MEASUREMENT AND PREVENTION OF MUSCULAR DECONDITIONING ON SKYLAB

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A major portion of man's musculoskeletal system is dedicated to supporting and moving his body against Earth's gravity. This mass of muscle places heavy requirements for support on other body systems. For example, maximum capacity of the cardiovascular and respiratory systems, and to a large measure their condition, is a function of demands from the body's musculature. It is a common experience that removal of muscle stresses under one-g, that is, lack of suitable exercise, results in atrophy of both muscle and its supporting systems. It could be confidently predicted that atrophy would occur rapidly under weightlessness unless suitable exercise was provided.

The time taken for such atrophy to occur allowed short missions such as Apollo to proceed without significant problems. No muscle function evaluations were originally scheduled, but some of us felt it was no longer possible to consider a long mission like Skylab without (1) some method of evaluating muscle condition, and (2) suitable inflight exercise.

On Skylab, we instituted first a minimum impact muscle function test, and as the mission demanded, added exercise and exercise devices and expanded the testing. The result was a different exercise environment on each flight, such that we had three experiments, with the results of each flight affecting the next. The flights will be described chronologically. This report will, insofar as possible, address only skeletal muscle since the cardiovascular aspects of conditioning and use of the bicycle ergometer are covered in another experiment.

Evaluation of the right arm and leg was done preflight and postflight on all missions with the Cybex isokinetic dynamometer. This dynamometer may be rotated in either direction without resistance until an adjustable limit speed is reached. Speed cannot be increased above this limit by forces of any magnitude, that is, the constant speed-maximum force of isokinesis is achieved. Input or muscle forces are continuously recorded. Various arms, handles, and the like may be attached to the dynamometer to couple any desired segment of the body to the machine.

Slide 2-1

The arrangement used on Skylab is shown here. A crewman, after thorough warm-up, made 10 maximum effort full flexions and extensions of the arm at the elbow and of the hip and knee at an angular rate of [redacted] per second.

45°

Slide 2-2

A continuous force record was made of each repetition at a rate of 25 millimeters per second and the integral of force, or under these conditions, work is recorded on a second channel.

Machine errors are small, 2 to 3 percent or less. The test gives a measurement of strength comparable to the more commonly used isometric testing, but has the great advantage of recording this force throughout the whole range of motion as well as allowing a number of repetitions for statistical purposes. It is sensitive enough to show small changes in performance which may occur in days.

A great deal of information is contained in the recording made, but only one quantity will be used here--the peak force of each repetition at the same point in the cycle. Use of a single point on the tension curve to represent the entire curve may be open to criticism, especially in the leg where a number of muscles are involved. However, for the purposes here, I feel this is a valid measure of strength of the muscles tested.

Slide 2-4

A plot of such peak points from a preflight and postflight curve is shown. The strength for a given movement is taken as the average of 10 repetitions. As you can see, a fatigue decrement is present and may vary. It is included in the strength figure by virtue of averaging the 10 repetitions.

On Skylab 2 only the bicycle ergometer was used for in-flight exercise. Pete Conrad used it in the normal fashion and was the only person on Skylab to use it in the hand-pedal mode and was the one person on this crew to exercise at rates comparable to those of later missions.

On Skylab 3, testing was performed at F-18 and R +5. It was recognized that this was too far removed from the flight, but was the best that could be done under schedule constraints.

By the time muscle testing was done on day 5, there had been a significant recovery in function; however, a marked decrement remained. Results from Skylab 2 will be shown in a moment in conjunction with the results from Skylab 3. The decrement in leg extensor strength approached 25 percent, while the arms had suffered less but also had marked losses. The commander's arm extensors had no loss, since he used these muscles in hand-pedalling the bicycle. This illustrates a crucial point in muscle conditioning: to maintain the strength of a muscle, it must be stressed to or near the level at which it will have to function. Leg extensor muscles which support us in standing and propel us in walking must develop forces of hundreds-of-pounds, while the arm extensor forces are measured in tens-of-pounds. Typical forces for pedalling the bicycle ergometer are a few tens-of-pounds and are totally inadequate. The bicycle ergometer is an excellent machine for aerobic exercise and cardiovascular conditioning, but it simply cannot develop either the type or level of forces to maintain strength for walking under one-g.

Immediately after Skylab 2 work was started on devices to provide adequate exercise to arms, trunk, and legs. A mass-produced commercial device, called Mini Gym, was extensively modified and designated "MK I". A centrifugal brake arrangement approximated isokinetic action on this device.

Slide 2-5

Only exercises which primarily benefited arms and trunk were available as shown here. Forces transmitted to the legs were higher than those from the ergometer, but they were still limited to an inadequate level by the maximum strength of the arms.

A second device, designated "MK II", consisted of a pair of handles between which up to five extension springs could be attached, allowing maximum forces of 25 pounds per foot of extension to be developed.

These two devices were flown on Skylab 3, and food and time for exercise was increased in flight. The crew performed many repetitions per day of their favorite maneuvers on the "MK I" and, to a lesser extent, the "MK II". Also, the average amount of work done on the bicycle ergometer was more than doubled on Skylab 3 with all crewmen participating actively.

Results of muscle testing of Skylab 3 crewmen demonstrated marked differences from the Skylab 2 crew.

Slide 2-6

Looking at arms on Skylab 3, one sees complete preservation of extensor function and almost complete preservation of flexor function in contrast to Skylab 2. The science pilot showed a marked gain in arm strength. This is the result of putting a good distance runner, which Owen is, on a weight-lifting program.

Slide 2-7

Looking now at leg function, we see a different picture. Only two Skylab 3 crewmen are shown since the commander suffered a recurrence of a back strain from a roll of the recovery ship--possibly another demonstration of the hazard of muscle deconditioning. Although there is a relative improvement in loss over Skylab 2, there nevertheless remains a significant reduction. It seems rather obvious that the "MK I" and "MK II" exercise devices did a good job in arm preservation but were still inadequate to maintain leg function.

Some device which allowed walking and running under the equivalent forces of gravity appeared to be the ideal answer to this problem and immediately after Skylab 2 work was started on a treadmill for Skylab 4.

Slide 2-8

It consisted of an aluminum teflon walking surface attached to the iso-grid floor. Four rubber bungees providing an equivalent weight of 175 pounds were attached to a shoulder and waist harness. By angling the bungees an equivalent to a slippery hill is presented to the subject who must climb it. High loads were placed on some leg muscles, especially in the calf, and fatigue was rapid such that it could not be used for significant aerobic work.

Film Clip: Treadmill

(NARRATE)

(As the mission progressed, launch weight of Skylab 4 became crucial such that the final design was simulation of a treadmill in response to the weight constraints--final weight for the device was 3 1/2 pounds.)

On Skylab 4 the crew used the bicycle ergometer at essentially the same rate as Skylab 3, and the MK I and II exercisers. In addition, they typically performed 10 minutes per day of walking, jumping, and jogging on the treadmill. Food intake had again been increased.

Even prior to muscle testing it was obvious that the Skylab 4 crew was in surprisingly good condition. They stood and walked for long periods without apparent difficulty on R +1 in contrast to the earlier missions. Results of the testing confirmed a surprisingly small loss in leg strength for almost 3 months in weightlessness. A summary of the exercise and strength testing is shown on this slide. of averaged values for the three missions. One point to be noted is the relatively small losses in arms as compared to legs in all missions. This is reasonable for in space ordinary work provides loads for the arms that are relatively much greater. The legs receive virtually no effective loading. With the MK I and II exercisers, arm losses were reduced to negligible values except in arm extensors on Skylab 4, most of which was accounted for by the commander. The next time Jerry flies, I must speak to him about that.

Slides 2-9 and 2-10

Slide 2-11

Size is another common measure of muscle condition, and a plot of average change in leg volume for each crew in the postflight period is shown. Changes for the first two days must be primarily fluid. Skylab 2 and 3 lost essentially the same volume in spite of a twofold difference in mission duration, while the longest mission lost only 1/2 of the volume of the shorter ones. A second point is that Skylab 4 quickly recovered their preflight volume in contrast to 2 and 3. Notice that this data parallels that of leg extensor strength losses which were roughly equal on Skylab 2 and 3, and sharply reduced on 4.

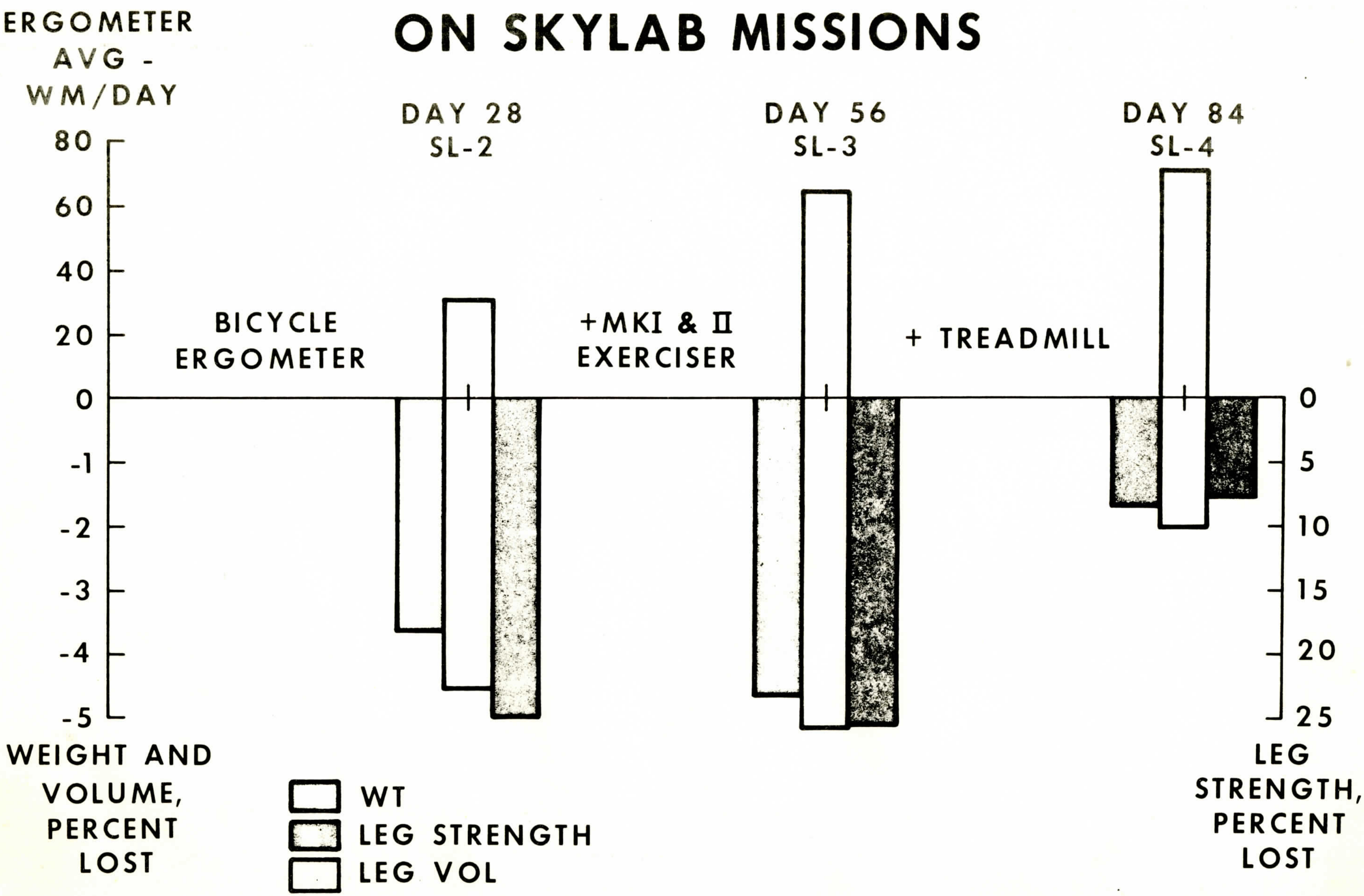
There was a 6 1/2- to 9-fold reduction in rate of loss of leg extensor strength, leg volume, lean body mass and total body mass from Skylab 2 to Skylab 4. One might argue that this reduction simply represents some kind of equilibrium with increasing mission duration, but this is not consistent with the next chart which shows absolute
Slide 2-12 losses. Again, Skylab 4 shows a marked improvement as regards weight, leg strength and leg volume. I feel correct in attributing the decrease in loss of muscle strength and bulk to the exercise devices and time that was added. There can be little doubt that adding the MK I and II improved the arm performance of Skylab 2 and 3. And equally little doubt that the treadmill sharply reduced loss of leg strength and mass, since there was negligible increase in leg exercise with other devices on Skylab 4. However, it must be recognized that another variable was present--food. Virtually all workers in nutrition--that I know--recognize that metabolic losses in normal subjects are mixed, i.e., both fat and muscle are lost. Vanderveen and Allen deliberately reduced caloric intake during a one-g chamber test simulation of spaceflight conditions using subjects chosen to be as equivalent as possible to the astronaut population. They found an almost pure muscle loss.

At this time I cannot escape the conclusion that muscle in space is no different from muscle on Earth, if it is properly nourished and exercised at reasonable load levels, it will maintain its function.

I feel that a properly designed treadmill used for considerably less than an hour a day will not only protect leg and trunk musculature, but will also provide aerobic exercise to cover the cardiorespiratory system. It will not be difficult to add arm exercise at the same time such that we meet the requirements for a single total body exerciser.

NASA-S-74-4806

EXERCISE RELATED QUANTITIES ON SKYLAB MISSIONS



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SUMMARY OF CREW AVERAGES OF EXERCISE RELATED DATA

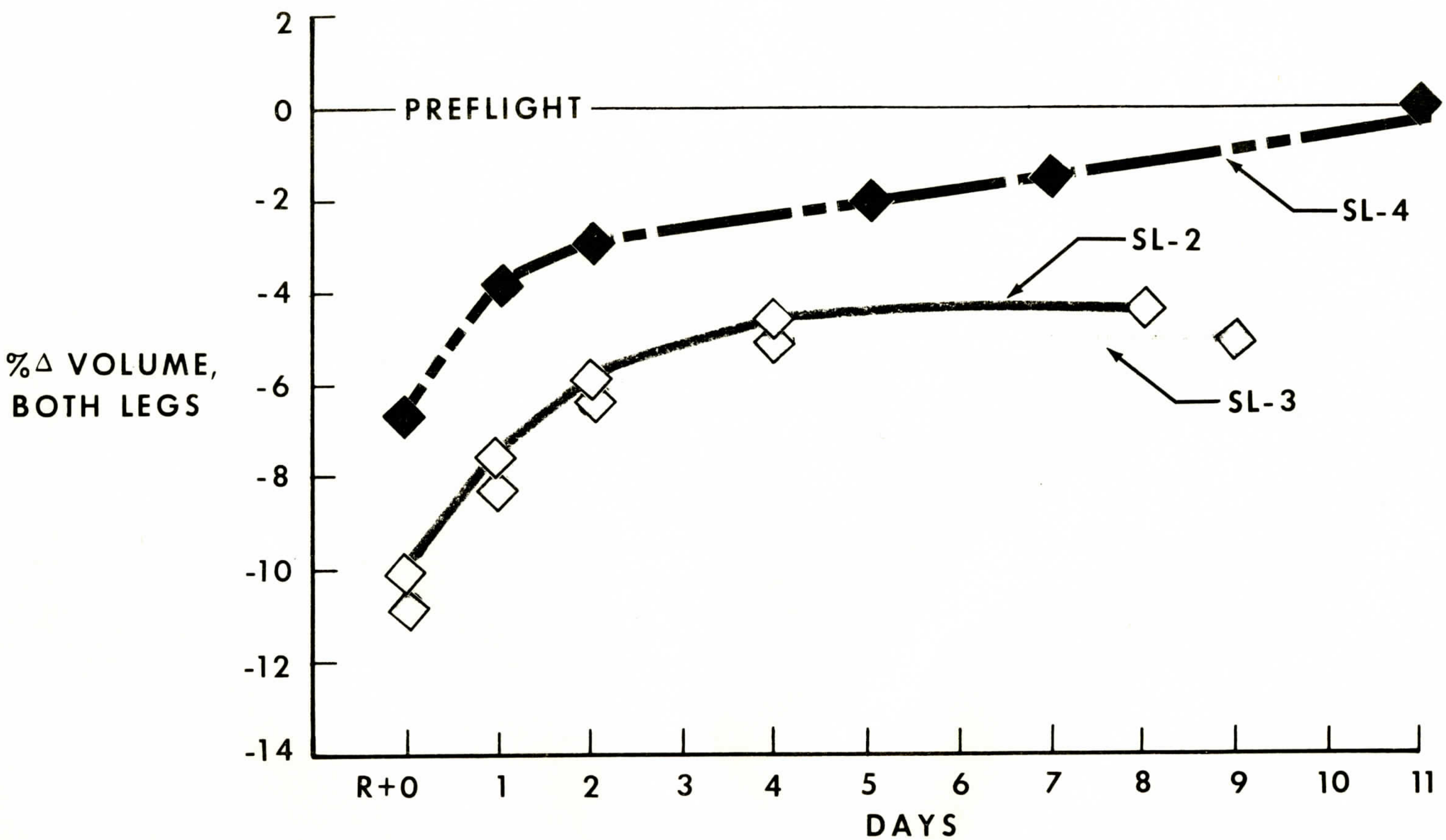
SKYLAB CREW	CHANGE IN LEG EXTENSION FORCES F-15 TO R+1, PERCENT/DAY	CHANGE IN LEG VOLUME F-15 TO R+5, PERCENT/DAY	CHANGE IN LEAN BODY MASS F-15 TO R+1, PERCENT/DAY	CHANGE IN BODY WEIGHT F-1 TO R+0, PERCENT/DAY	AVERAGE DAILY ERGOMETER EXERCISE, W-MIN/kg BODY WEIGHT
*2	-0.89	-0.160	-0.089	-0.13	31.3
†3	-0.44	-0.088	-0.019	-0.08	65.0
‡4	-0.09	-0.023	-0.011	-0.02	71.0

EXERCISE DEVICES AVAILABLE

* BICYCLE ERGOMETER
† BICYCLE ERGOMETER, MK-I AND MK-II EXERCISERS
‡ BICYCLE ERGOMETER, MK-I AND MK-II EXERCISERS, TREADMILL

NASA-S-74-4803

AVERAGE LEG VOLUME CHANGE, POSTFLIGHT - SKYLAB



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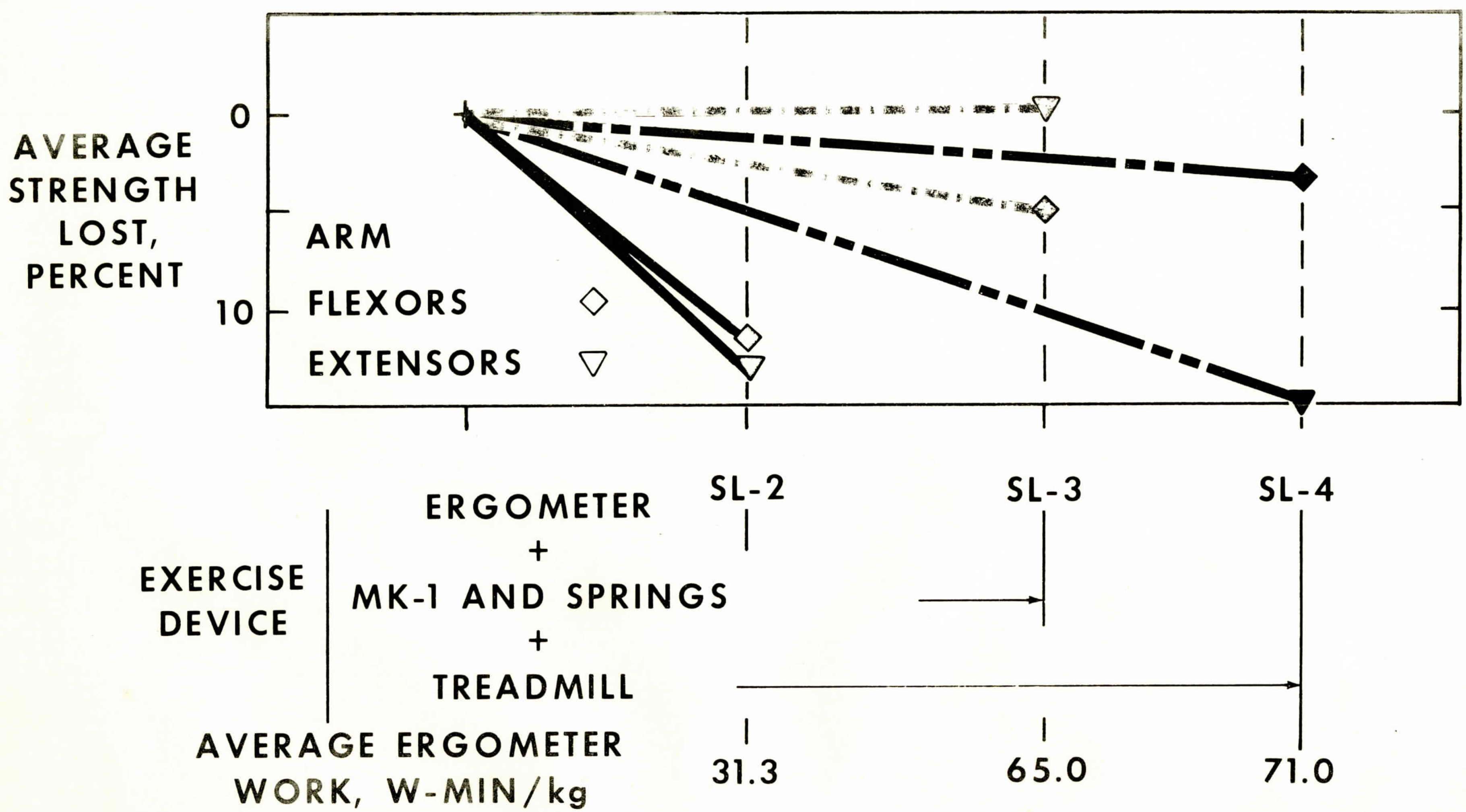
AVERAGE STRENGTH CHANGES, ARM



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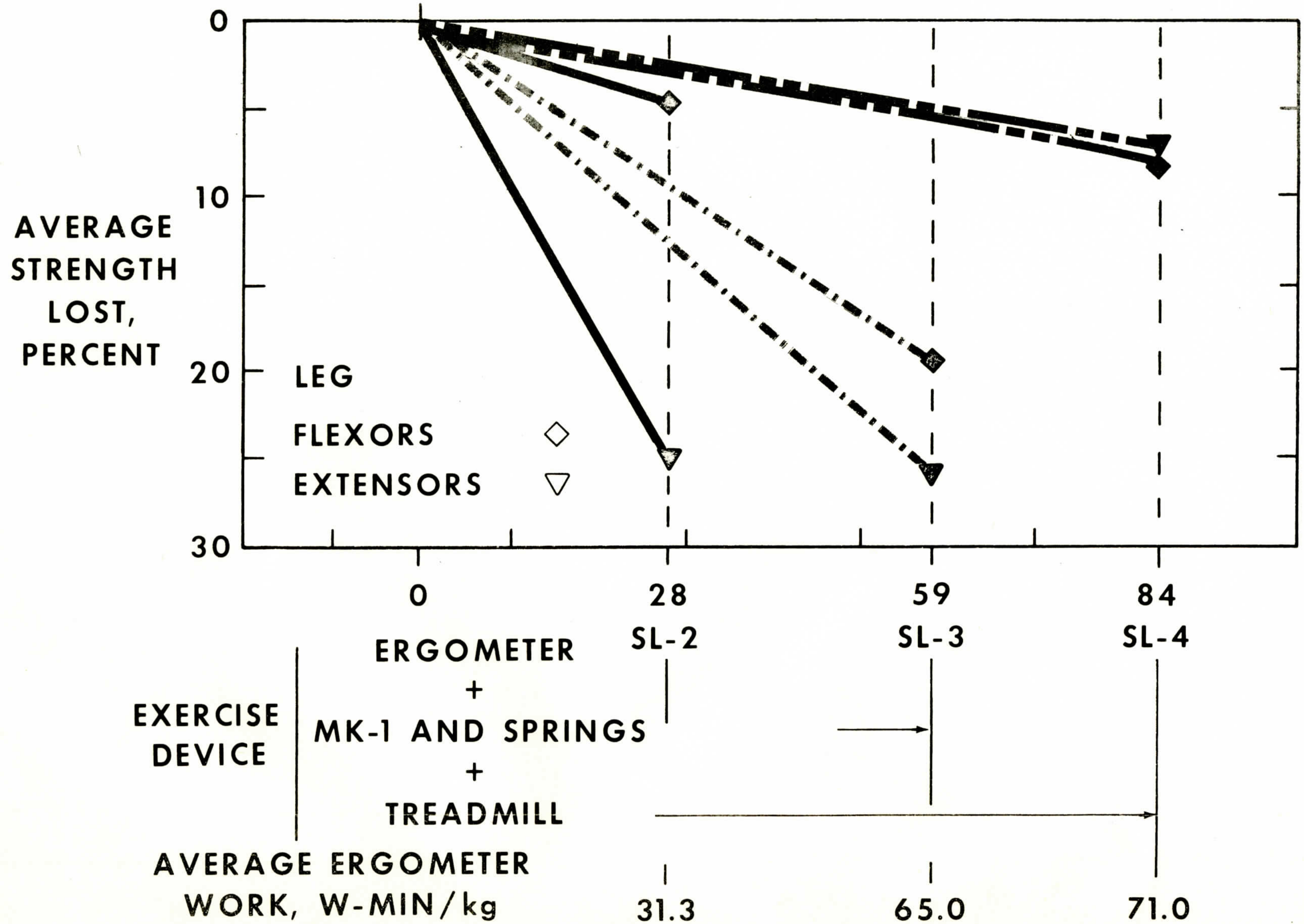
AVERAGE STRENGTH CHANGES, LEG



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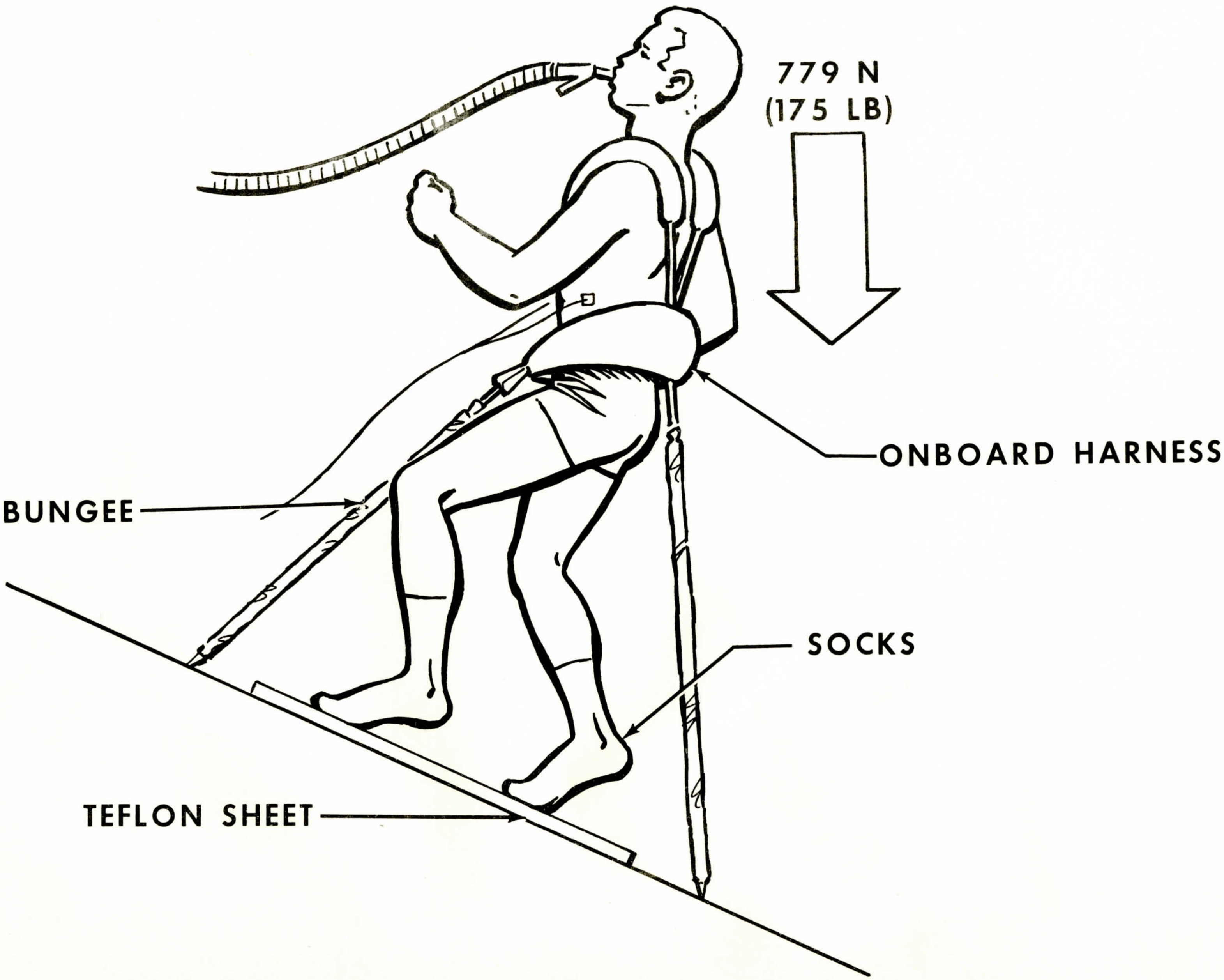
TREADMILL ARRANGEMENT



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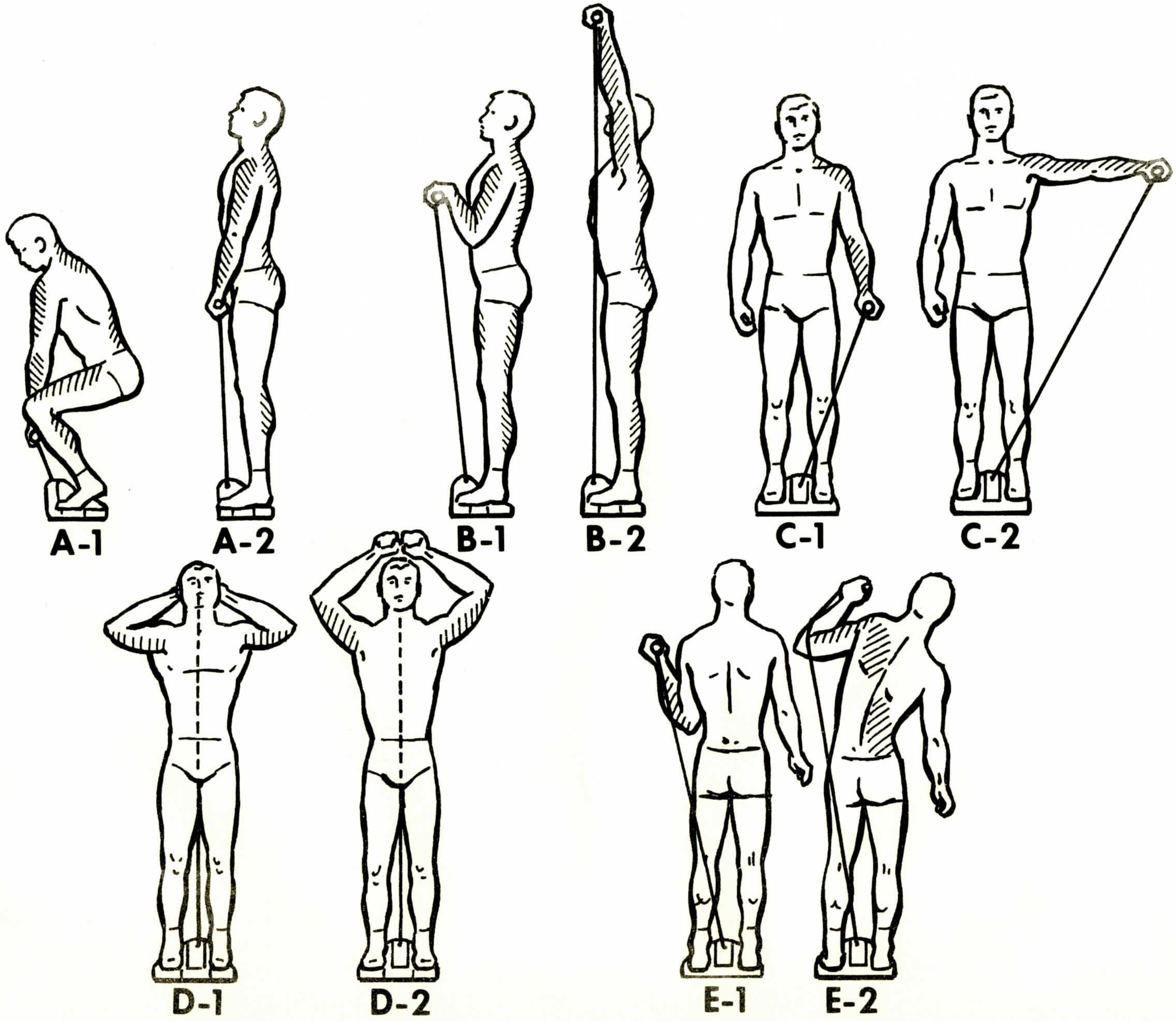
MKI EXERCISER POSITIONS



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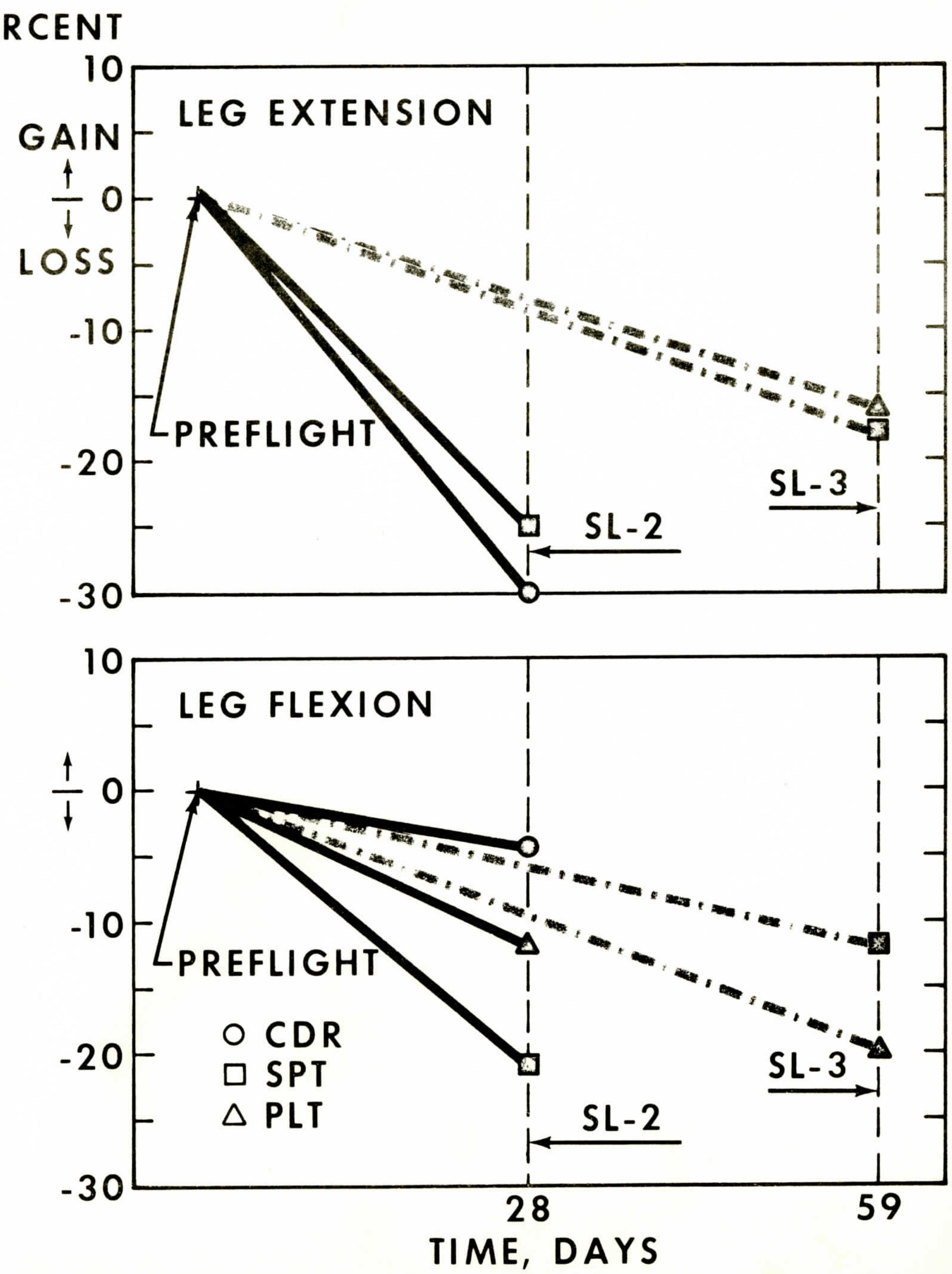
CHANGES IN LEG FORCES ON SL-2 & 3



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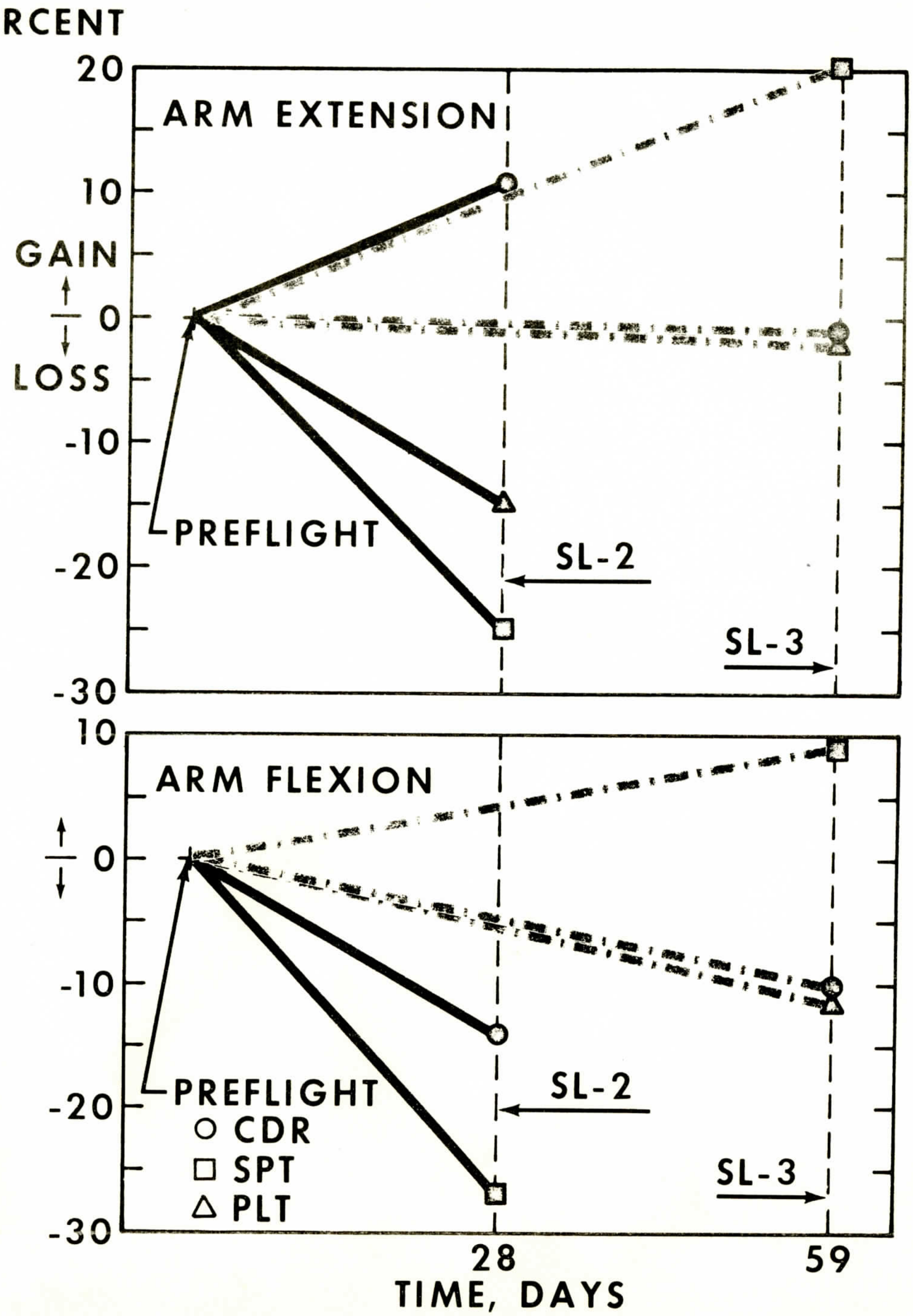
CHANGES IN ARM FORCES ON SL-2 & 3



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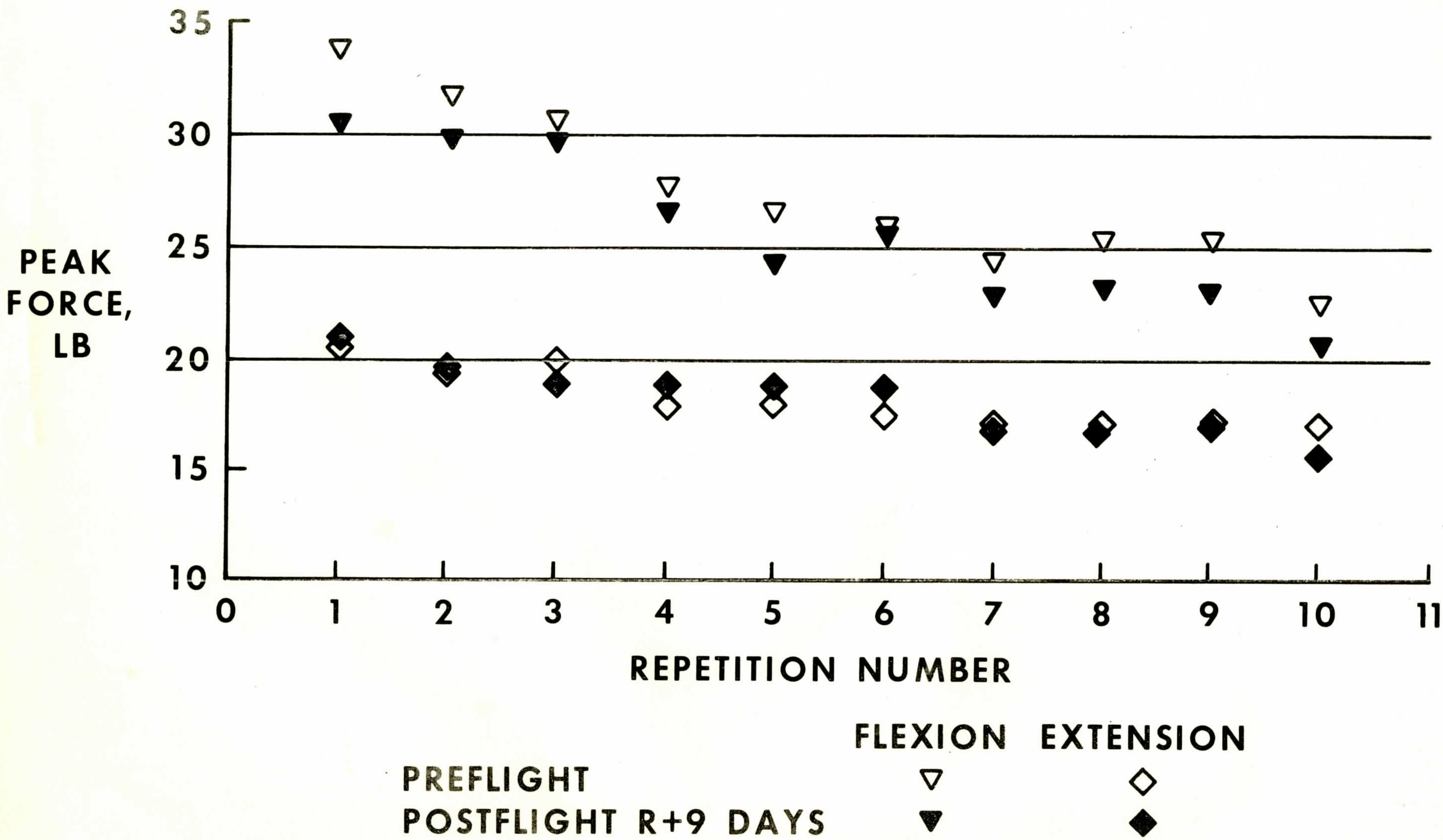
PEAK ARM FORCES, SL-3 CDR



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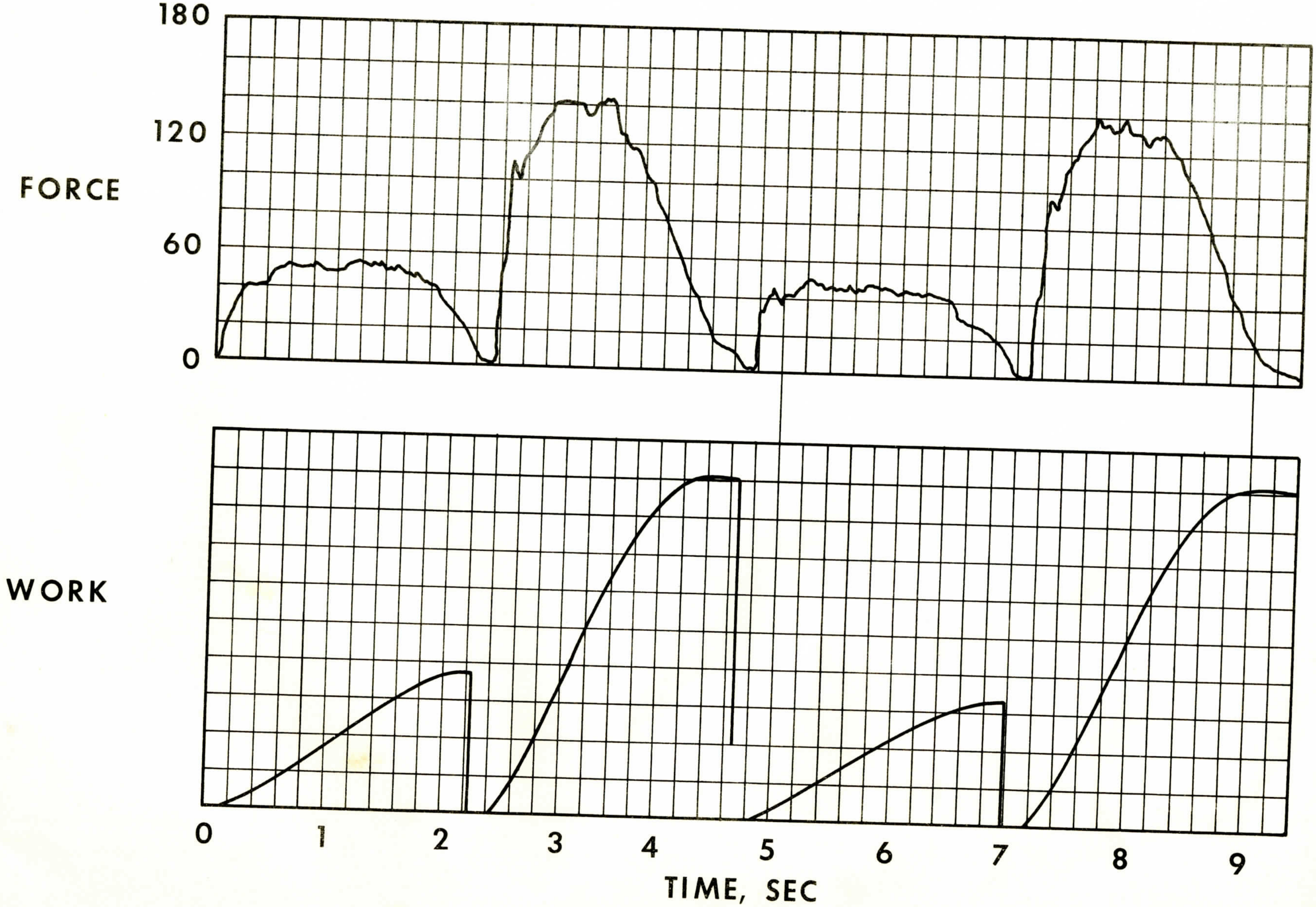
RECORDING OF MUSCLE FORCES
RIGHT LEG, SL-3 BACKUP PLT



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TEST ARRANGEMENT