A DTO for comparison of some Biomechanical Effects of Earth gravitational vs. external mechanical forces.

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Background:

It is a well known axiom of physics that all forces produce the same effect i.e. it makes no difference whether the force is gravitational, electrostatic, accelerational, mechanical, etc.. So long as the magnitude, distribution, direction and time course are equivalent on a body or system, the effects will be the same. Thus when it came time to choose a force to replace weight in weightlessness the type of force was irrelevant and was chosen for efficiency, eg weight, power, etc. The real problems were making the factors listed equivalent to gravity. An elastic bungee was chosen, the various factors examined theoretically and when possible practically. (Repeated attempts at inflight measurement by the developer of this system have been administratively thwarted.)

Distribution:

There is currently no way to achieve, other than with acceleration, the distributed force of gravity rather, discrete forces must be applied to sufficient points to produce reasonably similar results. To provide equivalent weight for locomotion in weightlessness, a three point axial load was applied as the minimum practical eg on the ischial crests and each shoulder. It would have been desirable to individually load the lower leg and thigh, arms and head but it is not practical. The major result of using 3 points as in the current treadmill harness is that weight loads are removed from leg flexors (acceleration forces remain) but this was considered acceptable for extensor forces are of chief concern here.

Direction:

The usual gravitational force on an erect human is along the body's long axis and that is the case with the bungee harness. Elastic elements also allow adjustment of the body's mean force vector in locomotion. Separate, adjustable fore-aft forces allow 'trimming' of forces to approximate the off center C. G. location on Earth.

Magnitude:

May be adjusted very precisely (requires a simple scale).

Time Course:

The force should remain constant (F=K) but the bungee force varies with displacement, (F=KX) and  F=K X but this can be made small by keeping the ratio of ( X/X) small. Locomotor movement, (which is time dependent) at waist level is only 1-2 inches hence by extending the bungee length by folding it over pulleys, a variation on the order of 2% is possible and negligible. Such variation can be reduced to any practical value by increasing bungee length.

In summary then the elastic bungee is a close approximation of weight except for motions of some body elements esp. flexor activity of leg.

Recently an evaluation of adequacy of these forces was proposed using indirect measurements from the existing STS T.M. Such an evaluation must be done with great care to produce meaningful results. Forces, in this case foot ground forces, must be registered with a minimum of distortion. The action studied should be as directly related to the forces studied as possible and unaffected by other factors eg. treadmill design, etc. If the effects of a machine such as a treadmill are to be evaluated it should be current practice and not an outmoded design.

For all of these reasons the following is proposed. The simplest possible interaction of the body and force was chosen with simple-high fidelity recording which will allow direct comparison of biomechanics, kinematics and to some extent, metabolic, effects of the two loads.

Once the fundamental question of effects of forces are determined the more complex case of locomotor activity on a current treadmill will be addressed.

The following is a direct and simple DTO which uses a sufficiently simple and accurate model to allow a realistic evaluation of a bungee force vs weight. Instrumentation is adequate. No attempt is made to evaluate such complex physiological effects as maintenance of muscle strength, etc. External, including metabolic loads can be controlled.

Brief description:

The activity consists of walking and jogging in place at controlled rates on earth and in space loaded by bungees and harness with forces adjusted for magnitude and balance equivalent to weight on Earth. A simple, single axis force plate of adequate and measured response will record vertical forces. A single axis camera can record motion adequately for kinematic analysis. Heart rate can give an indication of metabolic load and EMG could give some comparison of muscle activity if desired. Magnitude, rate of change and waveshape of forces would be compared and statistically analyzed for significance. Range of motion and motion patterns would be treated in the same way. An estimate of metabolic load caused by the same rate and amplitude of activity could be obtained for comparison from heart rate, however, other factors in space may also affect heart rate response.

The major hypotheses are that:

1. Foot ground forces at a given step rate under a close approximation of locomotion, with an axial mechanical force load, in weightlessness closely approximate those in 1 g. under equivalent conditions.

2. One g kinesiology is also approximated under the above conditions.

Some approximation of metabolic load may be obtained from heart rate and it is assumed that EMG activity will differ. (This can be measured if desired).

Schedule:

Four minute bouts of walking and jogging at individually determined and controlled slow and fast rates would be done at approximately L-30, 15 and 7 days, at L + 2 and R - 1, R + 0 and R + 5.

Five subjects should be used.

Hardware:

A simple strain gage supported single axis force plate with amplifies will be used and recorded on a standard existing flight tape recorder. Existing harness/bungee system would be used for external force. An existing flight DVM would indicated static loads from the force plate and existing flight camera used for kinematic study. Existing flight amplifiers could be used for EK EMG and their output recorded by the magnetic tape unit. The additional complexity and inherent limitations of EMG make the value of this questionable.

Personnel:

The author has had more experience with the theory and practice of artificial loads biomechanical in weightlessness systems than anyone else in this country. He has designed and ground tested the basic force measurement system described here and used it to validate this exercise in 1 g before it was flown on STS-2. He has wide experience including several extensively used patents in photo optics instrumentation and analysis and has done the only inflight kinematic study of the treadmill to date. He developed and used the first telometered EMG and arguably has unsurpassed experience in development and use of biomedical instrumentation on Earth and unequaled experience in space. Other investigators who have an interest in an can contribute to this work will be welcome as collaborators.

Commentary:

This study would provide a simple and direct answer to the adequacy (specificity) of mechanical loading.

The far more complex question of equivalence of 1 g locomotion on earth and inflight, to be valid, must await an adequate treadmill and proper instrumentation neither of which is currently available eg. the proposed treadmill is outmoded, cannot be guaranteed as regards elevation, has too short running surface and many other deficiencies. A current design now being evaluated in 1 g prototype will overcome these problems. It uses a new mechanical load system. Further it will incorporate a foot ground force measuring system. It still may be necessary to fly a modified belt and roller to get adequate frequency response or to use other means.