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January 26, 1994

Lt. Cdr. Les Fenton
Submarine & Diving Medicine Program Manager
Naval Medical Research and Development Command
Code 41, Bldg 1
Tower 12
Bethesda, MD 20889-5044

RE: Annual Progress Report on Project No. N000149310509 entitled "Effects of Combined Breathing Impediments on Diver's Respiratory Performance"

Dear Cdr Senton:

Please find enclosed our Annual Progress Report for the period February 1, 1993 to January 31, 1994.

Sincerely,

Claes Lundgren, M.D., Ph.D.
Principal Investigator

Encl.

xc: Administrative Grants Officer
Director, Naval Research Laboratory
Defense Technical Information Center

Annual Progress report on project N000149310509

Effects of Combined Breathing Impediments on Diver's Respiratory Performance

Reporting Period: February 1 - January 31, 1994

Center for Research in Special Environments
Department of Physiology
124 Sherman Hall
Buffalo, NY, 14214

Introduction

The goal of this project is to provide the Navy with information about tolerance limits for combined breathing impediments which will be applicable towards defining engineering standards for divers' breathing gear. We have, in earlier Navy sponsored studies, found maximal acceptable limits for static lung loads (SLL), flow resistive loads (R) and elastic loads (E) when they act separately. In a real-world breathing apparatus these loads are combined to a greater or lesser degree. In this project fractions of these maximally acceptable loads are combined and their effects studied. The experiments include heavy workloads for the subjects and both shallow and great depths (as deep as the standard US Navy air decompression tables go).

The technical setup in the hyperbaric chamber is shown in Fig 1. The subject is completely immersed behind the Lanphier-Morin barrier. A full face mask (1) is used with breathing hoses (2, 3) supplying air. One-way valves (7, 8) direct the expired gas to a CO_2 scrubber (4) and then to a bellows (5) from which air is inhaled. The movement of the bellows is sensed by a potentiometer (18), allowing continous spirometry. The inhaled air is sampled (13) and analysed. Oxygen is added to maintain the same O_2 fraction as in air by means of a controller (14), a mass flow regulator (15) and hoses (16, 17). The flow resistance is determined by inserting metal disks with differently sized orifices in tzhe mask (7, 8). The static lung load is set by adjusting the water level between the barriers in relation to the subject's lung centroid. The elastic load is determined by springs (9) on the bellows.

Progress

The technical preparations have included selection and manufacturing of orifice sizes in the flow resistance disks and spring combinations. Confirmatory test dives were also performed. Five subjects have been recruited and passed the physical examinations. Of these, one subject has completed all the 30 possible dives while the other four are in progress of completing theirs. The total number of experimental dives (as of Jan 26) totals 100. This exceeds the projected number for this year (72) by 39%. This extra effort will give a buffer for scheduled maintenance (e.g. replacement of windows in the chamber, hydro testing of gas storage cylinders), equipment breakdowns and for final reporting at the end of the project period.

Preliminary results.

Three of the subjects have completed all their experiments with a static lung load of 0 cm H_2O. Their preliminary results will be discussed below. More detailed discussions and statistical calculations will be provided when more subjects have completed their experiments.

The mean end-tidal CO_2 values, Fig 2, were 46.7 mm Hg at the shallow depth and 52.4 mm Hg at the great depth but they seem to be unaffected by the R/E combination. The minute ventilation ($\dot{V}_E$), Fig 3, was not affected differently by the R/E combinations, but the tidal volumes were reduced 8-20% by increased E. The breathing frequency showed a corresponding increase. The maximum voluntary ventilation (MVV), Fig 4, seemed to increase with increasing E/decreasing R at 15 fsw. At 190 fsw it was reduced by about 30-40% compared to 15 fsw and was not affected by the R/E combination. The expiratory reserve volume (ERV) was reduced by about 20% with the higher E. Similarly, the vital capacity (VC) was reduced by about 15%. The respiratory duty cycle (T_i/T_{tot}) was not affected by the R/E combinations but it increased from 0.45 to 0.47 with depth. The dyspnea scores, Fig 5, were not different for the different loads.

A tentative conclusion is that resistive and elastic loads are additive in their effects on divers' respiratory performance if a ststic load load is absent.

An abstract based on these findings has been submitted to be presented at the annual meeting of the Undersea and Hyperbaric Medical Society (June 22-25).

Respectfully submitted

Claes Lundgren, M.D., Ph.D.
Principal Investigator

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1994 UNDERSEA AND HYPERBARIC MEDICAL SOCIETY
ANNUAL SCIENTIFIC MEETING ABSTRACT FORM

EFFECTS OF GRADED COMBINATIONS RESISTANCE AND ELASTANCE ON DIVERS' RESPIRATORY PERFORMANCE. D.E. Warkander and C.E.G. Lundgren. Center for Research in Special Environments, Dept. of Physiology, School of Medicine, SUNY, Buffalo, NY, 14214.

Combinations of flow resistance (R), elastance (E) and static lung loading are present to varying degrees in all breathing gear for divers. We have, in earlier studies, determined the maximal acceptable levels for two of these loads, when acting alone, to be: E: 7 cm H_2O/L, R: such that the external work of breathing equals 1.5 to 2.0 J/L. Fractions of the acceptable levels of R and E (when acting alone) were combined such that the total fraction was 1. The subjects were exposed to five of these combinations (%R/%E): 100/0, 75/25, 50/50, 25/75, 0/100. No static lung load was imposed. Results are from 3, in an ongoing series of 12, submerged, air-breathing divers exposed in a hyperbaric chamber to 1.45 and 6.8 ATA; exercise was performed in the prone position at 60% of $\dot{V}_{O2}$. The mean end-tidal CO_2 values were 46.7 mm Hg at the shallow depth and 52.4 mm Hg at the great depth but were unaffected by the R/E combination. $\dot{V}_E$ was not affected differently by the R/E combinations, but the tidal volumes were reduced 8-20% by increased E. The ERV was reduced by about 20% with the higher E. Similarly, the VC was reduced by about 15%. The T_i/T_{tot} was not affected by the R/E combinations but it increased from 0.45 to 0.47 with depth. The dyspnea scores were not different for the different loads. Conclusion: R and E are additive in their effects on divers' respiratory performance. Supported by US Naval Medical R&D Command Contract N000149310509.

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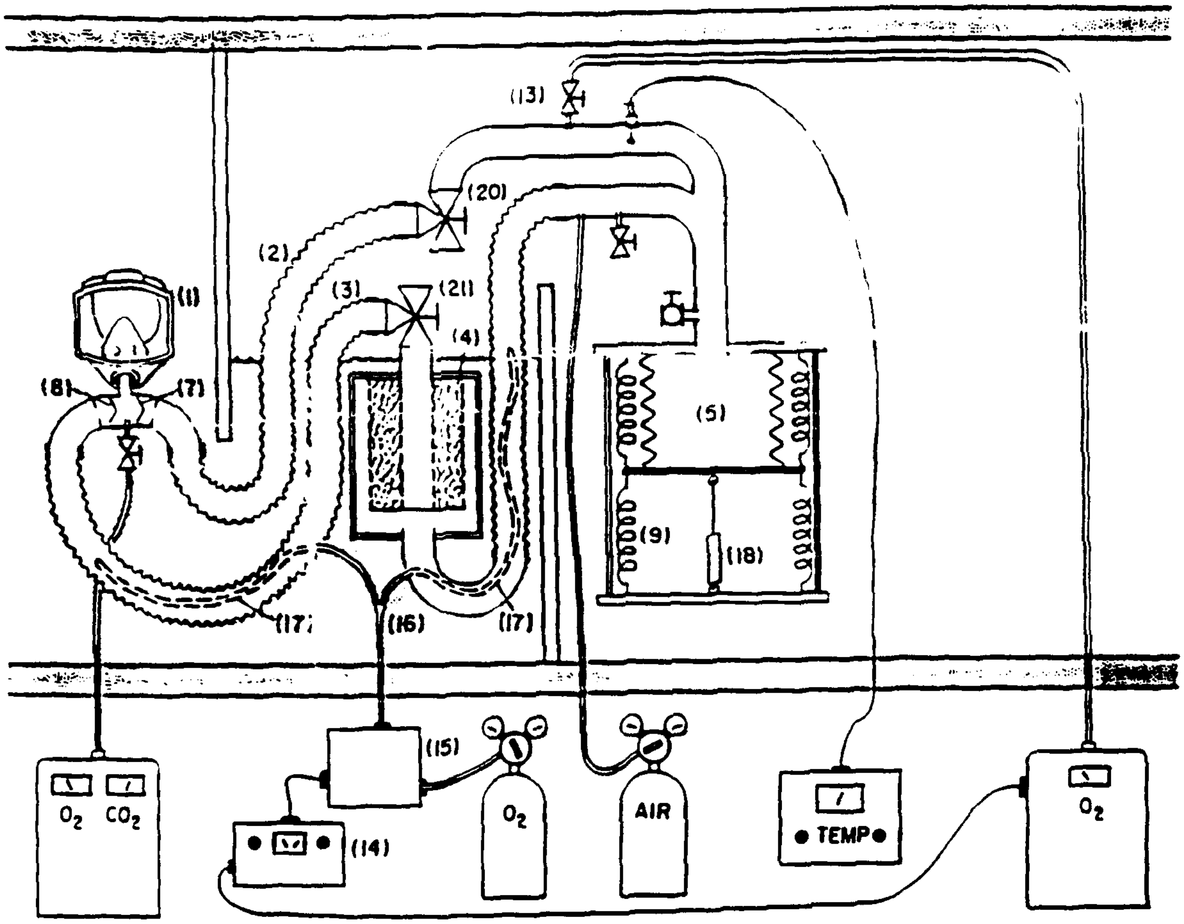

Fig 1. Setup of the equipment in the hyperbaric chamber. See text for explanations.

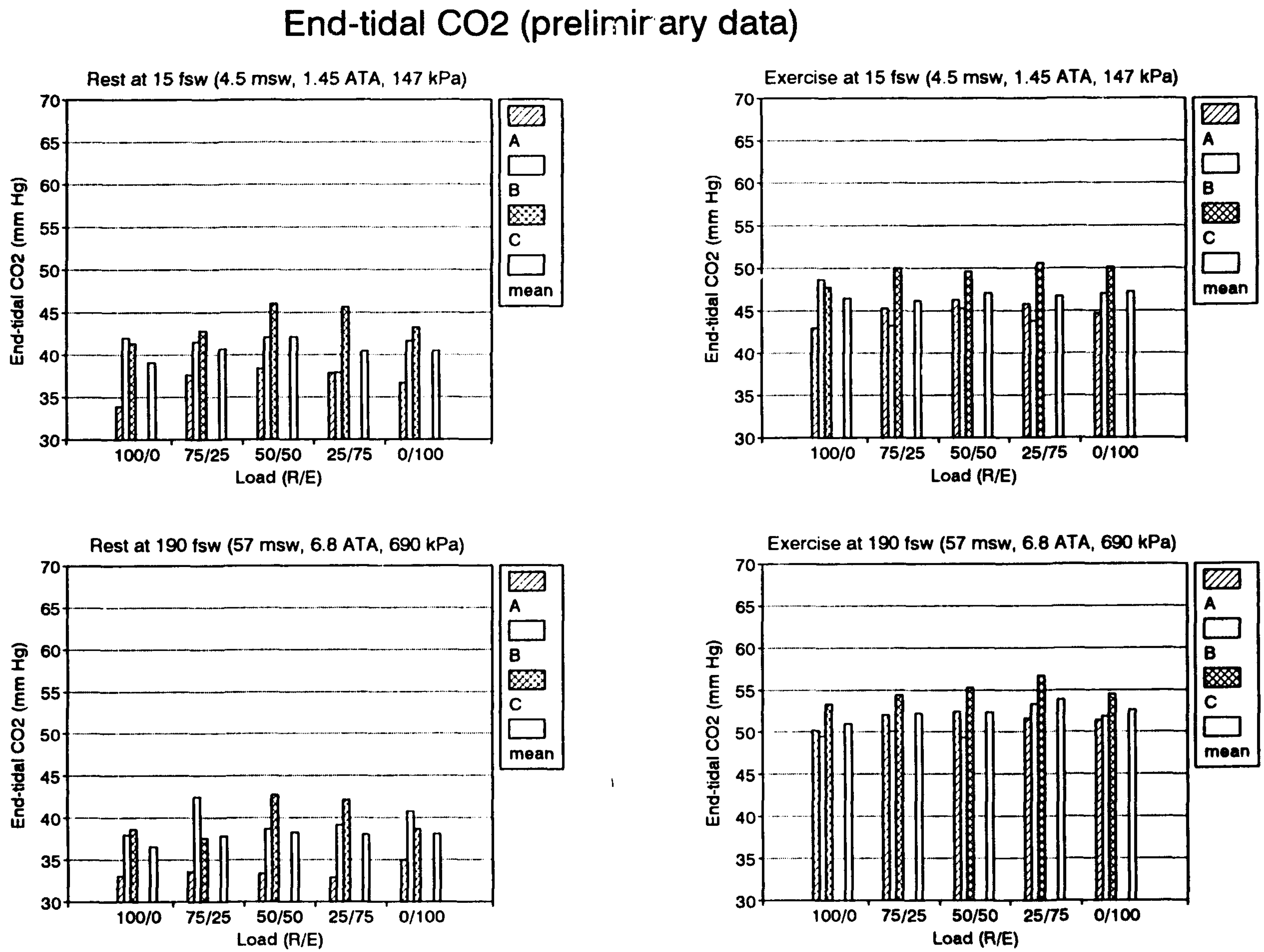

Fig 2. Preliminary data for end-tidal CO_2 plotted for the different load combinations. The panels show values from rest and exercise for the two depths, see panel headings. The bars show values for subjects A,B and C. The right most bar shows the group mean.

Ventilation (preliminary data)

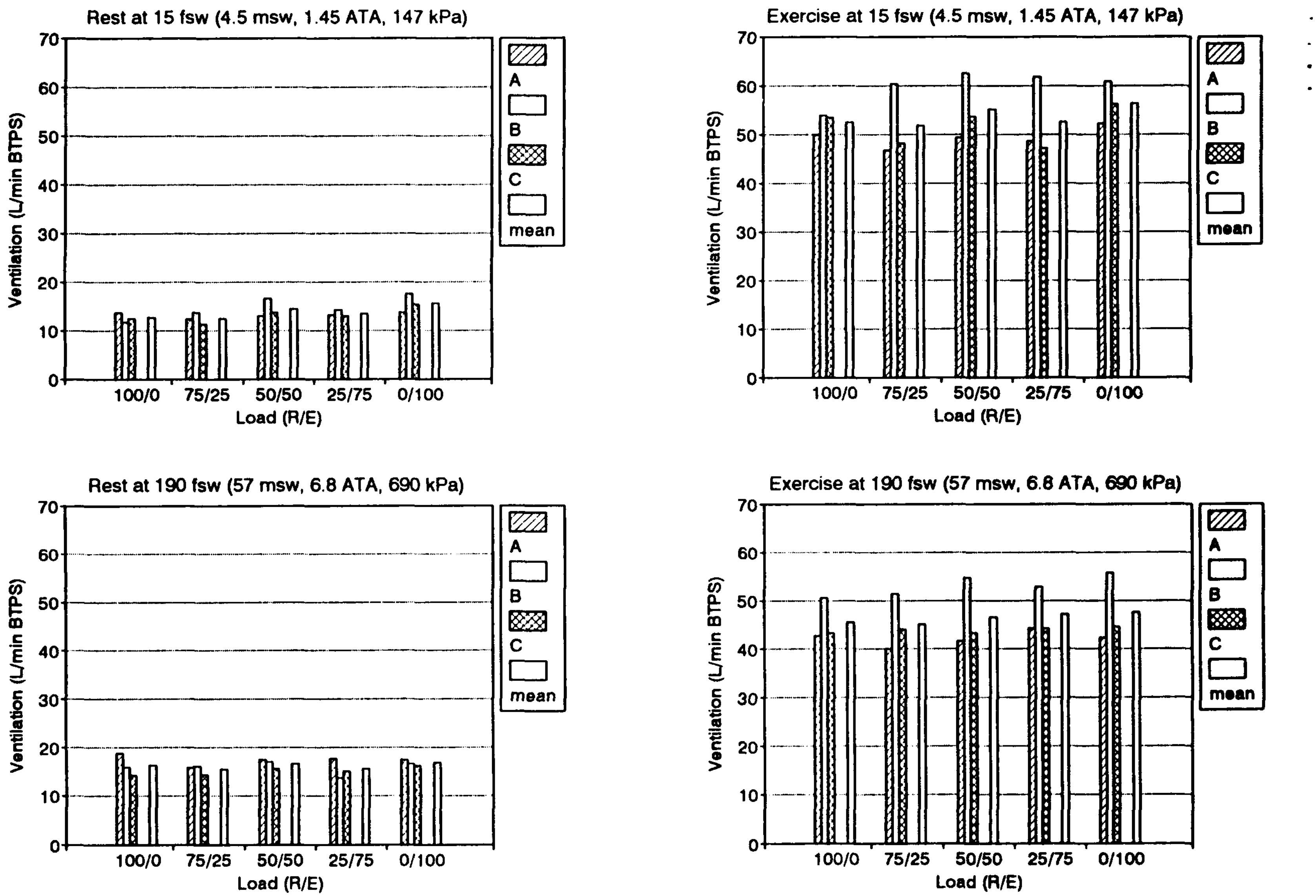

Fig 3. Preliminary data for minute ventilation ($\dot{V}_E$) plotted for the different load combinations The panels show values from rest and exercise for the two depths, see panel headings. The bars show values for subjects A,B and C. The right most bar shows the group mean.

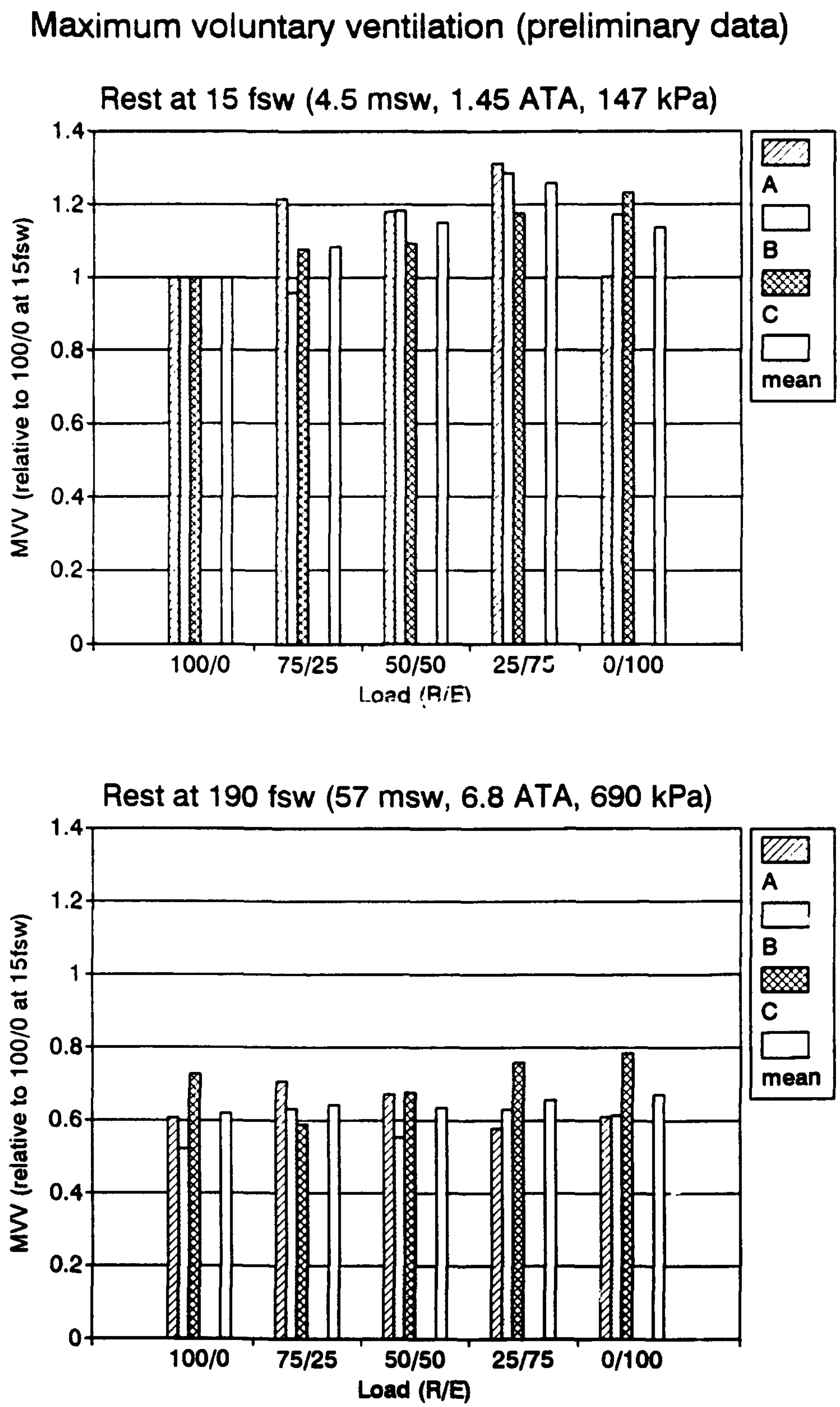

Fig 4. Preliminary data for maximum voluntary ventilation (MVV) plotted for the different load combinations. The panels show values during rest at the two depths, see panel headings. The bars show values for subjects A,B and C. The right most bar shows the group mean.

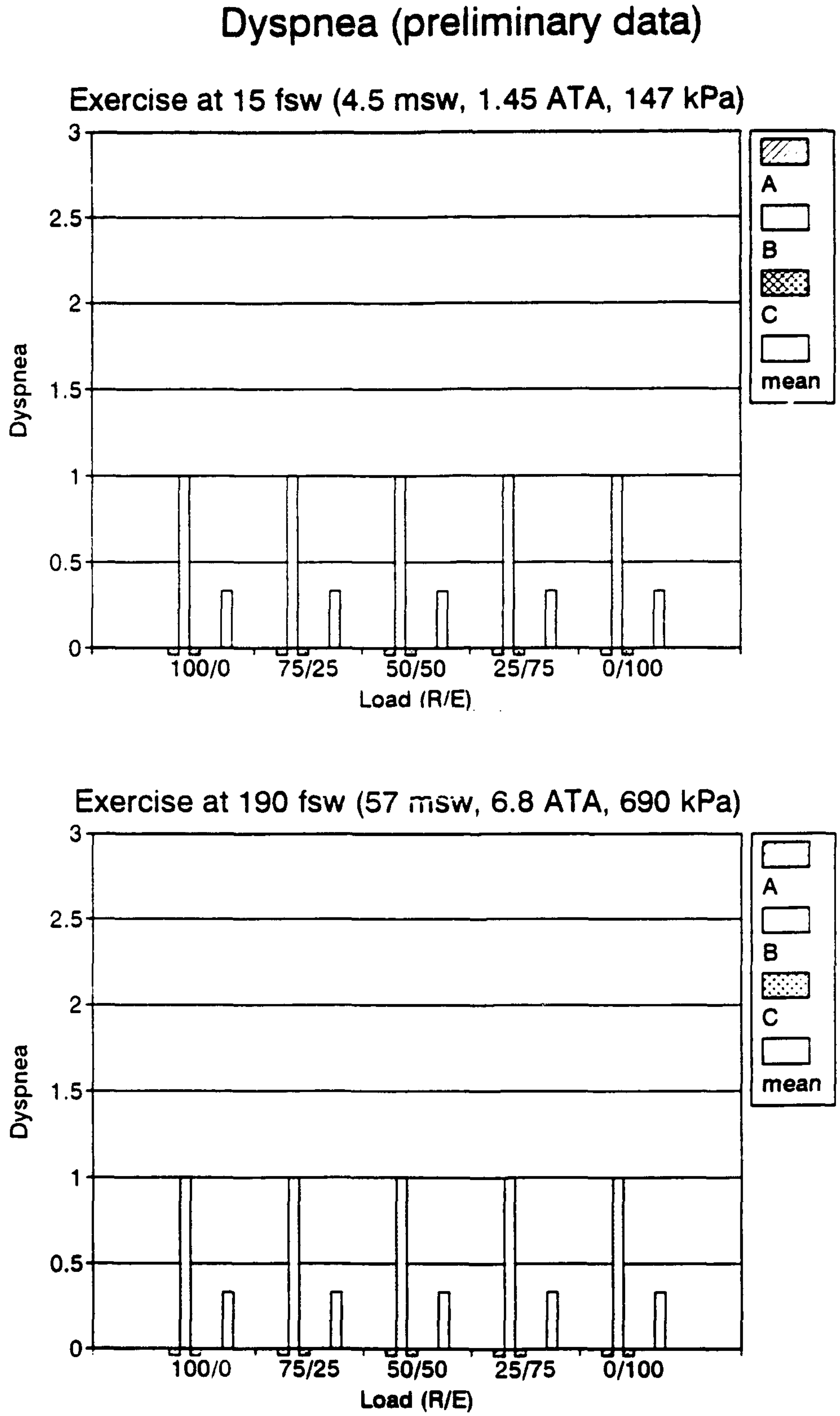

Fig 5. Preliminary data for dyspnea scores plotted for the different load combinations. The panels show values during exercise for the two depths, see panel headings. The bars show values for subjects A,B and C. The right most bar shows the group mean.