that subjective report at a higher level is assumed to be dependent upon physiological events and/or subjective report occurring at a lower level. Second, the *horizontal* arrows indicate that relationships are assumed to exist between the subjective report occurring within any level.

Within this schema, a single *superordinate* report of Undifferentiated Fatigue is composed of discrete symptoms occurring at lower levels. Therefore, this level of subjective report is the most remote from the physiological events that serve to generate discrete symptoms during work. Obviously, the relationships between such a superordinate report and a particular physiological event can be expected to be very difficult to define adequately since mediating symptoms and physiological events intercede.

This pyramidal schema should serve two important functions: first, it provides a way of analyzing what is meant by subjective report during work. By indicating that discrete symptoms may organize into related yet unique categories, and at different levels, it should encourage more precise definition of what is meant by terms such as subjective fatigue: what are people being asked to rate in studies involving subjective fatigue and how can other subjective events affect the ratings obtained? Second, it suggests that the relationships between subjective ratings and specific physiological events during work can be most *precisely* defined at the level of the discrete symptoms and most *imprecisely* at the level of Undifferentiated Fatigue, i.e. the Superordinate level.

In summary, progress in the area of the psychophysiological aspects of fatigue involving subjective symptomatology can best be achieved if the degree of "differentiation," i.e. discreteness, of the subjective report used can be specified clearly.

Psychophysiological Aspects of Subjective Symptomatology

A number of studies, some already reviewed, also have examined changes in subjective qualities during work together with changes in certain physiological parameters, including heart rate, skin and body temperature and heat conductance, sweating, heat loss from the skin, electromyographic (EMG) activity and catecholamine excretion. All of the studies provide some information about the physiological substrata affected during work performance and about the relationship of physiological factors to the genesis of subjective changes experienced.

Fatigue

Several studies have investigated the changes of heart rate and EMG in relation to reports of several forms of fatigue as illustrated in the schema described above (Fig. 14-6). Nunney (1963) obtained global reports of undifferentiated fatigue during physical work. Heart rate was significantly related to the work load and to a global report of undifferentiated fatigue. The most obvious, and also the most probable, conclusion would be the *more work* that one is doing, the *more fatigue* in a global sense one will report. This relationship between HR and ratings of undifferentiated fatigue is difficult to explain in more detail. An explanation of this is suggested in the above schema: undifferentiated fatigue is distant from the ongoing cardiovascular functioning and integrates many intervening, and as yet unspecified, discrete symptom qualities.

A psychophysical study of Bujas, et al. (1966), relating undifferentiated fatigue to isometric work has already been reviewed. They reported a remarkable similarity between the psychophysical power functions for both the perception of undifferentiated fatigue and the integrated EMG amplitude recorded midway through the task. One should note that the subjects were instructed to attend to specific subjective qualities and to give their estimates of fatigue so that the reports were closer to physiological events than the undifferentiated global report utilized by Nunney (1963). Consequently, it would be of interest to explore the relation between the growth of muscle electrical activity and the growth of fatigue reported as a consequence of isometric work.

Symptomatology categories representing more differentiated aspects of subjective fatigue belong to the ordinate and subordinate levels of subjective report (i.e. those described by Kinsman, Weiser, and Stamper, 1973 and Weiser, et al., 1973) and have not yet been related to changes in the physiological substrata. Changes in *motor unit* EMG activity could become synchronized during prolonged exercise with an increased amplitude as has been observed by Lloyd and his co-workers who studied the relationship between reports of pain and EMG activity during isometric work. Lloyd (1971) has shown that EMG changes are associated with a shift to higher amplitude, lower frequency motor unit activity. Since impulse frequency is proportional to motoneuron size (Ruch and Patton, 1967) this would correspond to a change from motor units having larger motoneurons, i.e. white muscle fibers (see Chap. 1), to less fatiguable red muscle motor units with smaller motoneurons. Within the muscle fibers, an altered sodium-potassium balance could produce muscle cell membrane hyperpolarization, while central nervous influences could increase motoneuron inhibition (see Åstrand and Rodahl, 1970).

In addition, Kogi and Hakamada (according to Åstrand and Rodahl, 1970) have reported decreased proprioceptive afferent impulses from muscle spindles during isometric-isotonic contractions. This suggests that *mechanoceptors* such as muscle spindles and Golgi tendon organs must be considered in any physiological explanations of changes in the Leg Fatigue symptom category. Moreover, *joint pain receptors* have been suggested by Basmajian (1967) to play a role in the local fatigue reported by subjects passively holding weights. This suggests that pain receptors in leg articular capsules and ligaments may be responsible for certain discrete symptoms of Leg Fatigue, e.g. Aching Legs. Also, compression of muscle blood vessels during exercise could lead to the release of potassium or bradykinin (Ruch and Patton, 1967), thereby activating leg *chemoreceptors*. Such changes are also associated with reports of an aching pain. Further research could proceed to evaluate the relationship (s) of symptomatology changes to the underlying physiological processes such as those mentioned above.

Perceived Effort

Scales of perceived effort are the best studied of the scales used for rating subjective qualities during work. By now, there has been sufficient research to demonstrate the validity, reliability, and replicability of the findings relating Borg's RPE scales, in particular, to various work levels and physiological parameters during standard work situations to recommend application in appropriate studies. Evidence suggests that the RPE scale may be *more* useful than physiological indices of working capacity in real-life situations (e.g. Borg, 1962) since it may merge both motivational factors and physiological cues in a single index. Additionally, its clinical application shows promise in some areas (e.g. Borg and Linderholm, 1970). For the first time, an active international research interest in the application of a single rating technique to a specific subjective quality has developed which has already begun to demonstrate utility.

The development of the RPE scale has been described in detail. Briefly, RPE was shown by Borg (1962) to increase generally in a linear fashion with an increase in work load on a bicycle ergometer. This observation has consistently been confirmed by others (Borg and Linderholm, 1967; Frankenhaeuser, et al., 1969; Skinner, et al., 1969; Kay and Shepherd, 1969; Ekblom and Goldbarg, 1971; Edwards, et al., 1972; Pandolf, et al., 1972; Bar-Or, et al., 1972; Gamberale, 1972; Henriksson, et al., 1972; Gerben, et al., 1972; Skinner, et al., 1973a, b; Noble, et al. 1973; Pandolf and Noble, 1973; Morgan, 1973; Weiser, et al., unpublished observations).

After four to six min. of work on a bicycle ergometer, RPE was also found by Borg (1962) to be elevated along with an increase in heart rate. In fact, as was reviewed earlier, RPE and HR were shown to be highly correlated. Borg (1973) has pointed out in a recent review that the scaling of RPE has been changed so that a new relationship, RPE = HR/10, could be obtained during standard bicycle work. He has suggested the RPE "can be of great help in the assessment of physical working capacity for work on the bicycle ergometer" (Borg, 1962, p. 41). Again, many reports have confirmed the RPE-HR relationship (see the references cited above). It is important to note that Borg limits this relationship to work on a bicycle ergometer in a thermoneutral environment (i.e. 24°C).

The question now arises concerning whether the RPE-HR relationship is true in general over all tasks and work situations. In the following discussion, this relationship will be shown to be highly dependent upon the task being performed. First HR during work in heat is increased about 1 pbm for every 1°C increase in environmental temperature (Kamon and Belding, 1969) and should be associated with a higher RPE. Skinner, et al. (1973b) found that for "lean" men walking on a treadmill in a progressively increasing work task at 32°C, the RPE scores were greater than the values obtained at 24°C. HR was elevated about 10 bpm in the heat. In contrast, Pandolf, et al. (1972) studied the effects of heat on the RPE-HR relationship during a prolonged bicycling task at about 40 percent max V_{O_2}, but in an environment having air moving past the subject at 30 meters per min. They found no differences between the RPE values obtained at 24°, 44°, or 51°C. HR was elevated about 20 bpm and 30 bpm at 47° and 54°C. In this situation, consequently, they concluded that "under the stress of heat, [HR] may not be the stimulus utilized for arriving at rated perceived exertion."

Second, working continuously on a bicycle ergometer at the same power, e.g. 1000 kpm/min., but at different pedalling rates produces the same HR response and should give similar RPE values. Henriksson, et al. (1972), however, found that pedalling at 30 rpm resulted in higher RPE scores than at 60 rpm, and Pandolf and Noble (1973) have reported higher values at 40 rpm than at 60 or 80 rpm. Both found similar heart rates at the equivalent power outputs, and both concluded that sensory input from mechanoreceptors may be another source of cues, in addition to HR, integrated via feedback loops into the report of perceived effort.

Finally, Ekblom and Goldbarg (1971) used autonomic blocking drugs elegantly to dissociate RPE from the HR response to bicycling. To block the sympathetic control of HR increase, propranolol was injected, while atropine was injected to block parasympathetic control. Neither drug altered max V_{O_2}, but propranolol decreased and atropine elevated HR at a given submaximal work load. However, *neither* drug changed the report of RPE at *any* given workload. Ekblom and Goldbarg conclude that "it is quite clear that tachycardia as such is not a primary factor for the [report] of RPE during work." They propose, furthermore, that a "local factor," i.e. the feeling of strain in the working muscles "is an important factor in [the report of] RPE."

RPE also does not seem to arise *per se* from the work load expressed in absolute terms or in terms of percent max V_{O_2}. That is, in the studies that investigated the influence of pedalling speed (Henriksson, et al., 1972; Pandolf and Noble, 1973), the higher RPE scores at lower rpm's were associated with oxygen uptakes that did not differ from the other pedalling rates. Also, Edwards, et al. (1971) compared an intermittent bicycle work task with continuous work at an equivalent power output and found higher RPE values for intermittent work that had the same oxygen uptake as a continuous work task. These observations suggest that RPE would be the result of motor system feedback and, consequently, might be highly dependent upon the task being performed.

That the RPE report is strongly affected by the work task becomes quite evident when one compares running or walking to cycling, arm to leg work, and eccentric (negative) to concentric (positive) work. Many studies have compared running to cycling (Ekblom and Goldbarg, 1971; Bar-Or, et al., 1972; Skinner, et al., 1973b), and all have found that at a given oxygen uptake, RPE was *greater* for bicycle work. However, Ekblom and Goldbarg (1971), Skinner, et al. (1927b), and others have found that max V_{O_2} was reduced when the work task was switched from running to cycling. Expressed in relative terms, i.e. as percent max V_{O_2}, RPE reports become similar for the two tasks (Ekblom and Goldbarg, 1971 and Skinner, et al., 1973b). Ekblom and Goldbarg (1971) have suggested that since there is more pronounced static work in cycling "the higher RPE scoring for a given submaximal work on the bicycle may be caused by the higher local muscular strain [associated with a] higher blood lactate concentration."

For walking, Noble, et al. (1973) observed that HR was less than running at velocities below 4.9 mph. At 4.9 mph, the HR values for walking and running intersected, i.e. were equal. Above 4.9 mph, walking gave HR's greater than running. RPE followed the same pattern, but the point at which RPE and velocity values for running and walking intersected was significantly lower (4.3 mph). Also at the same HR, RPE was higher for walking than for running. Noble, et al. concluded that the difference appeared to be due to the differing influence of the "local factor" proposed by Ekblom and Goldbarg (1971), i.e. strain in the working muscles.

Second, arm work is similar to cycling in that it gives higher RPE scores at the same HR (Gamberale, 1972; Ekblom and Goldbarg, 1971). RPE is also higher for armwork at the same oxygen uptake. However, changes in

RPE were associated with similar increases in blood lactate concentration. Gamberale (1972) suggested the following hypothesis: "the higher the blood lactate concentration an excercise produces as compared to oxygen uptake, the higher will be the level of the overall perception of exertion. . . ." Ekblom and Goldbarg (1971) further emphasized that "RPE . . . seems to be related to the size of the muscle mass involved.

Finally, Henriksson, et al. (1972) have shown that negative work done eccentrically on a bicycle ergometer is associated with higher RPE scores than positive concentric work at the same HR or oxygen uptake. They point out "that different types of information or sensory input are being integrated in various combinations or under different weightings in the two exercise conditions. In addition, the forced stretch placed on the muscle in eccentric exercise might result in an increase in Golgi tendon organ activity and, thereby, in an inhibition upon motor neurons [and could result in], greater numbers of motor impulses . . . to recruit the appropriate number of [motor units]. This may result in [an] increased exertion perception and would help explain the greater exertion perception in eccentric exercise at similar levels of metabolism and circulatory and ventilatory stress."

Additional evidence for motor systems feedback as the basis for perceived effort comes from studies on training, hypoxia, and prolonged work. Docktor and Sharkey (1971) found that training on a treadmill task (walking at 3.5 mph with the grade raised 1% per min.) showed no change in RPE for a work load that gave a HR of 150 bpm, although this workload had increased during training. Ekblom and Goldbarg (1971) tested men on a bicycle ergometer before and after eight weeks of cross-country running. Max V_{O_2} increased from 2.90 to 3.35 L/min, yet RPE scores were the same for relative workloads expressed as a percentage of max V_{O_2}. However, for the same absolute work load, RPE was decreased after training. Ekblom and Goldbarg suggested that the explanation "can be found in both the lesser strain on the cardio-respiratory systems and in the improved function of the working muscles, which is reflected in the lower oxygen deficit and blood lactate concentration." Chapter 2 points out that the adaptation to training results in muscle hypertrophy and enhancement of the capacity of the muscle to produce energy for contraction, along with an increase in capillaries especially around high-oxidative slow-twitch fibers. Thus after training, work at a given load level could be the result of fewer motor units contracting with the decreased motor units' recruitment. If so, this reduction in recruitment, via feedback pathways, would result in a lower perception of effort.

Hypoxia produces an effect opposite to that of training. Max V_{O_2} is decreased some 20 to 25 percent at 14,000 ft (see Chapters 13 and 14, Vol. 1). Gerben, et al. (1972) found that an hypoxic environment of 12 percent O_2 (approx. 15,000 ft altitude) significantly increased RPE for a given work task. Weiser, et al. (unpublished observations) studied six men working at about 30, 60, and 100 percent max V_{O_2} in Denver, Colorado (5,300 ft altitude) and on Pikes Peak (14,110 ft altitude). They observed that RPE was the same at both locations although the workloads were decreased at high altitude to match the Denver percent max V_{O_2} load levels. It is tempting to speculate that due to the altered oxygen gradient between muscle fibers and capillaries in the working muscles, more motor units were recruited to do the same relative work. Hence, motor activity would be increased and would be reflected by the increased RPE.

With prolonged work, Pandolf, et al. (1972), Morgan (1973), and Weiser, et al. (unpublished observations) have observed a gradual increase of RPE from the fifth min. of work to the end of the task. A speculation similar to that offered for hypoxia, i.e. increased recruitment of motor units, could be a partial explanation for these observations.

Thus, RPE has become widely accepted as a valid and reliable scaling tool for measuring perceived effort. In terms of the proposed model, RPE probably belongs to the superordinate level of subjective symptoms, and consequently is the result of the integration of many discrete cues having different weights, as Henriksson, et al. (1972) have suggested. If RPE is a superordinate quality, then it is not "close to" the physiological substrata. Of all the symptoms reported in this review, Borg's RPE has been best characterized, and two conclusions can now be drawn. First, as emphasized in Chapter 1 (see Figs. 1-1 and 1-6), perceived effort forms part of the overall feedback system that enables us to perform work. Much evidence now suggests that the information concerning perceived effort feeds back from the motor system. However, the direct neuronal linkage from the motor centers and the role of peripheral proprioceptive feedback loops are not known. Second, the relationship between RPE has been shown in the studies discussed above to be directly related to HR only under standard conditions, as Borg (1962) emphasized. Specifically, deviations from cycling in a thermoneutral environment and the use of autonomic nervous system blocking agents clearly demonstrate that RPE can be dissociated from cardiac frequency.

Pain

In a study reviewed previously, Lloyd, Voor, and Thieman (1970) also measured EMG changes along with pain ratings in an isometric hand dynamometer task using either 25, or 50 percent of maximum grip strength. This task involved the self-paced rating technique in which each subject was required to call out "1" when he first noticed perceptible pain, and so on while a final call of "5" was defined as intolerable pain corresponding to task termination. In general, average EMG amplitude of the biceps increased with time and with successively higher pain ratings. One of the more intriguing observations made by Lloyd, et al. (1970) was that EMG amplitude tended to increase rather abruptly toward the latter part of the task, closely associated with the onset of muscle tremors. It is interesting to note that Weiser, et al. (1973) also found a subjective symptom, Muscle Tremors, that was significantly increased during prolonged bicycle work. This increase in EMG amplitude was interpreted as the time corresponding to muscle fatigue, while the additional time that the subject persisted beyond this point was suggested to be due to psychological factors associated with motivational level.

Also, Lloyd (1971) had ten male subjects perform an isometric task involving sustained contraction of the elbow flexors at 30, 50, and 70 percent of their maximum level. EMG activity in the biceps, triceps, deltoid, and contralateral triceps were monitored throughout the task. As in previous studies by Lloyd, subjects were instructed to continue for as long as possible and to rate the level of pain intensity on a five-point scale using the self-paced technique. All subjects were run three times at each load level during nine sessions. Ratings of pain intensity were related quadratically with time on the task for the 30 and 70 percent load levels and linerally for the 50 percent load level. There were striking differences in the rate in which subjective pain intensity increased between load levels, increasing much more rapidly for the higher load levels (also see Menzer, Smith, and Caldwell, 1969; Lloyd and McClaskey, 1971; Lloyd, Voor, and Thieman, 1970). Mean EMG amplitude for the biceps at each of the ratings of subjective pain showed a clear increase for all load levels as ratings of pain intensity increased. Increases in EMG activity in the triceps, deltoid, and contralateral triceps also increased with pain ratings, although the contralateral triceps increased only for the high ratings of pain intensity (4 and 5) for the 70 percent load only. One of the outstanding features of this study involved frequency analysis of the EMG for each of the ratings of pain intensity. For each load level, but more so for the two higher load levels, as the rating of pain intensity increased there was a marked *increase* in amplitude in EMG amplitude for the lower frequencies and a lesser *decrease* in amplitude for the higher EMG frequencies. Lloyd suggested that with increasing pain intensity during isometric tasks, there is a recruitment of higher threshold motor units firing at a low frequency. An alternative concept specifying an increased *rate* of firing during increased fatigue received no support from Lloyd's data. This study stands as an excellent demonstration of the payoff potential in relating subjective report during work performance to physiological variables.

Lloyd (1972) has subsequently demonstrated that when an auditory bio-

electric feedback signal (biofeedback) proportional to EMG amplitude was provided to subjects doing isometric tasks similar to that used by Lloyd (1971), the level of muscle activity (mean EMG amplitude) required to maintain contraction was significantly reduced across all ratings of pain intensity. These differences were obtained in spite of the fact that mean endurance times and average times for successive self-paced ratings was not different for subjects provided and not provided EMG feedback. These results indicate that biofeedback improves efficiency of isometric performance without affecting total endurance time or the points at which various ratings of pain intensity are given. Since it may require a number of training sessions before significant improvement in performance is noted using biofeedback, it would be interesting to determine how biofeedback would affect endurance time and self-paced ratings of pain intensity across repetitive training trials during isometric work.

Thermal Discomfort

Changes in both the subjective qualities, Thermal Sensation and Discomfort, have been related by Gagge, et al. (1969) to physiological variables associated with thermoregulation; this study has been reviewed in detail. Briefly, the sensation of "warm discomfort" after 30 to 40 min. of work was related to metabolic rate, rectal temperature, skin conductance, and most highly to sweating rate ($r = .66$). In contrast, perception of thermal sensations were principally related to the ambient air temperature and to the skin temperature.

SUMMARY AND CONCLUSIONS

Many different subjective qualities have been measured during work representing different aspects of multidimensionally organized subjective symptomatology. These qualities have been measured either by using psychophysical methods (see Table 14-I) or rating scales (see Tables 14-II through 14-IV). A model has been proposed in this review (see Fig. 14-6) that stratifies these qualities into different levels of subjective report beginning with the discrete symptoms, forming categories of symptoms at intermediate levels, and finally converging into a global, superordinate level of report typified by Undifferentiated Fatigue. All levels of symptomatology are presumed to be linked by feedback loops to the underlying physiological substrata. Cues from changes in the physiological substrata during work give rise to the reported symptoms. In turn, the symptomatology experienced can affect work performance.

In the model, the concept of the ordinate and subordinate levels of subjective report also emphasizes that the significant subjective qualities experienced are highly dependent on the work task performed. First, the amount of muscle mass utilized, e.g. arm or leg work, will alter the discrete subjective qualities and the manner in which they group at the ordinate or subordinate levels. Second, the intensity of work relative to the maximal aerobic power obtainable for any task will determine the intensity of subjective symptoms experienced.

Viewed according to a classic division, work can be divided roughly into categories according to the predominant energy requirements of the task: mental, sedentary, and strenuous. In tasks studied to date wherein subjective fatigue has been measured, these divisions have not always been clear cut. Nevertheless, the object of the brief summary which follows is simply to show that the subjective qualities composing what is termed subjective fatigue differ according to task requirements.

A. As early as 1928, Poffenberger showed that a global report of undifferentiated fatigue increased in association with the amount of mental work performed and was related to performance decrement. The pattern of discrete symptom qualities involved in mental work and sedentary, light submaximal work appears to differ from those tasks that require a higher energy expenditure. Specifically, Kogi, et al. (1970) have found that individuals such as hospital pharmacists generally report experiencing infrequent discrete symptoms although about 25 to 37 percent of these complained of eye strain, shoulder stiffness, and heavy legs at the end of work. Engine drivers, engaged in a form of sedentary, light submaximal work, also complained of these symptoms most often. In contrast to factory workers engaged in heavy physical work, all symptoms reported were infrequent for the pharmacists and engine drivers while factor analysis indicated that the organization of the same set of symptoms into *categories* differed widely between these occupations. Any global rating of Undifferentiated Fatigue used would likely integrate numerous such discrete symptom qualities. In fact, it has been demonstrated that global reports of Undifferentiated Fatigue change, as expected, during housework (Gross and Bartley, 1951), operation of aircraft (Pearson and Byars, 1956; Buckley and Hartman, 1969), and formal psychomotor tasks (McNelley, 1957). The difficulty in interpreting all of these latter studies has simply been due to Undifferentiated Fatigue being a composite of discrete symptoms. The specification of the discrete symptom qualities involved in fatigue during mental and light submaximal work and the manner in which they group, is a useful area for further research.

B. Subjective symptomatology observed during moderate or heavy work tasks can be grouped into two major categories: perceived fatigue and perceived effort. Other symptoms studied have been perceived effort expended, pain, discomfort, and thermal sensations.

1. During these types of tasks, a definite grouping of discrete symptoms has been identified (Wolf, 1967; Kinsman, Weiser and Stamper, 1973) and labeled simply Fatigue.

   a. Reported qualities composing the Fatigue category are clearly dependent on the types of tasks being performed. Weiser, et al. (1973) have found that a distinct Leg Fatigue grouping of items could be separated from items descriptive of General Fatigue for subjects performing prolonged strenuous bicycle work. Again, Kogi, et al. (1970) have found that persons employed on differing physical tasks, such as iron foundry workers, report different frequencies of symptoms experienced and, in turn, demonstrate different organizational groupings of symptom qualities to form symptom categories.

   b. As the work load is increased on the bicycle ergometer, scores increase for Leg Fatigue, Cardiopulmonary, and General Fatigue categories reported after five min. of work (Weiser, unpublished observation). Nunney (1963) has found that the report for a global measure of fatigue increased with increasing work along with the expected increase of HR. Heuting and Sarphati (1966) also observed a greater rating of undifferentiated fatigue for a bicycle task that finished in a higher work load.

   c. Finally, throughout the duration of a prolonged work task, Weiser, et al. (unpublished observations) have observed increased scores for the Fatigue, Cardiopulmonary Fatigue, and General Fatigue categories. Buckley and Hartman (1969) found that the rating of global fatigue (Pearson and Byars, 1956) increased throughout a transatlantic helicopter flight, but decreased during the "flyby" staged in Paris at the end of the flight.

2. Borg's Rating of Perceived Effort (RPE) has become recognized as a valid and reliable scale, although the discrete symptoms integrated by RPE remain to be defined more completely.

   a. RPE scores are highly dependent upon the work task. Running produces a different RPE score when compared to cycling at a given heart rate (Ekblom and Goldbarg, 1971; Bar-Or, et al., 1972; Skinner, et al., 1973b) or to walking (Noble, et al., 1973). Arm work gives a higher RPE at a given heart rate than does cycling (Ekblom and Goldbarg, 1971; Gamberale, 1972). Negative, eccentric work also produces a higher RPE score at a given heart rate than does positive, concentric work (Henriksson, et al., 1972). In fact, for equivalent power outputs, subjects pedalling at 60 rpm have reported lower RPE scores than when pedalling at 30 rpm (Henriksson, et al., 1972) or at 40 rpm (Pandolf and Noble, 1973).

   b. When work is expressed as being a percent of maximal performance, the variability in RPE becomes markedly reduced. For example, the differences between cycling and running (Ekblom and Goldbarg, 1971; Bar-Or, et al., 1972; Skinner, et al., 1973b), cycling during normoxic and hypoxic environment (Gerben, et al., 1972; Weiser, et al., unpublished observations), and cycling before and after training (Ekblom and Goldbarg, 1971) can be explained by the changes in maximal aerobic power produced by these situations. Also, Schmale, et al. (1963) have observed that the effort involved in holding a weight measured by a psychophysical technique was similar for men and women if perceived effort was related to relative weight held, i.e. weight held divided by maximal weight that could be held.

c. RPE increases throughout the course of bicycle work at a fixed load level (Pandolf, et al., 1972; Morgan, 1973; Weiser, et al., unpublished observations).

d. In view of the observations presented, RPE appears to reflect the state of activity of the motor system. RPE is correlated to cardiopulmonary responses when different work loads are compared under standard work conditions, e.g. on a bicycle ergometer, a point clearly emphasized by Borg (1962).

3. A rating of perceived effort expended was found by Lloyd and McClaskey (1971) to increase linearly throughout a prolonged walking task, with the most pronounced linearity occurring only after several trials on the task.

4. Likewise, with practiced subjects ratings of pain and perceived effort expended have been shown to increase linearly during exhausting prolonged isometric work (Caldwell and Smith, 1967; Lloyd, et al., 1970).

5. The sensation of "warm discomfort" after 30 to 40 min. of work was found by Gagge, et al. (1969) to be related to metabolic rate, rectal temperature, skin conductance, and most highly to sweating rate. In contrast, they observed that the perception of thermal sensations were principally related to the ambient air temperature and to the skin temperature.

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