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PAPER FOR SESSION ON "SPIN-OFFS FROM SPACE TECHNOLOGY"

FROM "MOTOMIR" TO "MEDITRAIN":
MEDICAL INSTRUMENTATION AS SPIN-OFF FROM SPACE APPLICATION

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1. ABSTRACT

The medical instrument **MEDITRAIN**[r] (patented) is a computer controlled electromechanical ergometer, which can be used in the neuro-physiological and metabolic analysis of the human motoric system and can be applied in the training, diagnostics & rehabilitation of muscles of the upper or lower extremities.

The design is based on the flight hardware experiment "MOTOMIR", which was developed in the context of the joint Austro-Soviet Space Mission AUSTROMIR to the MIR Space Station. "MOTOMIR" was launched in August 1991 and was in use aboard the space station for basic muscle research and training of the Cosmonauts up to August 1992.

The functional principle of **MEDITRAIN** is based on the generation of precisely defined motion patterns through velocity controlled translatoric movement of two handles, to which the arms or legs of the patient are latched. These movements can be pre-defined as series of cyclic or acyclic runs of variable duration and velocity between defined start and end points. Via strain gauges in the handles, the isometric, concentric and eccentric forces exerted by the respective muscles are recorded in relation to the position & velocity of the handles (i.e. in relation to the angle and velocity of the respective extremity). In parallel, Electro-Myographic (EMG), Electro-Oculargraphic (EOG) and Electro-Cardiographic (ECG) measurements are performed and correlated to the force and machine data.

MEDITRAIN currently offers up to 32 analog channels operating at a standard sampling rate of 1 kHz. All measurement data can be displayed in real-time and are stored together with the personal data of the respective patient.

2. INTRODUCTION

The experiment MOTOMIR is a patented translatoric ergometric-dynamometric device, which can be applied as both muscle training as well as testing instrument of muscle-functions. It was originally developed by W. Bumba for the Institute of Sports Science in the context of the joint Austrian Russian Space Programme AUSTROMIR. MOTOMIR was launched to the MIR Space Station in August 1991 and experimentation conducted during two 2-hour sessions by the Austrian Cosmonaut and, subsequently, for long durations (up to 163 days) by Russian Cosmonauts up to end of August 1992.

The purpose of this experiment was to study the influences of weightlessness on the morphological as well as physiological properties of the human neuro-muscular system. From the viewpoint of exercise-physiology, the evaluation of the following factors are of primary interest:

- the behavior of human performance characteristics under zero-g, in particular endurance and strength;

- the influence of training in space on complex functional changes, in particular the cardio-circulatory and muscular systems, the fluid balance and bone density.

In order to obtain these data, velocity controlled measuring systems are commonly used in exercise-physiology, which register the generation of muscular force under precisely defined and reproducable angles of movement and velocity at defined body positions.

3. THE MEDICAL FLIGHT EXPERIMENT MOTOMIR

MOTOMIR generates these precisely defined motion patterns through velocity controlled translatoric movement of two handles (= man-machine interface) located on the left and right arm of the machine (see Figure 1: MOTOMIR - Overview). These handles can be used for arm-work (together with the chest-rest) or leg-work (together with saddle and specially designed sandal-like shoes).

The handle positions and forces are registered externally and correlated to neuro-physiological data obtained by integrated surface electromyographics (EMG), thereby allowing the objective and quantitative assesement of the isometric, concentric and eccentric force outputs of the knee or elbow extensor and flexor muscles.

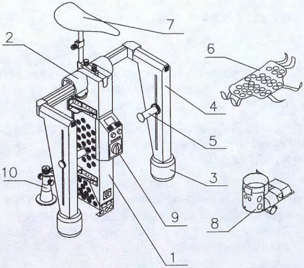
In particular, the detailed analysis of endurance and strength is made possible by the following functions of MOTOMIR:

- Translatoric handle movement within pre-defined ranges (0-450 mm), thereby definition of the joint-angles (the distance from the lowest handle position to the saddle/chest rest was costumised to the body measurements of the Cosmonauts);
- Controlled translatoric handle velocity selectable between 0.05 - 0.6 m/sec precisely defining the angular velocity;
- Cyclic (parallel or diagonal) movement of the handles in the sagittal plane (exercise of both extremities);
- Acyclic movement of single handle (exercise of single extremity);
- Frequency of handle oscillation (= muscular contraction frequency) selectable between 0 (isometric) up to 30 per minute;
- Presetable time constants for muscle contraction/relaxation periods;
- 12 measuring channels;
- sampling rate of 200 Hz;
- Measurement of following vertical and horizontal forces brought onto handles by test-person through strain-gauge system in handles: isometric (static load), concentric (force in direction of handle movement) and eccentric (force against direction of handle movement); the magnitude of the forces is shown in real-time by two 3-colored LED cells;
- Handle positions are coordinated and registered via sensors (encoders) in the drive-motors and motion controller (micro-computer);
- Definable and reproducable body position through fixation belts.

The range and velocity of translatoric handle movement, the sequence of movement patterns and the number of cycles per exercise were pre-defined in 12 different exercise programmes, which were conducted aboard MIR. These programmes were called up by push-buttons.

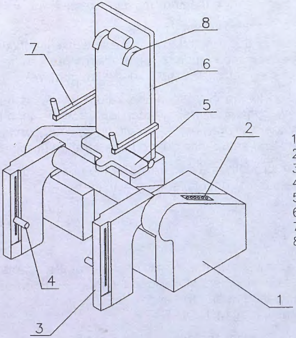
During exercise, two horizontal forces, two vertical forces, all positions of both handles, trigger points and four EMG were measured and recorded externally:

The data evaluation software allows the analysis of curve-shapes, endurance, and coordination by superimposition of measurement curves and fast fourier analysis.



1. CENTRAL CONSOLE
2. ADJUSTMENT PART
3. MOTOR
4. ARM
5. HANDLE
6. CHEST SUPPORT
7. SADDLE
8. SHOE
9. CONTROL PANEL
10. INTERFACE MOTOMIR/MIR

FIGURE 1 – MOTOMIR OVERVIEW



1. BASE WITH ELECTRONICS
2. CONTROL PANEL
3. ARM (WITH INTEGRATED MOTOR)
4. HANDLE
5. SEAT
6. BACKREST
7. ARMREST
8. SHOULDER STRAPS (ADJUSTABLE)

FIGURE 2 – MEDITRAIN OVERVIEW

3.1. MEDICAL AIMS OF THE EXPERIMENT MOTOMIR

3.1.1. Acyclic Measurements:

- At pre-defined positions given by MOTOMIR, measurement of the isometric, concentric and eccentric musclular strength of the upper and lower extremities in relation to the angle and velocity of the knee or elbow joint;
- For the evaluation of muscular strength per unit of active muscle-mass under zero-g, terrestric measurements were pre-conditional, in order enable the assessment of the quantitative influence of body weight on kinetic energy;
- The comparison of terrestric measurements to the results obtained under microgravitiy is thereby possible. In combination with the evaluation of the machine data, it is possible to perform myographic analysis of singular and combined contractions of individual parts of muscles in relationship to angle and velocity; special consideration is thereby given to the comparison of the concentric and eccentric contractions.
- The generation of loads varying in magnitude, direction and velocity during the performance of movements enables the analysis of the characteristics of motion control in the micro-g environment as well as the evaluation of changes in muscular strength.

3.1.2. Cyclic Measurements:

- Evaluation of the regulation of neuro- and muscle-physiological parameters of the upper and lower extremities during concentric and eccentric muscle-exercise of varying duration and intensity;
- The determining factors for the evaluation of this regulation under respectively concentric and eccentric loads are: the relative intensity, the number of contractions per minute, the range of motion, the velocity, the type of contraction and the work-pause pattern.
- The results of these tests in comparison to the corresponding values obtained during terrestric surveys contribute to the development of training concepts for the long-time adaptation to the microgravity environment with the aim of providing optimal conditions for the preservation of muscular strength and endurance during long-duration missions;
- The determination of muscular behavior, strength and endurance of the upper extremities should also give indications for the fitness of astronauts for EVA activities.

3.1.3 Results, planned continuation

These tests enabled the acquisition of data concerning the characteristices of the adaptation process to the micro-g environment and the development of muscular fatigue. Furthermore, it was shown that muscular mass actually increased during the approx. 150 day mission of the Russian commander, Col. Volkov, due to training on MOTOMIR.

The ultimate goal is the development of a multi-functional training instrument, not only to be able to assess the functional capabilities of the human body under microgravity but also to be able to effectively train individual muscular groups under varying conditions.

3.2. TECHNICAL OVERVIEW

The handles are driven by means of two brushless DC motors (0.5 kW at 1000 rpm) located at the bottom of each of the arms and controlled by two seperate amplifiers. The arm-positions are coordinated by motion controllers (micro-computers) and registered by sensors (encoders) located on the motors. Titanium ball-spindles for conversion of the rotating movement of the motor-shafts into the translatoric movement of the handles, cables for the power-supply of the motors, transmission of strain-gauge and encoder data and motion-control are contained within the arms :

Power supply was pulsed, in order to optimally ensure the stability of the handle velocity independently of magnitude and direction of forces applied.

The arms are attached to the central console via a lateral adjustment & swivel device. For flexibility in the positioning of the body of the trainee within MIR, the arms can be turned from 0 - 90° around the horizontal axis of the adjustment device. Depending on the exercise mode (arm or leg work), the arms can either be fixed right next to the console for arm work or are latterally pulled apart for leg work as in figure 1. Furthermore, the saddle or chest-rest (including fixation belts), the complete electronics for power and control, the PROGRESS and MOTOMIR / MIR mechanical interfaces, the control panel and plugs for power supply and data transmission are included in the central console.

In order to meet the stringent mass requirements, MOTOMIR was designed and built using titanium and aluminium alloys, minimising the necessity of steel components (total mass incl. MIR interface: 47.5 kg). The transport dimensions in a fully collapsed state were 1025 x 485 x 420 mm. Max. dimensions during arm-work: 1150 x 1760 x 652 mm and for leg work: 2063 x 667 x 626 mm. Supply voltage was 27 +7/-4 VDC, power consumption 750 W on average.

4. THE SPIN-OFF APPLICATION: MEDITRAIN r

Based on the same medical, mechanical and functional principles, a terrestric application of MOTOMIR named MEDITRAIN has now been developed. MEDITRAIN has been patented and is currently in the clinical test phase.

4.1 ADAPTATIONS AND IMPROVEMENTS COMPARED TO MOTOMIR

MEDITRAIN (see Figure 2) does not have the severe constraints concerning mass, interface and size requirements as MOTOMIR. Therefore, a number of improvements could be implemented in addition to the required adaptations to 1-g conditions:

- The entire structure is carried out in steel, making the whole structure more rigid and consequently eliminating interference with measurements through vibration .
- MEDITRAIN is an autonomous machine controled by PC and key-board (instead of pre-programmed exercise cycles). Therefore, any movement and velocity pattern can be generated (e.g. cyclic, acyclic and one-sided; handle oscillation in sine, rectangular, triangular or isokinetic mode etc.), enabling the tailoring of training programmes to the specifics of patients or athletes.
- In addition to the vertical and horizontal forces applied by the patient onto the handles, the momentum brought onto the handles by the ankle joint is measured.
- All measurement curves can be followed in real-time on screen and are stored on disk for subsequent evaluation. The data evaluation software allows the analysis of curve-

shapes, endurance, and coordination by superimposition of measurement curves and fast fourier analysis.

- All patient-specific data is stored on disk, in particular previous exercise programmes and max/mins of handle positions; at following training sessions, the patient can resume training where he has last left off.
- The seat is adjustable in height (up to 400 mm) and depth (see Figure 3) in order to accomodate varying body measurements of different patients. During the first training session, the seat is adjusted to the precise measurements of a particular person and stored. In subsequent session, these adjustments are carried out automatically to fit a particular patient.
- The seat and backrest are equiped with straps, in order to assure a precisely definded body position.
- The backrest can be transferred into a horizontal position (see Figure 3). By moving the arms with the handles to the center and attaching an add-on element to support the upper body and head, arm exercise is made possible.
- The seat and arms can be turned by up to 115° (see Figure 3), making the training of wheelchair-bound persons possible, if the machine is approached from the front.
- The sampling rate has been increased to a standard 1000 Hz (max. 3200 Hz).
- The number of measuring channels has been increased to a standard 16 EMG, 6 ECG, 10 EOG and 4 actor forces.

4.2 MEDICAL FIELDS FOR APPLICATION OF MEDITRAIN

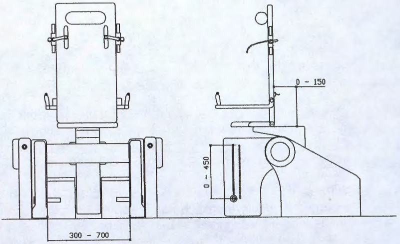
MEDITRAIN can generally be applied in physiology and sports medicine as a diagnostic, rehabilitation and training instrument of the muscular system of the upper and lower extremities. As MEDITRAIN allows the prècise and objective definition and reproduction of movement patterns in combination with the measurement of the applied forces and EMG, the progress of rehabilitation or training can easily be followed.

In the following, only a few possible applications of MEDITRAIN are listed:

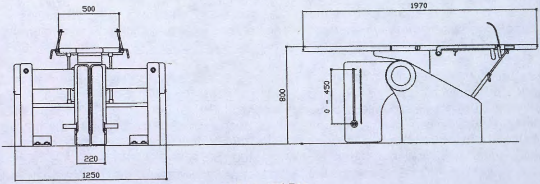
- following industrial or sports accident, rehabilitation of muscular atrophy due to rest after injury or operation of the passive motion-apparatus (e.g. ligament capsules); MEDITRAIN generates a physiologically adapted movement of the injured limb within the range that is pain-free;
- Cardio-circular training by arm-work;
- diagnosis of the causes of discoordinated or inaccurate movements
- diagnosis of reduced movement capabilities of joints (e.g. ankle, knee, elbow, shoulder)
- diagnosis of how muscles function relative to each other
- muscular tests with disabled persons and athletes
- training of specific muscles of athletes
- quick and efficient rehabilitation of athletes after accidents
- diagnosis of muscular fatigue, etc.

4.3 TECHNICAL DATA

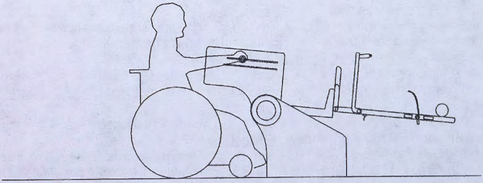
The dimensions of MEDITRAIN are 1250 mm wide, 2200 mm high (with max. elevation of seat) and 1970 mm deep (max). The total weight is 350 kg, supply voltage 380 VAC, 3 Phase, 50 Hz and power consumption a max. 5 kW. The complete electronics are located in the base.



LEG WORK



ARM WORK



ARM WORK FOR WHEELCHAIR BOUND PEOPLE

FIGURE 3 – TRAINING POSITIONS

6. LITERATURE

1. Bachl, N., Baron, R., Lechner, H., Bochdansky, Th., Prokop, L.: "Metabolic response of concentric and eccentric muscle work". Can. J. of Sports Sciences, Vol. 13, No.2, 48, 1988.
2. Bachl, N., Baron, R., Mossaheb, M., Bumba, W., Albrecht, R.: "Isokinetic force velocity and electromyographic characteristic of knee and elbow extensor and flexor muscels in the O.g environment", in: Proceedings of the Fourth European Symposium on Life Sciences Research in Space, held in Trieste, Italy, ESA SP-307. pp. 63-68, November 1990.
3. Bachl, N., Baron, R.,Petschnig, R., Liebenberger, S., Prokop, L.: "Concentric and Eccentric ExerciseTesting - A New Approach to a Four Extremities Ergometer", in: Advances in Ergometry, Springer-Verlag Berlin-Heidelber, pp. 393-305, 1991.
4. Baron, R., Bachl, N., Bochdansky, Th., Lechner, H.: "Untersuchungen von stoffwechselparametern bei kine-matisch unterschiedlichen Belastungen an einem Mechatronic-Belastungsgerät", in: Sportmedizin-Kursbestimmung. Hrsg.: H. Rieckert, 998-1003, 1987.
5. Baron. R., Bachl.N., Lechner, H., prokop, L.: " A new approach of a constant velocity ergometer". Can. J. of Sports Sciences, Vol. 13, No. 2, 48, 1988.
6. Convertino, V.A., Doerr, D.F., Mathes, K.L., Stein,S.L., Buchanan, P.: "Changes in volume, musclw compartment, and compliance of the lower extremities in man following 30 days of exposure to simulated microgravity". Aviat Space Environ. Med., 60, 653-658, 1989.
7. Convertino, V.A.: "Physiological Adaptions to Weightlessness: Effects on Exercise and Work Performance", in: Exercise and Sport Sciences Reviews, Eds.: Pandolf, R.B., Holloszy, J.O., American College of Sprots Medicine Series, Vol. 18, pp 119-166, 1990.
8. Dudley, G.A. Duvsisin, M.R., Convertino, V.A., Buchanan, P.: "Alerations of the In vivo torque-velocity relationship of human skeletal cuscle following 30 days exposure to simulated microgravity", Aviat. Space Environ. Med., 60, 659-663, 1989.
9. Grigoryeva, L.S., Koszlovskaya, I.B.: "Effect of weightlessness and hypokinesia on velocity and strength properties of human muscles", Kosm. Biol. Aviakosm. Med. 21(1). 27-30, 1987.
10. Kakurin, L.I., Cherepakhin, M.A., Pervushin, V.I.: "Effect of spaceflight factors on human muscle tone", Kosm.Biol.Med. 5(2), 63-68, 1981.
11. Kakurin, L.I., Cherepakhin, M.A., Pervushin, V.L.: "Effect of brief space flights on the human neuro-muscular system", Kosm. Biol. Med. 5(6), 53-56, 1971.
12. Koszlovskaya, I.B., Grigoryeva, L.S., Gevlich, G.I.: "Comparative analysis of effects of weightlessness and its models on velocity and strength properties and tone of human skeletal muscles". Kosm. Biol. Aviakosm. Med. 18(6), 22-26, 1984.
13. Leblanc, A. Gogla. P., Schneider, V., Krebs, J., Schonfeld, E., Evans, H.: "Calf muscle areaand strength changes after five weeks of horizontal bed rest". Am. J. Sports Med. 16, 624-629, 1988.
14. Tesch, P.A., Buchanan, P., Dudley, G.A.: "An approach to counteracting long-term microgravity-induced muscle atrophy", Physiologist 33, 1990.
15. Thronton, W.E., Rummel, J.A.: "Muscular deconditioning and its prevention in space flight", in Johnson, R.S., Dietlein, L.F. (eds.). Biomedical Results from Skylab, NASA SP-377, pp 191-197, 1977.
16. Tipton, C.M.: "Considerations for exercise prescriptions in future space flights", Twenty-Ninth Annual Meeting of the American College of Sports Medicine in Minneapolis, MN, May 1982.