# BIOMECHANICAL TESTING OF A COMPLIANT BENCH FOR STEP AEROBICS

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## INTRODUCTION

The purpose of this study was to determine if adding compliance to the bench used in step aerobics routines would decrease the stress on the musculoskeletal system. The stresses are imposed by the shock of the ground reaction forces (external) and due to joint compression caused by muscles attempting to absorb and generate forces (internal). Injury has been related to the amount of force and the frequency of force application (Radin et al., 1973). Repetitive strain was not a primary consideration in this study, but it was hypothesized that a compliant surface would distribute the impulse of landing such that the peak force would be attenuated and the rate of force loading would also be reduced.

## METHODS

The present investigation involved four experienced step aerobics instructors. Each subject performed two types of stepping exercises at a cadence of 120 beats per minute. The moves involved a simple step up onto the bench with the right leg followed by a step back down also with the right leg. The second move was a propulsion move in which a leap was performed off the right lead leg followed by a landing on the bench with the same leg before stepping back down with the right leg.

A compliant bench was constructed with similar dimensions to the traditional rigid bench. The major difference was that the compliant bench had an arched top of plywood that would deform by becoming more flat as it was loaded. The stiffness of the top was about 16 kN.m-1. Each subject performed each move on each bench for several minutes with data being collected during the last 30 seconds. The order of bench types was randomly set and fatigue was controlled by not allowing any of the sessions to last more than 5 minutes and giving plenty of rest between trials.

Two force plates were used in this study. Force plate 1 was situated on the ground in front of the bench and measured the ground reaction forces as the subjects stepped off of and back onto the ground. Force plate 2 was located under the bench with a steel frame so that the reaction forces on the bench could be measured. The data were sampled at 100 samples per second and ensemble averaged over 15 steps for each subject and each task to obtain a representative record and a measure of the variability. The representative record was analyzed for peak forces and each individual step was analyzed for the rate of rise of force. The rate of rise of force was processed by filtering out the high frequency noise of the force channel and differentiating the signal with respect to time.

The electromyographical activity (EMG) of the knee extensor muscles of the right leg was also examined. Since the bone-on-bone forces in the knee joint are based on the reaction forces from the ground plus the compressive forces of the muscles, it was thought that if the activity of the muscles was higher when exercising on one bench then it would be evidence of a possible cause of injury.

An additional 11 healthy subjects of recreational caliber participated in a step aerobics class of one hour duration. During the class, each subject left his/her station temporarily to perform the two types of stepping exercises on the rigid and compliant benches. Each subject performed both moves on each bench twice during the class.

The first time the subjects performed the moves was early in the class and the second time was near the end of the class.

EMG data were not collected on these subjects but force data was collected and analyzed as above. Four two-way analyses of variance with repeated measures were applied to the peak force and rate of rise of force data for the step and propulsive moves. The two factors were the type of bench and state of fatigue. The significance level was chosen to be $p < 0.05$.

## RESULTS

The step-to-step variability within each subject was quite low which made the ensemble average quite representative of each subject. Figure 1 shows the complete data of subject TT. Force plate 1 shows the ground reaction forces and force plate 2 shows the forces measured under the bench. The EMG is the electrical activity of the vastus lateralis of the "stepping up and down" leg. It can be seen that the forces on the bench were higher in the propulsive move than the step move but the ground reaction forces were quite similar in the propulsion and the step moves. It was thought that landing back on the ground following the propulsion move might have higher forces, but the results show that impact was absorbed while landing on the bench and a normal step down followed both moves.

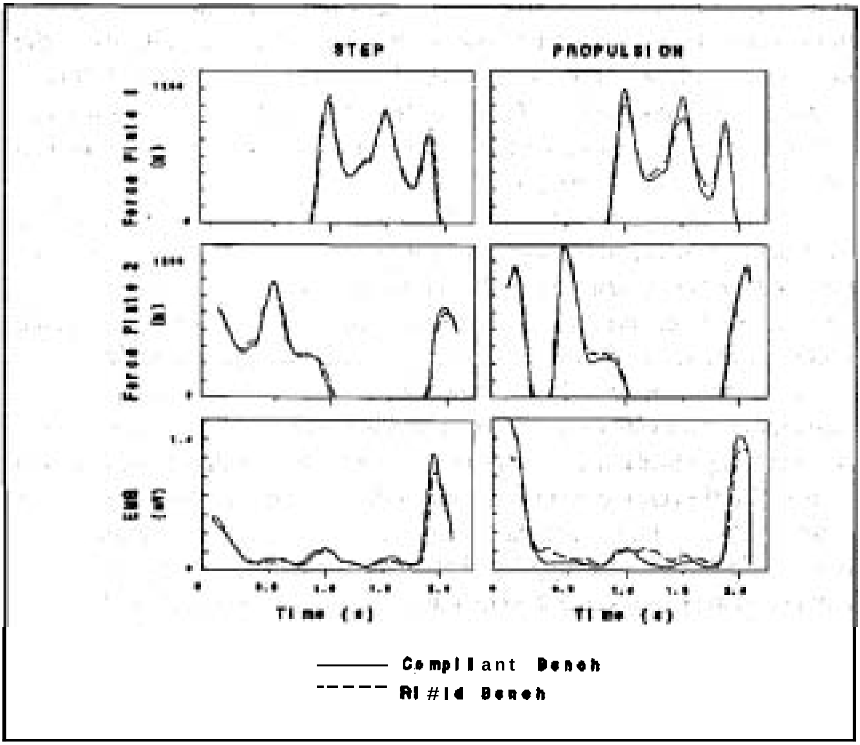


Figure 1. Ensemble average force and EMG data of a single subject performing the two exercises.

The peak ground reaction forces of the compliant bench were not significantly different from the rigid bench even though the height was 4 cm higher when not compressed and approximately 1 cm higher when supporting the full body weight. The additional height of each step was, therefore, about 10% higher and represented about 10% greater work in terms of gaining potential energy. This increased mechanical work was accomplished without an increase in peak force, but this was more likely due to a consistency of style by the subjects rather than due to a feature of the compliant bench (see below for a more complete explanation).

The pattern of force application is a function of the surface being stepped on and the style of stepping employed by the athlete. Peak forces can be high on a compliant surface if the body behaves very rigidly. Conversely, peak forces can be quite low if the body acts as a shock absorber. It was noticed that each of the experienced subjects in this study stepped quite softly on both benches and they cited proper form as being one in which you cannot hear the feet contacting the bench. It was thought that if the body was actively absorbing the shock, the EMG would be greater than if the shock was passively absorbed by the compliant bench. The EMG showed greater muscular involvement during the propulsion move compared to the step move but no difference between the rigid and compliant bench. This evidence does not support the notion that a compliant bench would necessitate less muscular activity for shock absorption, but at the times of landing either on the bench after the propulsion move or on the ground, the EMG activity was very low (activity was only substantial when stepping up on the bench). It should also be stated that perhaps the ankle plantar flexors are mostly responsible for the shock absorption on landing.

Ensemble averages of many steps yields a more representative pattern of the force application of cyclic movements such as those used in step aerobics. However, the process of ensemble averaging also smooths the data so that higher frequency shocks that are present may be masked by the process. High frequency (approx. 50 Hz) transients were seen with greater regularity in the rigid bench data than the compliant bench data and for this reason, the rate of rise of force was calculated from each individual step rather than from the ensembled data. Three of the subjects had substantially higher rates of force development in the step onto the rigid bench while one had higher rates when stepping onto the compliant bench. While the laws of vibration state that the visco-elastic properties of the compliant bench should act to attenuate the higher frequency shocks, the data did not reveal an effect that was large enough for statistical significance.

The high quality form demonstrated by the experienced subjects in this study may not have emphasized the potential for a compliant surface to reduce impact forces when impacted rigidly by a person who either has poor form or who is fatigued to the point of poor form. A fifth subject (RW) simulated a "stomping" style often witnessed by novice or fatigued participants in step aerobics classes. Figure 2 shows that the peak forces on the rigid bench were substantially higher than on the compliant bench. The solid line which represents the rigid bench data shows rapid increases in force to levels that are double those of the compliant bench. While no statistical tests can be performed on one set of data the evidence clearly shows the importance of good form and the potential benefit of a compliant bench when the body is not actively absorbing the shocks. The compliant bench acted as a lowpass filter and reduced the large amplitude, high frequency spikes seen when using the rigid bench. The results of the 11 recreational caliber subjects are shown in Figure 3. A main effect for fatigue

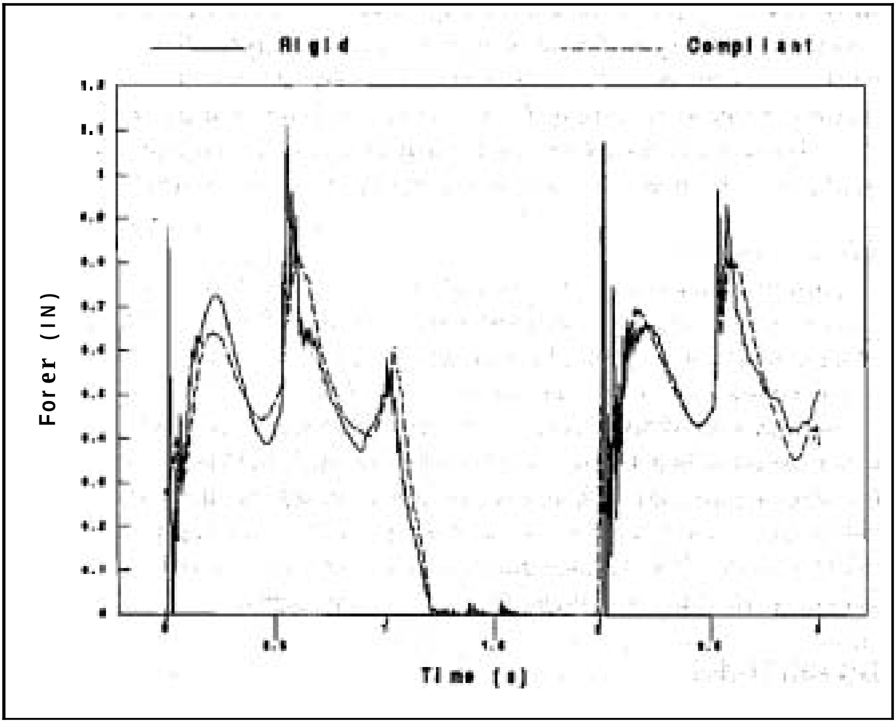


**Figure 2.** Attenuation of high frequency forces by the compliant bench with a "stomping" subject.

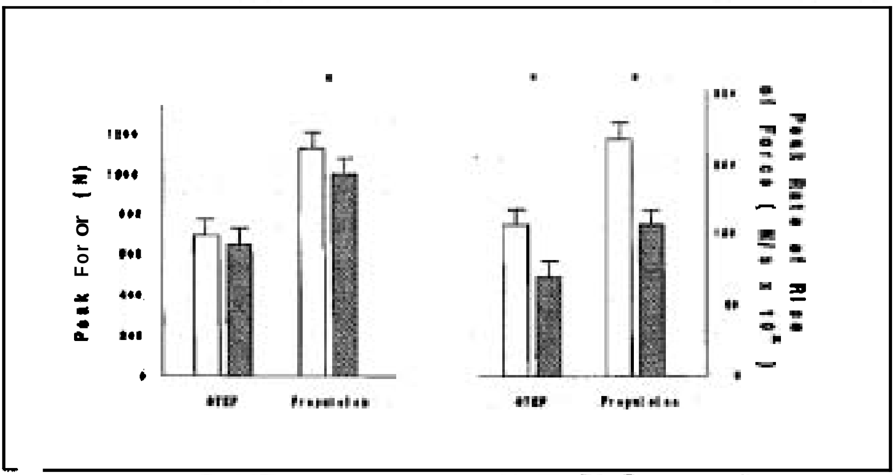


**Figure 3.** Means and standard deviations of the 11 recreational
*p<0.05

was not seen in any of the analyses of variance. There was, however, a main effect for:the type of bench in three of the four analyses. The compliant bench was found to have significantly lower rates of rise of force in both the step and propulsive moves and a lower peak force in the propulsive move. The peak forces were lower in the step move but not enough for statistical significance. There was no interaction between fatigue and bench type.

## CONCLUSIONS

Risk of injury by either high peak force or muscle force was neither increased nor decreased when the instructors used the compliant bench. This included the stepping back down onto a rigid surface following a propulsive move which lands on the bench. The peak forces and rates of rise of force were substantially lower when the recreational caliber subjects used acompliant bench. This effect was not changed with fatigue. It appears that professionals are able to provide musculoskeletal shock absorption without significantly increasing the muscle activation when performing on a rigid surface. Recreational athletes, however, were not as capable and would benefit more by exercising on a compliant surface.

## REFERENCES

Radin, E.L., Parker, H.G., Puch, J.W., Steinberg, R.S., Paul, I.L. and Rose, R.M. (1973). Response of joints to impact loading-111. Journal of Biomechanics. 6:51-57.