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RESEARCH IN HUMAN PERFORMANCE RELATED TO SPACE: A
COMPILATION OF THREE PROJECTS/PROPOSALS

Final Report

NASA/ASEE Summer Faculty Fellowship Program--1989

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ABSTRACT

Scientific projects have been developed in order to maximize performance in space and assure physiological homeostasis upon return. Three projects that are related to this common goal were either initiated or formulated during the Faculty Fellowship Summer Program. The projects were entitled: 1) Effect of simulated weightlessness (bed rest) on muscle performance and morphology; 2) Effect of submaximal eccentric muscle contractions on muscle injury, soreness and performance: A grant proposal; and 3) Correlation between isolated joint dynamic muscle strength to end-effector strength of the push and pull EVA ratchet maneuver. The purpose of this report is to describe each of these studies in greater detail.

EFFECT OF SIMULATED WEIGHTLESSNESS ON MUSCLE PERFORMANCE AND MORPHOLOGY

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HYPOTHESES

The following hypotheses will be investigated during 7 days of bedrest:

1. There will be significant decreases in muscle performance of upper and lower extremity flexors and extensors.
2. There will be a significant decrease in muscular electrical activity.
3. There will be measurable muscle atrophy in the vastus lateralis muscle without significant alterations in contractile protein and metabolic enzymes.

INTRODUCTION

Prolonged immobilization and bed rest are believed to have qualitative similarities to weightlessness (7). Limb immobilization and bed rest have been demonstrated to produce skeletal muscle atrophy and decreased muscle performance (2). Histological techniques have been utilized to further document atrophy in both Type I and II muscle fibers (3). In addition, electromyographic (EMG) activity decreases with chronic immobilization (5).

The purpose of this study will be to examine the effects of simulated weightlessness (bed rest of 7-days length) on muscle performance and morphology. It is hoped that the results of this study will aid to develop exercise countermeasures to combat muscular detraining.

METHODS

Subjects

Twelve healthy subjects will be recruited and undergo an Air Force Class III physical examination and treadmill exercise stress test. Subjects will be in the age group of 30-50 years old without cardiovascular disease.

Procedures

Three days prior to bed rest the subjects will be tested for concentric and eccentric isokinetic muscle strength. Electromyographic activity (EMG) will also be evaluated during muscle strength testing. Muscle strength and EMG testing will be repeated 24-hours later for test/re-test reliability. The subjects will have a needle muscle biopsy taken on the non-dominant leg the day of admittance for bed rest. Subjects will have seven days of complete bed rest with the second biopsy taken on the seventh day. Subjects then will be re-evaluated for muscle strength and EMG on the seventh day with measures repeated 24-hours later. Subjects will return at 1 and 2 week time periods for re-assessment of muscle strength and EMG.

Muscle Testing and EMG

Muscle performance will be evaluated each day utilizing the Biodex dynamometer (Biodex Corp., Shirley, NY). Concentric and eccentric maximum torque of the elbow, shoulder, trunk, knee and ankle flexors and extensors will be taken. The subject will be placed in the Biodex unit so that the axis of the specific joint tested will be directly in line with the axis of the goniometer. Prior to specific joint muscle testing the subject will perform 3 submaximal and 1 maximal warm-up repetitions at the designated testing velocity (elbow, shoulder, and trunk = 75 degrees/sec; knee and ankle = 30 degrees/sec). The subject will be instructed to give maximum efforts for each repetition and informed to flex and extend the body segment through the entire available range as forcefully as possible for the 3 repetitions. Data will be collected on the dominant side with 5-minutes of rest between each joint tested. EMG signals will be recorded by means of Ag/AgCl electrodes placed over the belly of each tested muscle group in a bipolar configuration with the site marked for identical placement on later trials. A reference electrode will be placed over a bony prominence (clavicle for upper extremity and trunk; head of fibula for lower extremity). The muscles studied for the elbow joint will be biceps brachii and triceps brachii; for shoulder anterior deltoid and latissimus dorsi; for trunk rectus abdominus and erector spinae; for knee vastus lateralis and biceps femoris; and for ankle anterior tibialis and gastrocnemius. Electrode placement will be preceded by abrasion and cleansing of the skin surface to reduce source impedance to less than 3000 ohms. During each contraction raw EMG signals will be amplified (Gould, band-pass 3-1000 Hz) recorded at a rate of 1250 Hz and stored on tape for further computer analysis (Ariel System). Signals will be processed for signal amplitude (IEMG) (10).

Morphology

Needle muscle biopsies of the vastus lateralis will be taken using sterile technique. Enzymatic analyses will consist of measuring succinate dehydrogenase, glycerophosphate dehydrogenase, myofibrillar ATPase, and myosin ATPase. In addition, the cross sectional area of the biopsy will be analyzed to determine changes of actual myofiber size.

Statistical Analyses

A two-factor factorial design will be employed to determine the effects of ambulatory status, time of measurement, and their interaction on muscle performance, EMG and muscle morphology. A two-way ANOVA, adjusted for repeated measures across time of measurement (split plot) will be utilized with significance established at $p < 0.05$.

EFFECT OF SUBMAXIMAL ECCENTRIC CONTRACTIONS ON MUSCLE INJURY, SORENESS AND PERFORMANCE: A GRANT PROPOSAL

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(Initial proposal submitted for Summer Faculty Fellowship Grant; Resubmission to NASA targeted for 12/89-with planned start of 2/90)

HYPOTHESES

The following hypotheses will be investigated immediately, 24 and 48-hours after eccentric knee extension exercise bouts of low and high load:

1. There will be no decreases in muscle performance following low load eccentric exercise, but significant decreases will occur following high load eccentric exercise.
2. There will be no change in EMG activity for any of the quadriceps muscles following low load eccentric exercise. However, EMG activity will significantly increase for rectus femoris and decrease for vastus lateralis and medialis following high load eccentric exercise.
3. There will be no change in muscle creatine kinase and muscle morphology following low load eccentric exercise. There will be an elevation of muscle creatine kinase and significant alteration in muscle and connective tissue indicating damage following high load eccentric exercise.
4. There will be no muscle soreness perception of the quadriceps musculature following low load eccentric exercise, but significant muscle soreness perception will occur following high load eccentric exercise.

INTRODUCTION

Muscle weakness and atrophy occurred after exposure to a zero-gravity environment during the Skylab missions (16). Concentric exercise programs were employed to neutralize these detrimental changes. However, most functional movements at one-g require both concentric and eccentric muscular contractions. At zero-g eccentric contractions of the lower and upper limbs may occur less frequently since weight-bearing is minimized in this environment. Upon return to a one-gravity environment after extended zero-gravity habitation, mission specialists may have difficulty performing normal dynamic functional activities requiring eccentric contractions of large lower limb muscle groups (i.e. stand to sit, sit to supine, and many deceleration functions of the lower limb segments during ambulation and stair decent). In addition, there is some cause for concern of potential muscle injury when eccentric contractions are required again. This concern arises from data on deconditioned patients who unexpectedly performed eccentric contractions during stair decent resulting in quadriceps muscle rupture at the musculotendinous junction (13, 14). Eccentric muscle contractions produce an equal amount of force with less active motor units, thus greater force per tissue area than concentric contractions. This is one explanation as to why micro-injury, macro-injury and muscle soreness occur at musculotendinous junctions when "unaccustomed" eccentric contrac-

tions are performed (1, 6, 15). Earlier data suggests that submaximal eccentric loads (60-80% of body weight) for the lower extremities does not initiate muscle soreness (8). However, little research has been performed to determine at what level of eccentric load (percent of body weight) may be noninjurious and yet provides sufficient eccentric stimulus to delay connective tissue weakening.

The purpose of this investigation will be to determine: 1) A dose-response curve of eccentric loads at various percents of body weight on indices of muscle damage and performance.

METHODS

Subjects

Twelve healthy subjects will participate in this investigation. All subjects will be male (non-smokers) ages 20-45 that will be recruited from the Houston/Galveston community by the Health Screening Facility of the Medical Sciences Division in Building 37. The subjects will not have had experience in weight-training nor have had any orthopaedic or neurological limitations of the knee joint (i.e. ligamentous surgery, Rheumatoid Arthritis of Osteoarthritis). All subjects will undergo an Air Force Class III physical examination and will be familiarized with the experimental procedures and possible risks involved, and asked to provide informed consent.

Procedures

On each test day subjects will report to the laboratory in a fasting condition. On the first session subjects will be randomly assigned to two treatment conditions (% body weight for eccentric load); one for each leg (1 limb low percent 60, 70 or 80%, and the other limb high percent 90, 100 or 110%) therefore an N of 4 limbs for each experimental condition. Immediately after baseline muscle force, plasma creatine kinase, electromyographic activity (EMG), and soreness data are collected the subjects will perform the eccentric exercise bout at the desired experimental load. The exercise bout will consist of 10-minutes incorporating 150 eccentric muscle contractions of the quadriceps. Immediately after the conclusion of the exercise bout subjects will have the opposite leg go through the same procedure, but at a different experimental condition. At the conclusion of both experimental exercise bouts the limbs will be evaluated for muscle force production, creatine kinase, EMG and muscle soreness perception. Subjects will return to the laboratory 24-hours and 48-hours post exercise, and will be evaluated again for force production, creatine kinase, EMG and muscle soreness. In addition, at 24-hours subjects will have a muscle biopsy excised.

Muscle Testing, EMG and Muscle Soreness

Force production will be evaluated at 2 velocity settings using a Lido isokinetic dynamometer (Loredan Co., Davis, CA). The velocities of the maximum contractions will be 60 degrees/second and 180 degrees/second. In addition, maximum knee extension isometric force (MVC) with knee joint stabilized at 60 degrees of flexion will be measured. The subject will be placed in the Lido unit so that the axis of the knee joint is directly in line with the axis of the goniometer. Prior to the knee joint muscle testing the subject will perform 5 submaximal repetitions at the designated

testing velocities. The subjects will be instructed to give maximum efforts for each repetition. Data will be collected at the high velocity (180 deg/sec) for 20-repetitions on both knee joints with 15-minutes of rest before data collection at the low velocity (60 deg/sec) for 5-repetitions. MVC measures will follow isokinetic knee joint testing after an additional 15-minutes of rest. Three MVC measures will be taken on each leg with a rest period of 3-minutes between contractions.

Areas over the mid-belly of rectus femoris, distal head of vastus medialis and proximal head of vastus lateralis will be prepared by abrasion and cleansing with alcohol to reduce source impedance to less than 3 Kohms. All areas will be marked so that identical sites will be used on subsequent testing. Raw EMG signals will be amplified, recorded at a rate of 1024 Hz, digitized and stored on hard disk for further computer analysis (Ariel Motion Analysis System) during MVC maneuvers. Mean power frequency and root mean squared will be computed by means of full wave rectification and fast Fourier transformation of raw EMG data (11).

A polyurethane sheet marked with a grid of intercepts 2cm apart, used as soreness test sites, will be attached to the anterior thigh with the skin marked to insure constant positioning in subsequent tests. A rounded metal probe (2mm diameter at tip) will be attached to a load cell (SensorMedics Model UL4-50) and a strain gauge (Gould-Statham Model UTC3). The load cell/strain gauge instrument is interfaced to the R511A SensorMedic dynagraph via a voltage/pulse/pressure coupler (SensorMedics Model 9853A) and to an 8-channel A/D board (Metrabyte DASH-8) and IBM 286 computer. The amplified force signal will be displayed and recorded on the hard disk of the computer for further analysis. At each test site, a gradually increasing force will be applied up to a maximum of 50 Newtons of pressure. The subject will be asked to verbally indicate when the sensation of pressure changed to discomfort. The amount of force will then be recorded via computer. If no indication of discomfort is reported up to 50 Newtons, soreness will not be considered to be present at the site. A standard pattern of testing will be performed in order to insure complete evaluation of the entire quadriceps muscle (9).

Muscle Enzymes and Morphology

Muscle creatine kinase will be evaluated from plasma samples. Histochemical analyses will be performed on muscle tissue removed via open muscle biopsy of the proximal head of vastus lateralis of both legs. Analyses will include trichrome, ATPase at pH 9.4, NADH-TR, succinate dehydrogenase and glycerol-3-phosphate dehydrogenase to document myofibrillar and/or connective tissue damage. Tissue samples will be analysed visually for damage using electron microscopy.

Statistical Analyses

A two-factor factorial design will be employed to determine the effects of the experimental conditions, time of measurement and their interaction on muscle performance, EMG, muscle morphology, muscle enzymes and perception of muscle soreness. A two-way ANOVA, adjusted for repeated measures across time of measurement (split-plot) will be utilized with significance established at $p < 0.05$.

CORRELATION BETWEEN ISOLATED JOINT DYNAMIC STRENGTH TO END-EFFECTOR STRENGTH OF THE PUSH AND PULL EVA RATCHET MANEUVER

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(Initial pilot data [2 cases] begun 7/89 with proposed study to begin 10/89 to 6/90).

HYPOTHESES

1. There will be a significant correlation between isolated joint maximum torque production and the EVA ratchet push/pull maneuver when adjusted for lean body mass of subject and ratio of EMG of primary muscle groups comparing both activities.
2. The predicted maximum torque production for the EVA ratchet maneuver will be highly correlated to actual measured EVA ratchet torque production.

INTRODUCTION

Development of an accurate predictive computer equations for graphical display and animation of EVA maneuvers requires establishment of a dynamic maximum muscle strength data base (4). The purpose of this project was to develop a protocol and mathematical equation to predict end-effector strength of a common EVA activity (push/pull ratchet maneuver) utilizing isokinetic isolated joint upper extremity muscle performance and lean body mass measures. The project was broken down into three portions for the initial 2 case studies: 1) Determination of end-effector strength and electrical myographic (EMG) activity of contributing muscles during a simulated ratchet tightening and loosening maneuver; 2) Determination of isokinetic isolated upper extremity joint maximum strength and EMG activity during varying angular velocities; and 3) Determination of lean body mass. Following completion of data collection an initial regression equation will be developed to predict end-effector strength from isolated joint maximum torque, EMG activity of contributing muscle, and lean muscle mass of the subjects. Following successful completion of the case studies; a data base of 80 subjects will be performed.

METHODS

Subjects

Eighty healthy subjects will be participate in this investigation. Approximately 40 males and 40 females without extensive weight training experience and orthopaedic limitations of the upper extremity will be recruited from the Houston/Galveston community by the principal investigator. All subjects will undergo an orthopaedic screening of the upper quarter by a certified Physical Therapist and will be familiarized with the experimental procedures and possible risks involved, and asked to provide informed consent.

Procedures and Instrumentation

Determination of End-Effector Strength, Angular Velocity and EMG During a Simulated EVA Ratchet Tightening and Loosening Maneuver

Specific NASA requirements for tightening and loosening bolts for shuttle bay doors with an EVA ratchet wrench have been established at 25 foot-pounds of torque requiring 5 loosening or tightening maneuvers. Simulation of this task can be accurately performed by utilizing a dynamometer which is able to apply a constant (isotonic) load for a ratcheting maneuver (Lido Multi-Joint Testing Unit, Loredan Biomedical, Inc., Davis, CA).

On day one the subject will perform the ratchet tightening and loosening maneuvers. The subject will be seated and trunk restraints will be applied to minimize trunk movement/muscle substitutions during the trials. Before each trial the subject will perform 3 submaximal repetitions at a low resistance (5 ft-lbs). The subject will then perform 5 maximum repetitions receiving strong verbal encouragement. The subject will perform 3 loosening and 3 tightening trials determined randomly with 5-minutes of rest between trials. Torque and angular velocity are determined during the ratchet maneuver by the Lido dynamometer. In addition, the tightening and loosening maneuvers will be filmed and segment/angular velocities will be determined for the elbow and shoulder joint by the Ariel Motion Analysis System. EMG activity will be measured during the tightening maneuver by isolating and recording signals from the primary movers of the shoulder and elbow joints (latissimus dorsi - shoulder extension and biceps brachii - elbow flexion); and the loosening maneuver (anterior deltoid - shoulder flexion and triceps brachii - elbow extension). Raw EMG signals will be recorded from Ag/AgCl surface bipolar electrodes (Pre-Amplifier Electrodes - Motion Control, Inc Salt Lake City, UT) located over the muscle belly at a rate of 1024 Hz, digitized, and stored on disk for further computer analysis (Advanced Logic 386 with Metrabyte Dash 16 A/D board). Signals will be processed for frequency content (mean power frequency [MPF]) via 512-point fast Fourier transformation, and for signal amplitude (root mean squared [RMS]) (11).

Determination of Isolated Isokinetic Muscle Strength and EMG Activity at Varying Angular Velocities

In order to predict end-effector maximum torque for any given upper extremity activity the isolated shoulder, elbow and wrist joints must be evaluated for maximum torque (Lido Multi-Joint Testing System, Loredan Biomedical, Inc Davis, CA) and EMG over the entire available range of motion, and at varying angular velocities (30 deg/sec upto 240 deg/sec). On days 2 through 5 the subject will be evaluated for shoulder abduction/adduction; shoulder internal/external rotation; shoulder flexion/extension; elbow flexion/extension; elbow (forearm) pronation/supination; Wrist ulnar deviation/radial deviation; and wrist flexion/extension. The subject will be seated for elbow and wrist testing while shoulder testing will be performed in the supine position. Each joint will be stabilized with velcro straps to minimize muscular substitutions and extraneous movement. During each testing day, 2 of the 7 joint movements will be selected randomly and evaluated. The testing protocol will consist of performing 3 submaximal contractions at the test velocity followed by 5 maximal repetitions. The subject will have 3-minutes of

rest, and the procedure will be repeated until all 8 velocities are evaluated. The order of velocity presentation will be randomized. Once one joint movement has been fully evaluated, 15-minutes of recover will be given before the next joint movement is tested. Four successive test days will be scheduled to accomidate all seven joint movements and allowing 24-hours of recovery between test sessions.

Determination of Lean Body Mass

Lean body mass will be determined utilizing the 1990B Bio-Resistance Body Composition Analyzer (Valhalla Scientific, El Cajon, CA). The subject will have the skin on the dorsum of the hand/wrist and foot/ankle prepared by abrasion and vigorous alcohol rub. Lead I electrodes will be placed on the dorsal surface of the right wrist bisecting the styloid processes of the fadius and ulna, and on the distal metacarpal of the index finger of the same hand. The second set of electrodes (Lead II) will be placed on the dorsal surface of the right ankle bisecting the medial and lateral malleoli, and on the first distal metatarsal of the same foot. The subjects will be placed in a supine position and asked to refrain from moving. Low amperage direct electrical current is generated, delivered into the subjects body at the proximal electrode and detected by the distal electrode. The difference between the charge introduced and detected is described as the bioelectric impedance. A close relationship has been established between lean body mass and electric current conductance (12). This procedure will require 15-minutes to perform.

Statistical Analyses

The relationship between end-effector maximum muscle strength and isolated joint maximum muscle strength (after lean body mass is accounted for and EMG activity for primary muscle groups is compared between the two tasks) will be determined by least-squares regression techniques. Regression equations will be developed for isolated joint maximum muscle strength curves (position to predict strength) at all 8 speeds, to predict push/pull end-effector task strength at any given angle.

SUMMARY

Exploration of space can be divided into stages of ascent, orbit, and egress. Physiological changes take place at each stage. One major concern with extended missions is the negative adaptations to a zero-gravity environment (16). Physiological measurements following SkyLab Missions suggested a decrement in muscle and bone tissue. Results from SkyLab data were instrumental in: 1) Developing further studies on effect of simulated weightlessness on muscle function; and 2) Developing exercise protocols to counteract the negative affects of zero-gravity adaptations.

Another area of concern with extended missions is performance of tasks within the shuttle or space station. Computer software programs have been developed to perform simulated tasks, prior to actual performance in mock-up or true space environment. Accurate information given to the computer model results in better task simulation.

The studies described in this report are derived to answer or clarify questions on human performance during and upon completion of space travel. The results from these studies will assist NASA in programming safe and productive missions in the near future.

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