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ABSTRACT

INTRODUCTION: During space flight, bone and muscle adaptations occur that can be hazardous to crewmembers' health and can inhibit their ability to successfully perform physically demanding mission-critical activities. Due to the limited number of astronauts exposed to microgravity, space flight analogs have been used to develop and study countermeasures for muscle and bone loss. Exercise has been proposed as a countermeasure for muscle and bone loss and previously has been studied in bed rest. Although squat exercises are considered to be central to exercise countermeasures during space flight, a device has not been available previously to allow the pelvis to displace vertically in a supine subject to mimic the action of the squat exercise during bed rest. Engineers and physiologists in the Exercise Physiology Laboratory at Johnson Space Center designed a horizontal exercise fixture that can be used in bed rest with the interim Resistive Exercise Device (iRED) to more closely mimic the biomechanical characteristics of the standing squat exercise. The pelvic sled of the horizontal exercise fixture is equipped with a counterweight that balances the pelvis in the vertical direction during movement. **PURPOSE:** The purpose of this evaluation was to determine if the current battery of iRED exercises could be performed on the horizontal exercise fixture. Additionally, this evaluation sought to develop an equation for determining the appropriate counterweight for the pelvic sled during squat, single-leg squat, and deadlift exercises and to evaluate the electrical activity of the Vastus Lateralis Oblique (VLO). **METHODS:** The evaluation was divided into two separate phases. For Phase I, two volunteers, who were representative of a 5th percentile female and a 95th percentile male, completed the investigation. Each of these subjects performed two sets of each exercise during one testing session to determine if the highest and lowest force levels were appropriate for a wide range of test subjects and if the exercise could be performed with similar mechanics in supine as compared to the upright position. During Phase II, pelvis sled counterweights were assessed for the squat, single-leg squat and deadlift. VLO activity also was evaluated during a squat on the horizontal exercise fixture. **RESULTS:** The squat, bent-over row, bicep curl, front raise, hamstring curl, hip abduction, hip extension, hip flexion, leg press, shoulder press, single-leg press, tricep pushdown, and upright row were performed on the horizontal exercise fixture without any significant performance issues, and therefore could be performed in a bed rest study. Minor modifications are necessary to perform the heel raise, single-leg squat, and single-leg heel raise. The deadlift, hip adduction, lateral raise, and rear raise could not be performed on the fixture. Additionally, two regression equations were developed to predict the ideal counterweight with and without bungee augmentation. The VLO was proportionally active during the squat. **CONCLUSION:** A bed rest study using the horizontal exercise fixture could be performed in which subjects execute a large number of the exercises that are similar to upright exercise.

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ACRONYMS

Amp	Amplitude
ARC	AMES Research Center
Avg	Average
BMD	Bone mineral density
BW	Body Weight
cm	Centimeters
COM	Center of mass
CSA	Cross sectional area
CW	Counterweight
EMG	Electromyography
F_z	Force in the z-axis
Ht	Height
iRED	Interim resistive exercise device
ISS	International Space Station
JSC	Johnson Space Center
kg	Kilogram
L	Load
MVIC	Maximal Voluntary Isometric Contraction
NASA	National Aeronautics and Space Administration
Rep	Repetition
ROM	Range of motion
Sec	Second
VLO	Vastus Lateralis Oblique

1.0 INTRODUCTION

Significant reductions in muscular strength and muscle cross-sectional area (CSA) have been reported in short- and long-duration space flight (7,11,12). During long-term missions, these adaptations could impair the crewmembers' ability to perform extravehicular activities, intravehicular activities, and emergency egress, as well as posing a health risk upon return to Earth (11). Six-degree head-down tilt bed rest has been shown to elicit similar muscle and bone loss to those experienced by crewmembers during space flight (9) and has been suggested to be an adequate ground-based model for microgravity research evaluating muscle strength losses, muscle atrophy, and bone metabolism.

Several countermeasures have been proposed to counteract musculoskeletal unloading. One of the most promising of these countermeasures is resistive exercise (3). Resistive exercise in a normal gravity (1-G) environment stimulates increases in muscular strength, muscle CSA, and bone mineral density (BMD) (3,9). The most common form of resistive exercise in ground-based studies is weight training. Several researchers have used weight training during bed rest in the supine position to maintain muscular strength (4), muscle protein synthesis (10), muscle CSA (1), and BMD (6,16).

In microgravity, without force due to gravity, the use of weights for resistive exercise is not a plausible option. Until recently, a resistive exercise system that provides a significant variety of exercises and loading has not been available for use in microgravity. Astronauts and cosmonauts aboard Skylab and Mir had the capability to perform aerobic exercise and limited resistive exercise using bungee-type loading (13). Even with bungee resistive exercise, marked post-flight losses in BMD, muscle strength, and CSA still occurred (13).

Currently, the interim Resistive Exercise Device (iRED) is aboard the International Space Station (ISS). The iRED uses an elastic polymer system to provide resistance. On ISS, the iRED can be configured to allow performance of at least 18 different exercises for both upper and lower body muscles. Ground-based research on the training response of ambulatory subjects has been performed on the iRED (14) at NASA-Johnson Space Center (JSC), but no bed rest data exist using this device. Because iRED had a load limitation of 136 kg (300 lb), bungee cords were used to augment the iRED load and provide increased resistance. Each iRED canister had attachment points for up to three bungee cords. In this evaluation we use a total of four additional bungees (2 per side). At maximum stretch, approximately 84cm, a single bungee was capable of producing approximately 31 kb of resistance. The engineers and exercise physiologists in the Exercise

Physiology Laboratory at JSC developed a horizontal exercise fixture (Figure 1) that allows the use of the iRED during bed rest. The fixture was built at the Ames Research Center (ARC), Moffett Field, CA, to simulate upright exercise while the subject remains in a horizontal position; in this way, the orthostatic gradient on the cardiovascular system and gravitational limb loading are minimized.

Other capabilities of the fixture include multi-dimensional movement of body segments, including vertical displacement of the pelvis. The device is equipped with a counterweighted pelvic sled intended to neutrally balance the pelvic area against the force of gravity during exercises such as the squat, single-leg squat, and deadlift. The device is unique in that most leg strength devices used in bed rest research allow only a knee extension or a leg press movement. By using a knee extension or leg press movement, the moment on the pelvis is considerably less than what would be experienced during a squat (2) and the back muscles are unloaded. This new horizontal exercise fixture allows vertical displacement of the pelvis, and therefore would afford a movement more similar to the squat.

The purpose of this evaluation was to determine the ability to perform 20 different resistive exercises in the horizontal position and to determine the appropriate counterweight for a pelvis displacement for use in future bed rest research.

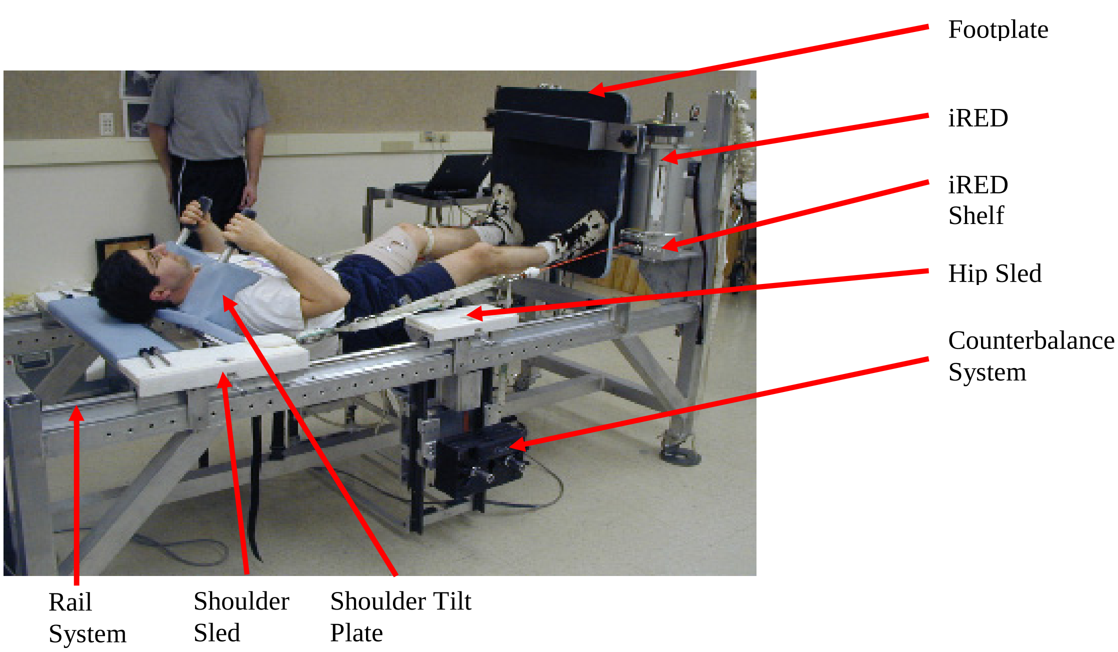


Figure 1: Subject performing a squat on the horizontal exercise fixture.

2.0 METHODS

All subjects passed an Air Force Class III physical and were given a written and oral explanation of the study before participating. The NASA Committee for the Protection of Human Subjects and the ARC Institutional Review Board reviewed and approved the project. Evaluation of exercise on the horizontal exercise fixture was divided into two phases. During Phase I of the study, a 95th percentile male and 5th percentile female performed one set of up to 12 repetitions of all exercises during a single training session (Tables 2 and 3).

During Phase II, five subjects performed four training sessions during which electromyography (EMG), pelvic reaction force, and questionnaire data were collected (Table 1). During these training sessions, pelvic sled counterweights of 38%, 43%, and 48% of body weight were used in a random order; the subjects were blinded to the condition and order of testing. One training session was used only to collect questionnaire data on Phase II subjects.

Table 1: Overall Protocol for Phase II of Evaluation

Session	*Exercises*	*Sets x Reps*	*Data Acquisition*
1	Squat	6 x 5-10	EMG/FP/Quest.
2	Auxiliary/Heel Raise	2 x 12	Quest.
3	Squat/Single Leg Squat	3 x 5-10	EMG/FP/Quest.
4	Squat	3 x 5-10	Quest.

EMG = electromyography; FP = force plate; Quest. = questionnaire

Phase I:

Two volunteers were selected that represented a 5th percentile female (160 cm, 50.0 kg) and a 95th percentile male (185 cm, 90.9 kg). These subjects were recruited separately from the subjects in Phase II to test the limits of the iRED horizontal exercise fixture and did not participate in Phase II of the study. The goals of Phase I were to determine: a) if all exercises (Table 3) could be performed in the horizontal position with the device; b) if the resistance could be decreased low enough for all subjects (including 5th percentile female) to perform 12 repetitions on each exercise; c) if the test fixture was long enough to accommodate the height of a 95th percentile male on all exercises; and d) if the iRED could provide enough resistance to obtain a six repetition maximum (6 RM) on each exercise.

To test the lower limits of the canisters, the iRED canisters were decreased to the lowest resistance (canister or "can" mark 0) and the 5th percentile female attempted 12 repetitions of each exercise. To determine if it was possible to test for 6 RM of the 95th percentile male, the subject performed warm-up exercises, and then resistance was increased until the subject could not perform six repetitions. Subjective data were also obtained via a questionnaire (See Appendix B) and by visual observations of the subjects' form by the test operators.

Phase II:

Subjects: Four male subjects (29 ± 5 yrs., 78.5 ± 9.4 kg, 182.3 ± 7.3 cm) and one female subject (41 yrs., 69.6 kg, 163.8 cm) with no previous history of musculoskeletal injury volunteered to participate in Phase II evaluation of the horizontal exercise fixture. Two of the subjects were experienced weight lifters; three were not.

Counterbalance: Vertical reaction force (F_z) at the pelvis was measured using a force plate (Advanced Medical Technology Inc. Model OR6-5-2000, Watertown, MA) between the pelvis and the pelvic sled. The force plate was set up such that prior to data collection, F_z was zeroed to the static force imparted to the force plate by the subject's body weight when the subject was in the starting position of the squat, single-leg squat, or deadlift exercise. Data were sampled at 200 Hz for 40 seconds.

Electromyography : EMG was measured from the left Vastus Lateralis Oblique (VLO) during the squat and single-leg squat. The belly of the VLO was palpated, shaved, abraded with 3M sandpaper tape, and cleaned thoroughly with an alcohol pad. A bipolar surface electrode with a built-in amplifier was placed over the prepared site parallel to the pennation of the VLO. The electrode was connected to the amplifier system (Therapeutics Unlimited Model 544, Iowa City, IA), where the EMG signal was amplified ×5 and band pass filtered between 10 and 350 Hz. A Compaq Armada E-500 notebook computer (Compaq Corp., Houston, TX) running LabVIEW 6.0 software (National Instruments, Austin, TX) recorded the EMG signal at 1000 Hz, and processed the data using a 12-bit analog to digital (A/D) converter.

Data were acquired for 6 seconds during each of three maximal voluntary isometric contractions (MVIC) on the VLO. The subject achieved the MVIC by performing an isometric knee extension with the femur fixed against the horizontal exercise fixture and the knee joint set at 90^o, 45^o, and 0^o. One minute of rest was allowed between each MVIC. The highest signal from the three contractions was used for normalization of the horizontal squat data.

The subject then performed six sets of 5 to 10 repetitions of the squat exercise on the horizontal exercise fixture at various intensities (Figure 2). EMG data was collected during one repetition per set. The repetition was randomly chosen before initiation of the set. All EMG raw signals were rectified, integrated, and normalized to %MVIC during analysis using LabView 6.0

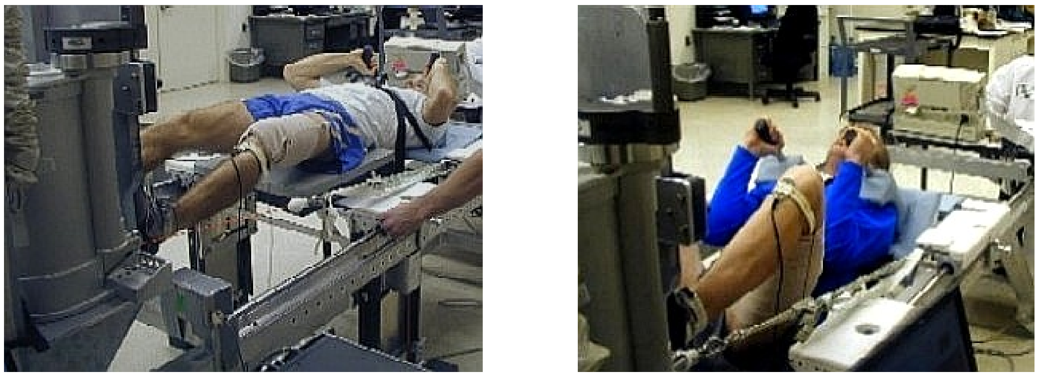


Figure 2: Subjects performing squat with EMG and force plate measurement.

Calibration: Prior to beginning the study, all data collection instrumentation (i.e., force plate and load cells) was calibrated in accordance with manufacturer guidelines. Additionally, the iRED was calibrated from can mark 0 – 12 in half can mark increments. The calibration was performed by attaching the on-orbit calibration tool to the distal end of the iRED cable and pulling the cord at a constant velocity (28 cm ·sec-1) to 56 cm. The calibration tool is a handheld mechanical scale that resembles a fish scale and is used on ISS to perform periodic calibrations of iRED. The tool provides only a maximal load reading for a given pull. Three pulls were performed at each can mark and an average of the three data points was used to estimate loading throughout testing. Quantitative loads from the bungees were estimated according to previous load testing performed with the bungees stretched to 84 cm. A table of the calibrated loads for iRED alone and iRED augmented with bungees is provided in Appendix A.

Engineering Log Data: The repetition count for each set of exercise was recorded for each canister in a notebook along with any problems associated with the iRED.

Statistical/Data Analysis:

Phase I:

No statistics were performed; however, a pass-fail criteria was implemented for each exercise. For an exercise to pass, the 5th and 95th percentile subjects had to comfortably perform the exercise with mechanics similar to upright exercise (by operator observation and subject feedback). If the exercise was similar to upright but was limited by a minor hardware problem, the exercise conditionally passed. If the exercise was impossible, it was assigned a failing score.

Phase II:

Force Plate Data: Force plate data was analyzed using Microsoft Excel software. Throughout the data collection, the pelvic sled frequently impacted the bottom of the fixture when the force plate was attached, due to a limitation in the vertical range of motion of the pelvis caused by the added height of the force plate. This caused a large fluctuation in the force data that was not relevant to determining the appropriate counterweight. Therefore, to filter the data, a mean and standard deviation of every 50th point of the raw data files was calculated. Every point that exceeded two standard deviations above or below the mean was eliminated. Following this, another mean and standard deviation were calculated from the filtered data. Equation 1 was derived by doubling the standard deviation, which provided an estimation of the average amplitude of F_z above and below the mean. Amplitudes of force were calculated using Equation 1 and are shown graphically in Figure 3.

$$F_{amp} = 2 \cdot \left[\frac{\sqrt{n \sum x^2 - \left(\sum x\right)^2}}{n\,(n-1)} \right]$$

Equation 1: Amplitude of reaction force at the pelvis during a squat. F_{amp}=amplitude; n=number of samples; x=pelvic reaction force.

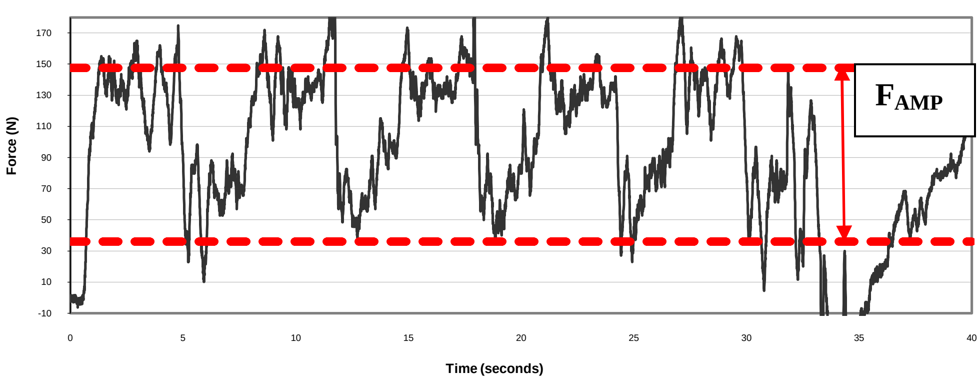


Figure 3: Vertical force measured at the pelvis during a horizontal squat performed at can mark 8+B; Counterweight 34% body weight (BW).

From the data, equations were developed to predict the correct counterweight, and a stepwise regression analysis was performed. Variables considered in the model were subject height (ht; cm), weight (weight of subject + weight of the force plate; lbs), counterweight (F_{CW}; lbs), amplitude of forces at the pelvis (F_{amp}; lbs.), and calibrated load from the iRED (F_L; lbs). The factors that did not significantly contribute to the accuracy of the equation were eliminated from the model. All statistics were performed using SigmaStat 2.0 (SPSS Science, Chicago, IL.).

EMG Data: A Pearson's correlation was calculated between the %MVIC and the calibrated load during exercise. Because the purpose of EMG collection was simply to verify muscle activity in the VLO, no other statistical tests for the EMG data were warranted.

3.0 RESULTS

Phase I:

Tables 2 and 3 provide a summary of the results for exercise evaluation. The pass-fail criteria are provided in Appendix C. Several exercises were given a conditional pass status contingent upon minor modifications to the horizontal exercise fixture.

Table 2: Exercise Pass/Fail for Primary Exercises

Exercise	*Pass*	*Cond. Pass*	*Fail*	*Reason for Failure*
Squat	✓			
Heel Raise		H		Need modification to foot plate
Dead Lift			H	Cannot perform with proper mechanics
Single-Leg Squat		H		Need foot plate to rest uninvolved leg
Single-Leg Heel Raise		H		Need modification to foot plate

(H) = Limitations of horizontal exercise fixture; (I) = Limitation of iRED

Table 3: Pass/Fail Status for Auxiliary Exercises

Exercise	*Pass*	*Cond. Pass*	*Fail*	*Reason for Failure*
Bent-over Row	✓			
Bicep Curl	✓			
Front Raise	✓			
Hamstring Curl	✓			
Hip Abduction	✓			
Hip Adduction			H	Foot plate interferes with cable
Hip Extension	✓			
Hip Flexion	✓			
Lateral Raise			I	Min. load too heavy for 5th percentile female
Leg Press	✓			
Rear Raise			I	Min. load too heavy for 5th percentile female
Shoulder Press	✓			
Single-leg Press	✓			
Tricep Pushdown	✓			
Upright Row	✓			

(H) = Limitations of horizontal exercise fixture; (I) = Limitation of iRED

Resistance:

Table 4: Resistive Force (N) During Study Based on Calibration Points Derived Prior to Testing.

Exercise	*Number sets performed*	*Minimum Load*	*Maximum Load*	*Average Load*	*StDEV Load*
Squat	154	343	3051	1272	579.6
Heel Raise	27	549	3051	1473	787.7
Dead Lift	25	343	638	474	84.8
Single-leg Squat	41	422	804	587	122.0
Single-leg Heel Raise	3	716	1422	1187	407.8
Bent-over Row	4	177	177	177	0.0
Bicep Curl	27	88	520	220	91.6
Front Raise	20	88	98	91	4.4
Hamstring Curl	8	88	98	89	205
Hip Abduction	2	88	88	88	0.0
Hip Adduction	2	88	88	88	0.0
Hip Extension	2	88	88	88	0.0
Hip Flexion	2	88	88	88	0.0
Lateral Raise	4	88	88	88	0.0
Leg Press	3	422	1422	853	514.3
Rear Raise	13	88	147	97	22.1
Shoulder Press	15	177	275	195	32.4
Single-leg Press	3	422	1422	853	514.3
Tricep Pushdown	23	177	343	200	49.4
Upright Row	22	177	275	209	46.2

Phase II:

Counterbalance: Backward and forward stepwise regression analyses were used to calculate a regression equation to predict the ideal counterweight for each set. Two separate equations were developed due to a large degree of variability between exercising with bungee augmentation and without bungee augmentation. Figure 4 demonstrates the variability between the two conditions. The derived equations are as follows:

$$F_{CW} = \frac{.239\ (BW) + (F_{amp})\ min + 23.309}{.0959}$$

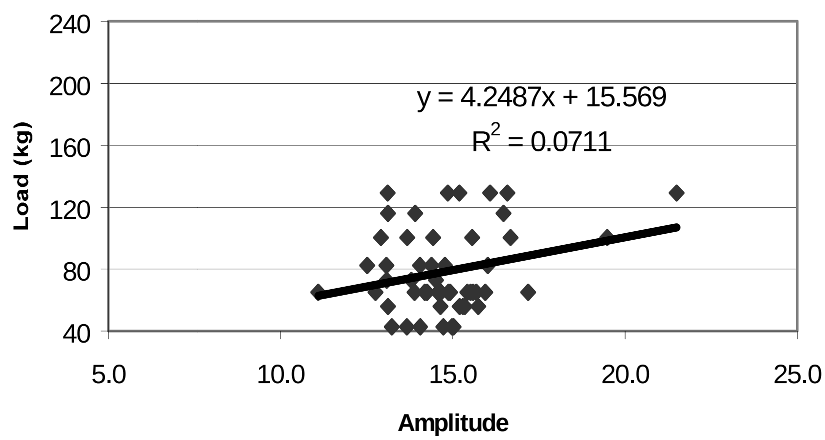
$$(F_{amp})min = -23.309 - .239\ (BW) + .0959\ (F_{CW})$$

Equation 2: Predicted ideal counterweight without bungee augmentation.

$$F_{CW} = \frac{.127\ (BW) + (F_{amp})min + 15.424}{.142}$$

$$(F_{amp})min = -15.424 - .127\ (BW) + .142\ (F_{CW})$$

Equation 3: Predicted ideal counterweight with bungee augmentation.



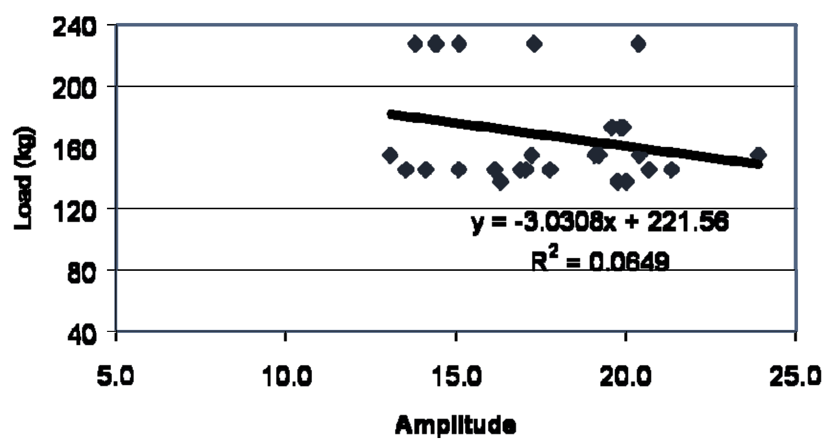


Figure 4: Effect of load (iRED) vs. F_{amp}(pelvic reaction force) in a horizontal squat performed without bungee augmentation (top chart) and with bungee augmentation (bottom chart). Notice the direct relationship in a squat without bungee augmentation and

the inverse relationship with bungee augmentation. The relationships are not statistically significant, but noteworthy.

EMG: Figure 5 represents the results of VLO activity during a bilateral squat. There was a positive correlation between load and percent activation for both the two-legged ($r=0.749$, $P<0.001$) and single-leg ($r=0.639$, $P<0.01$) squat.

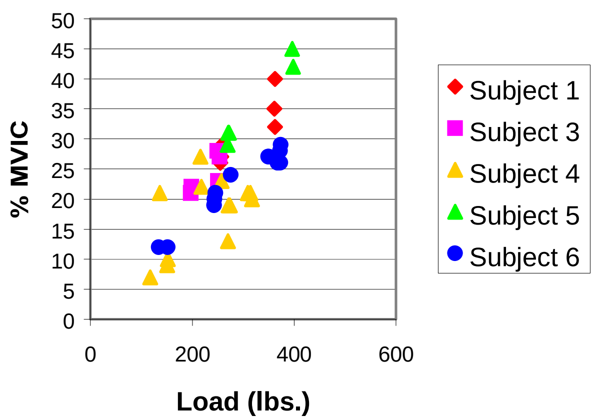


Figure 5: EMG activity in the VLO during a bilateral squat.

Subject Questionnaire: Results provided in Appendix B.

Engineering Log Data: Three thousand and eighty three repetitions were completed on the iRED with no significant problems with the canisters.

4.0 DISCUSSION

Phase I:

The purpose of Phase I of the evaluation was to determine the feasibility of performing exercises in the supine posture, as would be conducted during a bed rest study, using the horizontal exercise fixture in conjunction with iRED with different sized subjects. It was determined that in the current hardware configuration, some exercises could not be performed during bed rest, because the resistance could not be decreased enough to allow weaker individuals to perform the exercise (lateral raise and rear raise). Also, some exercises would be excluded, because they cannot be performed horizontally with similar mechanics to the exercise in the vertical position (deadlift and hip adduction). However, the majority of exercises, including the squat, can currently be performed on the horizontal exercise fixture with mechanics similar to upright exercise. Other exercises could be performed provided that slight modifications were made to the horizontal exercise fixture (heel raise, single-leg squat, and single-leg heel raise.)

The investigators determined that squat exercise could be performed satisfactorily, but some issues were noted with respect to the rotational axis of the shoulder tilt plate. The pivot point was noticeably lower than where a bar typically sits on the back during an upright squat. As a result, when the subject initiated the squat movement, it was necessary to force the pelvis down to produce enough torque about the tilt plate to rotate the shoulders forward. As the load was increased, this became more difficult, especially with the heavier counterweights (i.e., >43% BW).

The bent-over row, bicep curl, front raise, hip abduction, hip extension, hip flexion, leg press, single-leg leg press, shoulder press, and upright row were performed by both subjects with no significant issues. Two variations of the hamstring curl were evaluated and could be performed with the horizontal exercise fixture. Subjects first performed the exercise in the prone position with the exercising leg supported by the fixture. A second variation was successfully performed with the subject in the supine position while the exercising leg was unsupported. Both of the hamstring curls could be performed during bed rest and would resemble the on-orbit exercise currently being performed.

The tricep pushdown in the supine position with the subject inverted with respect to the foot-plate was successfully performed. However, with heavier resistance, it may be necessary to manufacture foot straps to anchor the subject's feet to prevent the subject's body from moving toward the foot plate.

Several other exercises were given a conditional pass status contingent upon slight modifications to the hardware. For example, the length of the horizontal exercise fixture was not adequate for the height of the 95th percentile male when performing the heel raise exercise. During the concentric portion of the heel raise, the shoulder plate contacted the top of the rail system, stopping the subject short of a full range of motion. During the evaluation, the ARC engineers produced a modified footplate. This footplate sat deeper in the fixture and thus alleviated the length problem. However, due to the configuration of the iRED shelf on the horizontal exercise fixture, the modified footplate was positioned higher than the original footplate. This limited the subject's range of motion in the dorsiflexed position. Moving the shoulder pads on the horizontal test fixture to higher on the shoulder plate may allow normal dorsiflexion and plantarflexion while using the original footplate.

The single-leg squat also received a conditional pass status because there was no place to rest the non-exercising leg during the exercise. During the evaluation, the non-exercising leg was placed on a portion of the force plate that was temporarily attached to the pelvic sled. However, without the force plate in place, which is the normal configuration, a modification is required to accommodate a resting place for the uninvolved leg of the subject.

Four exercises failed the evaluation. The rear raise and lateral raise failed the evaluation, because the lowest iRED setting (can mark 0) was too heavy for the 5^{th} percentile female to perform 12 repetitions. Also, subjects were unable to perform a deadlift with correct body mechanics on the horizontal test fixture. Proper shoulder position relative to the bar could not be achieved to allow for a mechanically correct deadlift. In other words, the subjects were unable to raise the shoulders above the plane of the bar, which is crucial to perform a deadlift correctly. Also, the pelvic sled bottomed out during the movement. The result was an exercise that resembled a modified back extension—not a deadlift. Hip adduction could not be performed because of the proximity of the footplate to the iRED cable. When the subject moved his or her leg during the exercise, the iRED cable contacted the outside edge of the footplate. This would cause damage to the cable and likely result in a failure.

Phase II:

Counterweight: The purpose of the counterweight was to counterbalance a portion of the subject's body weight such that their pelvis was supported, but could move freely in the vertical direction. To date, no other investigators have constructed a device that allows vertical translation of the pelvis during a supine squat. For this reason, the determination of an appropriate counterweight was derived. It was decided that the best way to counteract gravitational force in the supine position would be to counterweight the pelvic sled such that variations of the reaction forces between the pelvis and pelvic sled were minimized. Adding the correct amount of counterweight is important to ensuring that the effect of gravity acting perpendicular to the pelvis is reduced. With appropriate counterbalancing, the squat performed on the fixture would be very similar to the squat performed in an upright position, thus ensuring that similar musculoskeletal adaptations would result.

Originally, it was hypothesized that the pelvic sled would support the majority of the mass of the trunk, arms, and thighs. By using anthropometrical data, the average mass of these segments was estimated to be around 60% of body weight (8,15). However, when this level of counterweight was applied to the pelvic sled, subjects with previous experience performing the squat in the upright position determined that the counterweight provided too much upward force and could not be controlled. This was evident from both verbal feedback from the subject and visual observations from the test operators. As a result, the counterweight was gradually lowered until the subject felt comfortable performing the movement. A comfortable counterweight for the initial three subjects was approximately 43% of body weight. Therefore, 43% of body weight was set as the starting point for the counterweight throughout testing.

Amplitude was chosen as the dependent variable to assess F_z because it defined a range of force above and below the initial force of the weight of the pelvis. This was significant since vertical translation of the pelvis during a squat elicited an F_z above and below initialized force during the eccentric and concentric phases of the squat, respectively. Amplitude is defined mathematically as the difference between the maximum and minimum value of a periodic curve measured along its vertical. The challenge was to determine a standard way of measuring the amplitude of F_z. This was particularly difficult because each squat was mechanically unique, and thus produced different amplitudes of F_z.

It was determined that there was a correlation between resistive load and amplitude of F_z. When a subject performed a squat without bungee augmentation, resistive load and amplitude of F_z were directly proportional. Conversely, when the subject performed a squat with bungee augmentation, load and amplitude of F_z were not proportional. Due to this variation, sets performed with and without bungee augmentation were analyzed independently. A regression analysis was performed to determine an equation for each condition that would predict the counterweight that would yield the lowest amplitude of F_z. Unfortunately, the data set was too small and variable to accurately define an acceptable regression equation. Further testing would be warranted using the prediction equations to confirm their validity.

EMG: In the upright position, the squat is used as a primary exercise to develop muscle hypertrophy and muscle strength of the lower body (2). The squat also provides significant axial loading and the muscles active in the squat attach to bony landmarks in and around the femur (2); therefore, the squat is generally considered the prime exercise for maintaining BMD in the proximal femur and lower vertebral column. However, since the movement had never been performed in a supine position, there was a question as to whether the quadriceps muscles were active during this movement. In EMG research involving the quadriceps, the VLO is often used to measure level of activity in this muscle group. For this reason, we chose the VLO as our dependant measure of activity of the quadriceps during a horizontal squat. Also, the VLO is often used for muscle biopsies during training studies and determination of the activity of the VLO was needed to justify the expense of biopsies for future bed rest studies using the device.

A positive correlation between the %MVIC of the VLO muscle and load was observed during the squat. This provides confirmation that the muscle is active during a squat on the horizontal exercise fixture, and the force/muscle activity patterns closely resemble force/muscle activity patterns during an iRED upright squat (5).

There is a possibility that during a training study, the strength of the subject could exceed the load capabilities of the iRED. One subject during our evaluation was able perform a squat with the highest iRED loading plus all three additional bungees. The subject was outside of the normal bed rest population or astronaut population due to his exceptional strength. There also exists a possibility that the subjects could exceed the limits of the iRED with augmentation on the heel raise exercise. For all other exercises that were judged to be acceptable during the evaluation, the iRED provides more than adequate force to perform the exercises.

5.0 CONCLUSION

The purpose of this evaluation was to determine the feasibility of using the horizontal exercise fixture in conjunction with iRED during a bed rest study. A significant number of exercises, including the squat, may be performed during bed rest and appear to mimic the same exercise in the upright position. Furthermore, a bed rest study using the horizontal exercise fixture may approximate the exercises being performed on orbit and provide valuable information as to the effectiveness of the iRED.

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7.0 APPENDICES

APPENDIX A: iRED Force Calibration Table

Canister Mark	*Canister 1005*	*Canister 1006*	*Combined*
0	85	89	174
1	89	98	187
2	134	143	276
3	161	178	339
4	210	210	419
5	245	245	491
6	276	272	548
7	321	317	638
8	357	357	713
9	401	406	807
10	491	495	985
11	557	580	1137
11.5	638	629	1266
6 B	633	629	1262
7 B	678	673	1351
8 B	713	713	1427
9 B	758	763	1521
10 B	847	852	1699
11 B	914	936	1851
11.5 B	994	985	1980
6 BB	990	985	1975
7 BB	1035	1030	2065
8 BB	1070	1070	2140
9 BB	1115	1119	2234
10 BB	1204	1208	2412
11 BB	1271	1293	2564
11.5 BB	1351	1342	2693

B denotes single bungee and BB denotes double bungees used in addition to iRED canister load.

APPENDIX B : Summary of Subject Comments

Squat:

1. Was it difficult to maintain proper form while performing the squat (one-leg squat) exercise? If yes, why?
    - *No, being taught the proper form was helpful.*
    - *There was a learning curve; squats were difficult to perform at first, but as the subjects did more reps and got used to the machine and the motion squats became easier to do.*
    - *Form was difficult to maintain if the counterweight was too heavy.*
    - *As the iRED load increased, form became more difficult to maintain because the pivot point of the tilt plate would not rotate correctly.*

2. How comfortable did you feel while performing the squat (one-leg squat) exercise?
    - *For the most part, all subjects felt comfortable. The shoulders began to experience some amount of discomfort as the loads started to increase.*

3. Did you feel your hips were properly supported during the squat (one-leg squat) or did you feel the sled was forcing your hips to move? Why?
    - *For the most part all subjects felt adequately supported.*
    - *If the counterweight was too heavy, it became difficult to push the sled and move the hips.*
    - *If the counterweight was too light, the hip sled would slide out from underneath the subjects.*

4. Did you experience any joint or muscle discomfort performing the squat (one-leg squat) exercise? Explain.
    - *Discomfort was experienced in the shoulders due to heavy loads.*
    - *Discomfort was experienced in the mid to upper back due to the tilt plate pressing into the mid/upper back area when high loads were being used.*
    - *Discomfort was experienced in the neck from having to support the head in the horizontal position while exercising.*

Deadlift:

5. Was it difficult to maintain proper form while performing the deadlift exercise? If yes, why?
    - *Yes, the motion was awkward and it was difficult to coordinate hip and knee motion.*
    - *Lack of experience with this exercise made it difficult to perform even with training.*
    - *The arms and feet are pulled down by gravity. This made it difficult to get your hands past your knees and if there was any reduction in load (i.e., cable fully retracting) it became difficult to keep the feet up.*
    - *Also, the hip sled bottomed out on a cross beam in the fixture, which made the motion more difficult.*

6. How comfortable did you feel while performing the deadlift exercise?
    - *The comments were mixed. Some felt fine while others felt uncomfortable.*
    - *Those that felt uncomfortable were so because of neck strain due to supporting the head, and the straps used to attach the subject to the fixture dug into them.*
    - *Some were also uncomfortable because the exercise was awkward.*

7. Did you feel your hips were properly supported during the deadlift or did you feel the sled was forcing your hips to move? Why?
    - *For the most part, everyone felt well supported unless the counterweight was too heavy or too light. Comments in question #3.*

8. Did you experience any joint or muscle discomfort performing the deadlift exercise? Explain.
    - *Neck strain due to having to support the head during exercise.*

Other:

9. Did you experience any problems while getting on or off the bed rest fixture? If so what?
    - *No.*
    - *Placing one of the shoulder restraints (used during the squat and heel raise) with the handhold aided the subject in getting on and off the fixture because there was something to grab and pull on.*

10. Did you experience any problems maintaining proper form during any of the other exercises? If so, which exercises and why?
    - *For the most part, no comments.*
    - *Heel Raise – Standard footplate did not leave enough room to perform the exercise. Modified footplate was too high and did not allow a good range of motion (ROM) or form. The heel block was too small (3" height was not tall enough for a good ROM).*
    - *Front raise – When the weight was heavy, it was difficult to maintain good form.*

11. Did you experience any joint or muscle discomfort performing any of the other exercises? If so, which exercises and why?
    - *Almost all subjects said the upright row provided discomfort in the anterior deltoid. The motion was not the same as when doing the exercise standing up.*
    - *One comment about the heel raise when under high load. The subject felt some discomfort on the shoulders and upper back region.*

12. How would you describe the movement of the shoulder sled?
    - *Supportive, smooth, and fluid.*
    - *The female subject noted her hair would get caught in the shoulder sled, mainly between the tilt plate and the shoulder sled when the tilt plate came back to its starting position.*

13. How would you describe the movement of the tilt plate in the shoulder sled?
    - *Under high load, the tilt plate becomes difficult to move. There was some resistance to tilt.*
    - *Lightening up the counterweight made the tilt plate rotate easier.*
    - *The axis of rotation seemed to be different from axis of rotation of shoulders.*

14. How would you describe the movement of the hip sled?
    - *General agreement the movement was smooth.*
    - *A few general comments it was smooth as long as the counterweight wasn't too heavy or too light.*

15. Did you feel uncomfortable pressure while exercising? If yes, where?
    - *One subject stated there was some pressure on the shoulders during the shoulder press.*
    - *Upright row in the anterior deltoid.*
    - *In the shoulders during heavy load exercises using the shoulder restraints.*

16. Did you experience any pinching while exercising? If yes, where?
    - *Staples poked through the padding and the vinyl covering.*
    - *Hair got caught between the tilt plate and shoulder sled.*

17. Did you feel that supine exercise on the bed rest fixture simulated upright exercise? Why or why not?
    - *All comments stated that the bed rest fixture did simulate upright exercise.*
    - *Subjects said all the exercises they performed felt similar to how they would perform them in the gym.*
    - *One person made the exception with the deadlift, saying it did not feel similar.*

Additional Comments:

- *There was discussion about altering the pivot point of the shoulder sled. I am sure this is easier said than done, but I think it might help.*
- *The exercises were all comfortable except for the rear raise.*
- *One comment from last time was that the hand bar was a little rough on the lower legs during the dead lift. Rollers or pads might be a good idea. I could see some subjects having problems with it.*
- *The tricep exercise needs to be performed at 45 degrees "arm to body" position to get the best tricep workout/results.*
- *Even on the lowest setting, the front raise exercise is quite challenging and should not be recommended for average bed rest candidates. All other exercises (shoulder/ "military" press, curl, tricep, heel raise) are all acceptable for bed rest subjects.*

- *Be careful on upright row for any subjects with shoulder or neck strain/injuries.*
- *On heavier loads, this iRED machine needs some way to compensate for over exertion on the shoulders and provide better support for the back being jabbed by the shoulder/tilt plate.*
- *Observation – It seems much harder to support the heavier weight at the top of the slide than it is to hold it up when in a squatted position.*
- *The one-leg squat was easy to do and easier to perform than the two-leg squat. It reminded me of the difference between water skiing on one ski vs. water skiing on two skis.*
- *I'm not sure how "heavy" the heaviest squat setting was, but I suspect it is more weight than I could lift normally. However, the machine allows you to successfully handle these higher weights.*
- *I feel my neck and shoulders got more of a workout than my legs or arms.*
- *It definitely takes awhile to get used to the alternate movements.*
- *It helps to have coaching on form when performing these exercises. The astronauts might wish to exercise in pairs or provide a mirror for self-evaluation.*

APPENDIX C

Exercise:	Yes	Maybe	No	Comments
1) Can the exercise be performed with the proper ROM?				
2) Can the exercise be performed with the correct technique?				
3) Can the exercise be set up in 5 min?				
4) Can the subject remain on the fixture during setup?				
5) Can a 4 RM load be achieved for the exercise?				
6) Can a 12 RM load be achieved for a 5th percentile female?				
7) Was Augmentation necessarry to perform the exercise?				
8) Can the exercise be performed within the constraints of bed rest?				
9) Can the exercise be coached in a reasonable amount of time?				

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13. ABSTRACT *(Maximum 200 words)*
INTRODUCTION: Countermeasure exercises have been developed to reduce bone and muscle loss during space flight; however, until now no exercise device has been available to mimic vertical pelvis displacement in squat exercises with supine subjects during bed rest. A horizontal exercise fixture (HEF) was designed to be used with the interim Resistive Exercise Device (iRED) to mimic the biomechanical characteristics of a standing squat. The pelvic sled of the HEF is equipped with a counterweight that balances the pelvis in the vertical direction. PURPOSE: The purpose was to determine if iRED exercises could be performed on the HEF. Additionally, this evaluation sought to compute the appropriate counterweight for the pelvic sled exercises and to evaluate the electrical activity of the Vastus Lateralis Oblique (VLO). METHODS: Phase 1 used a 5th percentile female and a 95th percentile male to determine if the highest and lowest force levels were appropriate for a range of test subjects, and if a supine exercise could be performed with similar mechanics to the upright position. Phase II assessed the pelvis sled counterweights for various exercises, along with VLO activity. RESULTS: A number of exercises were performed on the HEF without any significant performance issues, and therefore could be performed in a bed rest study. Additionally, regression equations were developed to predict the ideal counterweight. CONCLUSION: A bed rest study using the HEF could be performed in which subjects execute a large number of the exercises that are similar to upright exercise.

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