The Metabolic Cost of Performing a Specific Exercise in a Low-Friction Environment

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THE TRACTIONLESS aspect of zero gravity may cause degradations in the output characteristics of work manually produced by the unbraced operator. These degradations can appear as either efficiency or total output capability decrements. In addition, they may be of sufficient magnitude to significantly impair the effectiveness of the human as a work and force producer in the tractionless state.

Previous simulated zero-gravity studies have shown that adequate levels of sustained work can only be obtained by efficient bracing of the force producing operator.[4, 5] This necessitates that the man, in combination with his bracing technique, produce a force equal and opposite to the resisting force. In a tractionless environment, the development of resultant forces may entail the utilization of muscle groups other than those normally employed, with a consequent reduction in efficiency which can cause penalties in terms of the metabolic cost of work. Such reductions could result in design requirements for tractionless environments differing substantially from those utilized within a fixed object/fixed operator relationship. If system requirements are not consonant with the efficiencies derived via diverse bracing techniques, substantial reductions in efficiency might be effected which could necessitate changes in life support system sizes, access areas, work space volume requirements, etc.; in short, such changes could alter current concepts of system sizing, cost, and/or manpower requirements for a specific mission.

Need now exists for data detailing the effects of bracing techniques on operator efficiency since changes in efficiency may be reflected throughout the entire system.[1] A requisite step in the evaluation of bracing techniques is the determination of a base level to which obtained efficiency values, the results of bracing technique investigations, may be compared. In the context of engineering design needs, a cogent and reliable reference system can be derived from the relationship between power output under various work loads and metabolic costs. This relationship, utilized previously in ergometric studies,[6, 8, 9, 11] enables the procurement of data directly applicable to hardware design by system engineers.

To obtain a quantitative measurement of the changes in efficiency produced by the presence or absence of traction, a study was executed which examined the relationships between total output, power and metabolic cost. The study, which required the production of work in tractive and non-tractive states, was designed to answer the following questions:

What are the differences in the metabolic cost of performing work of a specific nature, the rates at which such work is produced, and the total amounts of work produced which are attributable to the absence or presence of traction during the working period?

PROCEDURE

Subjects and Method: The subject population, consisting of 16 male employees of The Boeing Company, and ranging in age from 18 through 51 years, represented the 5th through 95th percentile in stature.[7] The task, self-paced in mode, consisted of a horizontal reciprocating motion made on the handle of a modified wall exerciser with the right hand while the subject stood on a horizontal platform. The actual work was produced by pushing a shaft through a ball bearing

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guide which effected the raising and lowering of a 7 or 15-½ pound weight a distance of up to 22 inches one way. The exerciser handle, located 47 inches above the platform, was grasped with the right hand in the zero degree pronation position while isometric bracing was effected by simultaneously grasping in the same fashion a vertical bar with the left hand. The bar was placed at the same height as the exerciser handle, but 16 inches to the left and 7.5 inches forward of the resting position of the exerciser handle. During the test period, oxygen consumption was obtained via a Collins Gasometer, modified to function as a closed-cycle rebreather system. The Gasometer was integrated with an X-Y recorder and produced a 1 mm. change on the recorder per 60 cc. change in Gasometer volume. The vertical displacement of the weight was measured with an accuracy of ±2%. Gliding cyclography[2, 3] was used to obtain time ratios of the extension-flexion phases, a necessity in the calculation of negative work output and concomitantly, work output totals.

Subjects assumed the position previously described on a one-degree-of-freedom reciprocating platform. The platform was held stationary by locking pins during tractive tests. During non-tractive tests the platform was free to reciprocate, parallel to the long axis of the "push bar," on ball bearing sheaves. The test period of 30 minutes' duration was programmed as follows:

Pre-test Adaptation

0-3 minutes:	Standing at rest, breathing ambient air through mouthpiece.
3-13 minutes:	(Two five-minute periods) Standing at rest, breathing 100 per cent oxygen, one five-minute period with the platform locked and one five-minute period with the platform unlocked.

Exercise

13-23 minutes:	Ten minutes' exercise, breathing 100 per cent oxygen.

Recovery

23-30 minutes:	Seven minutes' recovery, standing at rest, breathing 100 per cent oxygen, tractive.

The two five-minute periods encompassed by minutes 3 through 13, one period with the platform locked and one with platform unlocked, were systematically alternated. This was done to balance differences in the rate of oxygen consumption caused by diffuse restless motor activity.

The subjects performed either for two or four test sessions, depending upon subject availability. All subjects received at least two test sessions, one each in a tractive and a non-tractive mode for the same weight loadings. Ten subjects performed with the 15-½ pound load and 14 were utilized for the 7.0 pound load. To eliminate serial order effects, half the subjects received the tractive test condition at a given weight loading first, and the other half received the non-tractive work situation first. Each session, for a given subject, was administered at the same time daily to eliminate diurnal effects.

RESULTS

The data were subjected to analyses via a correlated "t" test (two-tailed).

A. *Pre-test Adaptation Period*
   No significant differences in oxygen consumption were found when comparing the two five-minute periods, one with the platform locked and one with it unlocked.
B. *Exercise Period*
   1. 7-pound Load
      a. The non-tractive O_2/HP ratio was 12 per cent larger than the tractive (significant at the 0.01 level). (Table I.)

TABLE I. METABOLIC COST FOR 7 POUND LOAD
(10 MINUTE WORK PERIOD)
N = 14

	Mean (Liters O_2/-min/HP)	Standard Deviation	Range (Liters O_2/-min/HP)
Tractive	36.7 } *	6.5	28-49
Non-tractive	41.2 }	5.1	33-50

Standard Error of the Mean of the Differences = 0.98.
Product—Moment r Between Tractive and Non-tractive States = .59.
* 12% Mean Increase Significant at .01 Level.

TABLE II. METABOLIC COST FOR 15-½ POUND LOAD
(10 MINUTE WORK PERIOD)
N = 10

	Mean (Liters O_2/-min/HP)	Standard Deviation	Range (Liters O_2/-min/HP)
Tractive	29.8 } *	3.9	25-37
Non-tractive	38.6 }	5.9	32-50

Standard Error of the Mean of the Differences = 1.35.
Product—Moment r Between Tractive and Non-tractive States = .69.
* 29% Mean Increase Significant at .001 Level.

      b. No significant differences in work rate were found between tractive and non-tractive periods. The average rate was 0.015 HP.
      c. The total work for the non-tractive condition was 1 per cent less, not statistically significant, than the tractive condition.
   2. 15-½-pound Load
      a. The non-tractive O_2/HP ratio was 29 per cent larger than the tractive.
      b. No significant differences in work rate were found between the tractive and non-tractive conditions. The average rate was 0.022 horsepower.
      c. The total work for the non-tractive condition was 4 per cent less, not statistically significant, than the tractive condition.
C. *Combined Exercise and Recovery Period*
   1. 7-pound Load
      The oxygen consumption for the non-tractive condition was 10 per cent more than for the tractive (significant at the 0.025 level).
   2. 15-½-pound Load

The oxygen consumption for the non-tractive condition was 25 per cent more than for the tractive (significant at the 0.005 level).

DISCUSSION

The study, prompted by a desire to ascertain quantitative information about the decrement imposed on man's work producing capability by a non-tractive environment, has shown the results of a specific exercise. These data should serve primarily to point out the necessity for an extensive investigation of the sources of force and work decrements and the means for minimizing these. Since the experimental procedures in this study utilized a one-degree-of-freedom system, task execution within a relatively confined postural approach regime was facilitated. Extraneous energy expenditures due to the correction of lateral body displacements via weaker muscle process outputs (abduction and adduction) were thus minimized. Despite the advantages that such a regime offers metabolically over a six-degree-of-freedom situation, any assumption that the experimentally obtained values represent either a minimum or a maximum decrement in efficiency would be completely unwarranted. The actual efficiency level attained by a space worker will be determined by the interaction of many variables. Primary among these are the personal protection equipment, the nature of the task, the specific bracing technique employed, the work output rate, and appropriateness of tools and the anthropometric considerations.

The study results are of primary importance in terms of their implications for advanced system design, planning and research. Pragmatically, efficiency decrements can result in reconsiderations and evaluations of future system sizing, manning requirements and operator requirements, all of which may result in increased over-all cost of future systems. Decrements in performance of the space worker are to be anticipated; how much, in what fashion and how may they be minimized, are the answers which must be provided to ensure both technical and economic feasibility.

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