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Computers in Biology and Medicine 33 (2003) 143–167

Computers in Biology and Medicine

www.elsevier.com/locate/compbiomed

Physiological state model for human ergonomic workload

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Received 28 June 2002; accepted 28 October 2002

Abstract

Twenty ergonomic tasks were evaluated in which human operators performed mixed static work and dynamic work. Steady-state physiological data are the input into a model as regressor variables, which are then multiplied by the respective regressor coefficients. The resultant physiological state model output is a single response variable that represents the workload. Mixed stepping regression techniques were utilized to calculate the regressor coefficients. Ten physiological state model equations resulted. A lower order equation (with three regressor variables) accounted for 80% of the observed variance. The highest order equation (with ten regressor variables) accounted for 89% of the variance.

Keywords: Human workload; Physiological state; Multiple regression; Mathematical model; Ergonomic engineering

1. Introduction

Workload has been defined by Phillips [1] as the reaction of the human body when performing external work. When the external work is physical work, the bodily reactions consist of physiological adjustments and adaptations required for the performance of that external physical work. When these physiological adjustments and adaptations can be measured and quantified, the ergonomic engineer has an analytical basis for the quantitative assessment of human physical workload. The acquisition of physiological data with respect to the neuromuscular system and the cardiopulmonary system is necessary [2]. The quantification of such physiological data and the application of these quantitative relationships represents a physiological state model for human workload.

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0010-4825/03/$ - see front matter
doi:10.1016/S0010-4825(02)00064-1

Most work performed during ergonomic tasks is a combination of *static* work (muscle generates internal force, but without external movement) and *dynamic* work (muscles generate force that results in external movement). With *static* work, then no external work is accomplished in the environment. *Dynamic* work, however, occurs when external work is accomplished in the environment. Consequently, it is helpful to briefly review the physiological reactions to both static work and dynamic work.

1.1. Physiological background

The cardiopulmonary responses associated with static work reflect the human reaction to isometric muscle contraction as described by Petrofsky and Phillips [3]. When isometric contractions are sustained at muscle forces that are *non-fatiguing* (forces that are below 10% to 15% of the muscle's maximum strength), heart rate and blood pressure rise to a certain level and are then maintained throughout the duration of the static work. This represents a steady-state response in which the blood pressure will rise 10–20 mmHg, and the heart rate will rise 10–20 beats per minute. However, there is a dramatic rise in blood pressure (both the systolic pressure and the diastolic pressure) during the time course of the *fatiguing* isometric muscle contractions (see below).

The cardiopulmonary responses to fatiguing static work are not only of greater magnitude, but also of a different pattern than of those observed during dynamic work. For example, during dynamic work, Asfraud and Rodahl [4] observed that the systolic pressure will increase, but the diastolic pressure will decrease, and the peripheral resistance will decrease during the time course of the fatiguing dynamic work. By contrast, during the course of fatiguing static work, both the systolic pressure and the diastolic pressure will increase and there will also be a boost in the peripheral resistance.

Cardiac output increases modestly during fatiguing static work. A resting cardiac output of 5 l/min will usually only become boosted to about 8 l/min over the duration of fatiguing static work. The heart rate response during fatiguing static work is much more modest than during dynamic work. The heart rate may augment to a level above 200 beats/min (during dynamic work). However, during static work the heart rate rarely exceeds 120 beats/min.

Oxygen consumption ($\dot{V}_{O_2}$) during fatiguing static work also intensifies modestly. However, ventilation ($\dot{V}_{AIR}$) can increase markedly. Some individuals will actually experience a distinct hyperventilation. Although heart rate and blood pressure continuously rise throughout the time course of fatiguing static work, there is little change in $\dot{V}_{AIR}$ or $\dot{V}_{O_2}$ until approximately halfway into the duration of fatiguing static work. After that, these parameters increase and may become enhanced markedly.

When an individual performs moderate dynamic work, vasoactive metabolites are produced and accumulate in the working muscles [5]. This results in a dramatic dilation of the blood vessels in the working skeletal muscle. As a result, the blood flow through the working skeletal muscle advances to amounts from 10 to 20 times that of the resting (non-working) state. Venous return to the right side of the heart can also be augmented due to the enhanced contraction of skeletal muscles around the veins returning blood to the right side of the heart. This occurs because of compression of the veins and the subsequent one-way displacement of the blood toward the thorax. The enhancement in body temperature (which is produced by the dynamic work) will further dilate blood vessels in the skin in order to offload heat. The net effect of this vasodilation of skeletal muscle and skin blood vessels is to dramatically reduce the systemic peripheral resistance (R). However, there is marked vasoconstriction in the viscera (stomach, intestines, kidneys, etc.) so that blood flow to these organs