MAXIMAL WORK CAPACITY ON MOVING PLATFORMS

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INTRODUCTION

In the scientific literature some general attention has been given to the phenomenon of Motion Induced Fatigue (MIF; Colwell, 1989). However, only few attempts have been made to investigate the actual energy expenditure by the human body during work in a moving environment or to study fatigue in relation to the relative work load, expressed as percentage of maximal workload or as percentage of maximal oxygen consumption. The results of these studies showed only a minor increase in oxygen consumption during simulated ship movements, while the subjects looked rather fatigued (Crossland, 1994; Wertheim et al 1995). This was surprising, as the work loads used (< 30% Vo_2max) were well below the standard for acceptable **8** hour work level, i.e. 40% Vo_2max (Evans et al, 1980; Åstrand & Rodahl, 1986).

In this respect these studies seemed to suggest that expressing workload as a percentage of the Vo_2max measured before the experiments is possibly misleading, when judging fatigue. In an attempt to understand this finding, it was hypothesized that maximum work capacity in a moving environment might be less than in a stationary environment (Wertheim et al, 1995). If that is correct, Vo_2 during work inside the moving Ship Motion Simulator (SMS) should not have been expressed as a percentage of maximum capacity as measured before the experi-ments, but as that measured in the moving SMS.

A reduction of maximum work performance could be expected from restrictions imposed on the body stemming from additional muscular activity required for maintaining one's balance. But to the extent that oxygen consumption reflects muscular exertion, a reduction of maximal performance would not automatically imply a decrease of maximum oxygen consumption. If no reduction in maximum oxygen consumption is observed together with a decrease of maximum performance, a decrease of efficiency of work would be implied.

The present experiment was designed to answer the following questions by performing maximal tests in both the stationary and the moving SMS: is it a reduction of maximum power or a reduction of efficiency or both, which underlies the fatigueing effects of working on a moving platform?

MATERIALS AND METHODS

Experiments: In balanced order a graded exercise test (GXT) on a cycle ergometer (Lode Excalibur) was performed by subjects inside a moving or stationary SMS, untill exhaustion was reached. Both experimental sessions were separated by approximately a week, to prevent physical fatigue affects from one session to another. **A** complete GXT lasted for approximately 15-20 minutes. Dependent variables were maximum power, maximum oxygen consumption (Vo_2max), metabolism and efficiency. The efficiency was calculated as the quotient of power and metabolism. Metabolism was calculated from averaged Vo_2 and Vco_2 according to ISO 8996 (1990).
In addition, also heart rate was measured, and **an** attempt was made to measure blood lactate levels.
Ship Motion Simulator (SMS): The SMS consists of a large cabin, placed on top of a hydraulic cylinder system. The cabin can move with three degrees of freedom: vertical motion, pitch and roll. The experimental design consisted of a movement condition and a stationary control condition. In the movement condition the SMS moved according to a profile of a small boat on a calm sea (Wertheim et al, 1996a).
Subjects: Eight physically fit subjects (four men and four women) participated in this study. Subjects had been screened medically and found healthy. Data from one male subject had to be rejected, as during his debriefing after participation in a follow-up experiment he confessed to suffer **from** exercise induced asthma. All subjects gave their written informed consent and the study was approved by the ethical committee of the Institute.
Statistics: All data were analyzed with the statistical software Statistica for Windows (Statsoft Inc.) with a p-value<0.05 as the significance level.

RESULTS

On average the maximum power reached in the maximal tests was lower in the moving SMS (301W) than in the stationary SMS (311W), but the difference just failed to reach significance ($p=.07$), because one subject showed an effect in the opposite direction.
The efficiency during the GXT showed no significant differences between the moving (24.7%) and stationary **(24.5%)** conditions.
Vo_2max, defined as the highest Vo_2 of the successive one-minute periods of the GXT, was significantly lower in the moving SMS than in the stationary SMS (Fig. 1).
Maximum heart rates (HR) were **always** observed to occur during the highest power step completed in each of the maximal tests, but no systematic differences were observed between the stationary and moving SMS conditions. Also no systematic differences in lactate level were observed between the moving **and** the stationary SMS conditions.

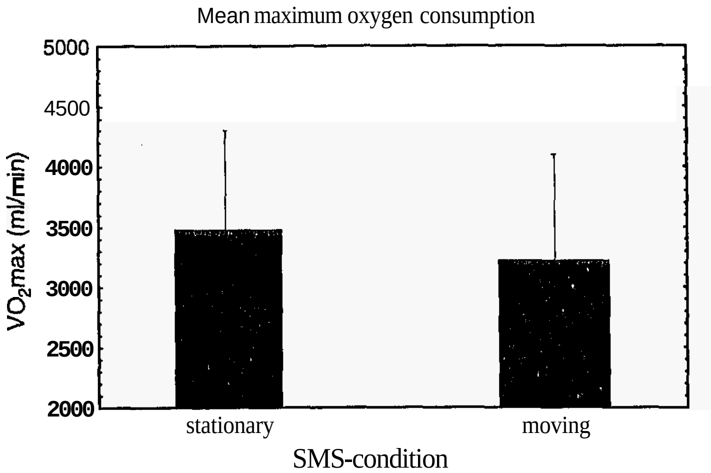

Fig. 1: Mean Vo_2max (± sd) in the moving and stationary SMS

DISCUSSION

The results suggest that maximum power reached in the maximal tests was lower in the moving SMS than in the stationary SMS. Though this effect just failed to reach significance, in a follow-up experiment with the same subjects (Wertheim et al, 1996b) maximum power scores were significantly lower in the moving than in the stationary SMS. Pooling the present data with the data from the follow up experiment did not affect this result ($p=.03$). Hence the conclusion that maximum power is indeed reduced in a moving environment, appears to be justified.

During SMS motion, group mean Vo_2max was reduced by approximately **8%.** Using Vo_2max as measured in the respective condition as indicator for work load means that **for** a fixed task inside the moving environment maximum work load was higher than in *a* stationary environment. In addition, in earlier studies (Heus et al, 1994) Vo_2max was defined as the highest measured Vo_2-value observed in the maximal test. Averaged Vo_2max values are by definition always lower than the breath-by-breath measured values (in the present study by approximately 10%). Hence, if in former experiments work load inside the moving SMS had been expressed as a percentage of averaged Vo_2max values and obtained inside the moving SMS, work load would have appeared to be much higher. This quite likely explains why work load in those experiments appeared to have been under-estimated, although the workload in those studies (Heus, et al, 1994) still does not exceed 40% Vo_2max.

Average efficiency did not differ between SMS motion and stationarity. This means that the reduced level of Vo_2max seems to be related to a reduction of muscular activity on the cycling task. Possibly the energy requirements of muscular activity for maintaining one's balance besides the normal task are not exclusively based on oxygen consumption, but also to some extent on the anaerobic metabolism. However, no significant change in blood lactate was observed in the moving as compared to the stationary **SMS.** Thus a clear explanation for **a** lower Vo_2max in a moving environment is not yet available.

In conclusion then, even though the phenomenon cannot easily be explained, the fact remains that maximum work capacity (Vo_2max) on a bicycle ergometer is reduced on a moving platform. This concomittant increase, due to movement, in relative workload for a fixed task is the most likely cause for the observed MIF. A valid predictor of MIF should be obtained if Vo_2 in the moving SMS is expressed as a percentage of the Vo_2max as determined in the moving SMS. What remains to be done in a follow-up experiment, is to quantify **MIF** in terms of loss of working time (Bink, 1962) due to platform motion.

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