Cantaurus, Vol. 13, 18-22, May 2005 © McPherson College Division of Science and Technology

Human Performance Assessment Using the DYFORMON Exercise System

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ABSTRACT

The DYFORMON (Dynamic Force Monitor) system was used to assess human exercise performance by integrating user output force over time. This result, the momentum generated, was determined to be a better measure of exercise effort than power output. One subject exercised with the DYFORMON machine twice a week for 5 weeks, varying between two different workouts to prevent muscle fatigue. Workout sessions consisted of bench press, pull-downs on the bench, and a set of 50 interval bench press reps on Mondays and pull-downs from the ground, bar curls, and military presses on Wednesdays. The bench press with a protocol of 5 sets at 10 reps per set was the only exercise evaluated. Results showed an increase in total generated momentum from week to week for the bench press. The 50-interval reps bench press protocol seemed to show better improvement with a two-week recovery period, rather than a one-week. The goals of this study were to recalibrate the DYFORMON machine and to find meaningful ways to convert raw data to better understand human performance on the DYFORMON. This was not a statistical study, but demonstrated the basis for such a study.

Keywords: Dynamic Force Monitor, momentum, eccentric, concentric, impingement, exercise

INTRODUCTION

Athletes constantly try to find new methods to improve physical conditioning in less time and receive feedback for further improvement. Two basic methods for load bearing exercise exist: Weight lifting targets multiple muscles and allows an individual to know how much is being lifted and the amount of repetitions. Ergometrics isolates single muscles, providing varying forces for a power output, meaning the force is not dictated by gravity or acceleration. The Dynamic Force Monitor (DYFORMON) combines the two methods, applying the motions of weight lifting and working multiple muscle groups with the ability to measure the forces applied. With this new data, the user has a more detailed idea of how his/her body works and can improve upon his/her deficiencies to optimize a workout or decrease rehabilitation time.

Resistance training has increased muscular strength as well as overall health according to almost all studies (Van Etten et al. 1997). It has reduced risk factors of non-insulin–dependent diabetes and colon cancer; prevented osteoporosis; promoted weight loss and maintenance; improved dynamic stability and preserved functional capacity (Kraemer et al. 2002).

One study compared accommodating resistance devices (ARD) to weight resistance devices (WRD). The results concluded that both ARD and WRD were effective over a 20-week period of increasing strength and muscle size (O'Hagan et al. 1995).

The DYFORMON provides an individual with data on the exact amount of force applied throughout the entire exercise. Since there are no weights being used, moving impingement resistance is applied by the individual; the user does not need to worry about the bar falling, and can exercise until he/she is unable to apply any force. The user is able to concentrate on the process of pushing as hard as he/she can on the bar without having knowledge of the applied force. The data is able to show the point in each cycle where the most force is applied and also where he/she is the weakest.

Using this data, work done per cycle, average power per cycle, instantaneous power, momentum per cycle, etc. can all be measured and used to find the workout providing the greatest amount of effective exercise over the least amount of time. The purpose of this study is to establish operating parameters for the DYFORMON system and develop various exercises for further long-term statistical studies.

MATERIALS AND METHODS

The DYFORMON was the primary piece of equipment used. Dr. Kent Noffsinger and Dr. William Kraemer invented it in 1980 while in graduate school at the University of Wyoming. Two prototypes were created, and McPherson College had the opportunity to obtain one, the DYFORMON. The other machine, known as ABLE I, is currently being used for research studies at the University of Connecticut. The DYFORMON uses a five horsepower motor to move an Olympic style weight bar up and down and is capable of producing 2000 pounds of force. This exercise system can be described as a dynamic, isometric system, that is, the user resists a moving object rather than a static object and does so as if an isometric exercise is being performed. This defines the concept of impingement exercise. Exercise is performed when motion of the bar is resisted either antagonistically, pushing against the bar's movement, or protagonistically, pushing with the bar (Koster 1999). The machine has been significantly upgraded with new sensors that measure the amount of force being applied to each end of the bar separately in terms of voltage. The new sensors are highly reliable and can show forces applied in two dimensions; therefore, the machine was recalibrated.

For the recalibration, two weight scales were placed on blocks under the middle of the exercise bar with a board across both. A board was placed vertically in the center of the bar and the scale board. Using the motion control box, force was applied gradually and measurements were taken of the voltage and the combination of weights registering on the scale. The exercise bar was cycled both down and up to get a better collection of data points for the calibration curve. From this data, equations were derived for each side of the bar, which were used to convert voltages to pounds.

After the recalibration, we worked with one subject and refined our data-taking measures and converted the raw data into usable data. New software, DataStudio™, was purchased to record the data being received from the analog to the digital box. The data being taken included time, position of bar, and left and right sensor voltage. Raw data was entered into EXCEL™ spreadsheets for processing. EXCEL™ spreadsheets are generic enough to be accepted by such programs as MathCad™ and Mathematica™. The software packages were used to convert raw data into physics data, including work, power, momentum, force, and cycles and sets. These measurements allowed us to quantify the data and compare it to other runs.

For this experiment, strength is defined to be, in technological terminology, the peak force at the "sticking" point of an exercise. Peak (average) performance is expressed as peak (average) power output (force times velocity). Effort is calculated by integrating a force over time for a single rep, or an exercise set, and is quantified as a generated momentum. Fatigue/Recovery are based on a change in generated momentum per cycle, or set.

Duty cycle was the major factor in determining how much exercise occurred in a single rep. It can be described as one full repetition of the exercise bar motion. Duty cycle consists of two forms of muscle contraction, which are eccentric and concentric as can be seen in figure 1. The eccentric half has been found to have up to a 30% greater force generation than the concentric half. Unlike weights, the DYFORMON system allows the user to select any portion of the duty cycle for force application, whereas, weight lifting requires force application over a full repetition.

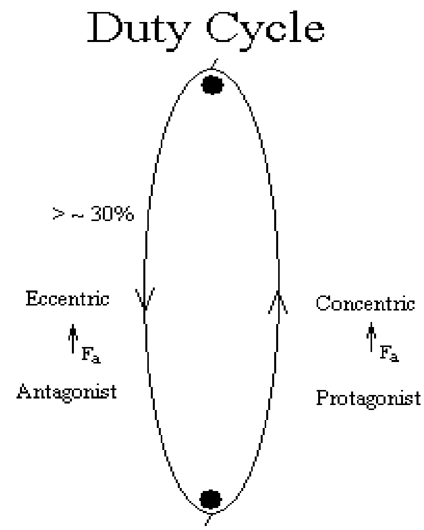

Fig. 1

Most experiments of this type use the data to measure the work performed per rep or set. However, with this study we dealt primarily with generated momentum. Work is described as force times distance, but with the machine, and other forms of lifting, much force is applied at the motion turning point. Consequently, despite the amount of force applied at each of the points (top and bottom), little distance is actually gained, diminishing the results at these points where the bar is essentially static. In this study, we used momentum, which is a force integrated over time rather than distance and can be better understood by viewing figure 2. The measure of work, which only follows the direction of the bar motion, is shorter than the measure of effort, which follows time, rather than direction. This measurement of momentum is more physiological than a calculation of work and produces a better measure of effort level because it quantifies potential momentum applied to the machine.

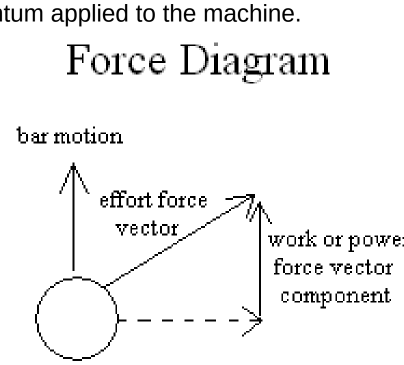

Fig. 2

Work is described as force being applied over a distance, and with weights the applied force $\vec{F}_a(m,\vec{g},\vec{a})$ is dependent not only on the direction of the bar motion, but also on mass(m), gravity($\vec{g}$), and acceleration($\vec{a}$), which are all determined externally. However, with the machine, work is not determined by external sources, but by the user. The force applied does not have to be in the direction of the bar motion. It is dependent on user effort(E), (intensity and mental focus), speed($\vec{v}$), recruitment(r) of other muscles, geometric effects($\bar{y}$), such as sticking point, and physical characteristics. These would include such characteristics as height, weight, muscle mass, age, and physical conditioning $\vec{F}_a(user[E,\vec{v},r,\bar{y},phys.]$. Another difference between weight lifting and exercising on the machine is the inertial effect. With weight lifting, the effective weight increases depending on how quickly one lifts, due to acceleration. The machine however, has a zero- inertial effect, as the acceleration of the lift is provided by the machine.

The exercises in this experiment were done twice a week and consisted of bench press, pull-downs on the bench, and a set of 50 interval reps on Mondays, and pull-downs from the ground, bar curls, and military presses on Wednesdays. The subject was only allowed to exercise with the instructor present.

Before exercising with the DYFORMON, the test subject had been lifting weights sporadically for seven years. His diet remained the same before and during the experiment. For the first three weeks of the experiment, the subject only exercised with the machine, after which, he began to lift weights regularly on Fridays and Saturdays.

RESULTS

The calibration curves from the recalibration gave a linear equation with an R^2 value close to 1 at 0.9861 for the left sensor and 0.9878 for the right, as seen in Fig. 3. Linear equations were fit to the data to convert sensor output voltages to equivalent pound-force readings.

The areas of each run were obtained by integrating force over time. By doing this, the results are actually given as a momentum (lbs x secs). As shown in Fig. 4, the total area for each run increased the first three times. In comparison to the first week, there was a 14.1% increase in the second week, a 21.6% increase by the third week, and only a 12.4% increase the fourth week. Breaking it down into individual reps for each run showed a gradual decrease in momentum from the first rep all the way to the last for each run, as seen in Fig. 5. Finally, the data was graphed by adding each rep together one at a time for individual runs, as shown in Fig. 6. From this data one can see a steady, gradual increase from rep 1 to rep 12.

In figure 7, a single rep near the beginning of a bench press exercise is shown. This reveals the exact amount of weight being lifted at each point of the exercise and reveals the location of the bar. This shows that the user peaked out at approximately 250 lbs on the eccentric half of the exercise, and 200 lbs on the concentric. The subject's strength can be seen at the peak sticking point, which occurs at 3 seconds and has an outcome of 175 lbs.

A comparison of generated momentum for eccentric and concentric exercise was also done, as can be seen in fig. 9. Results of the data showed greater generated momentum in the eccentric portion of the duty cycle than in the concentric. However, after each run both types gradually decreased with the eccentric decreasing at a higher rate than the concentric

Results focused primarily on the bench press. Analysis of bench press data acted as a model procedure for future analysis of other exercises.

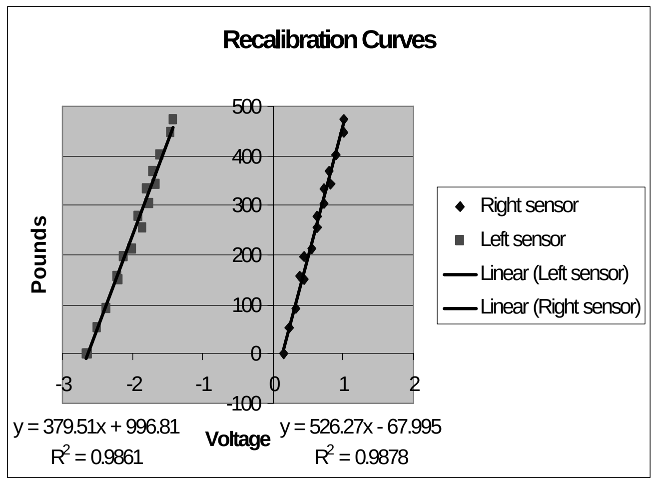

Fig. 3

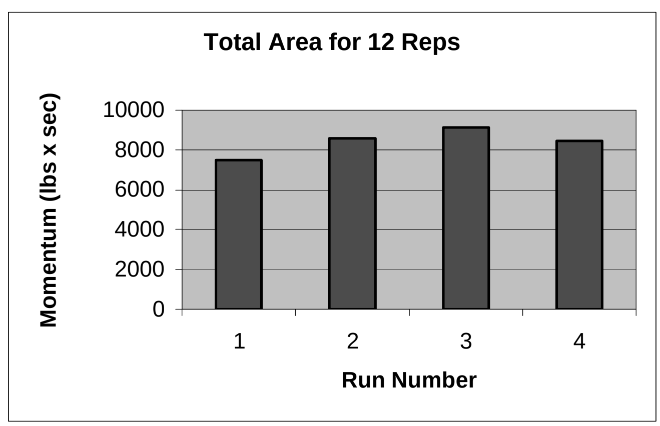

Fig. 4

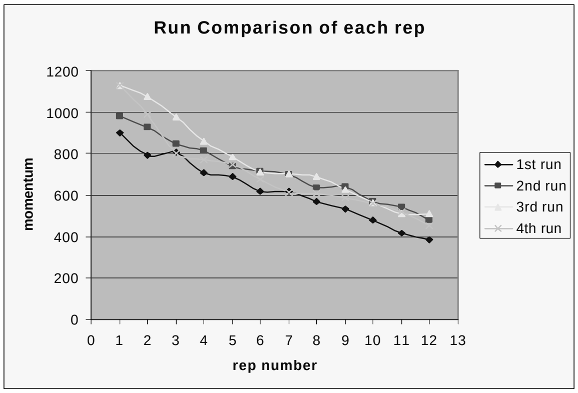

Fig. 5

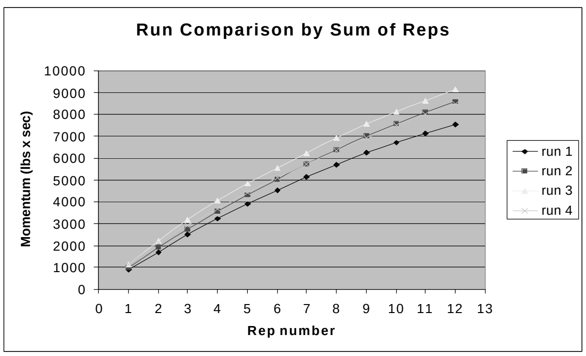

Fig. 6

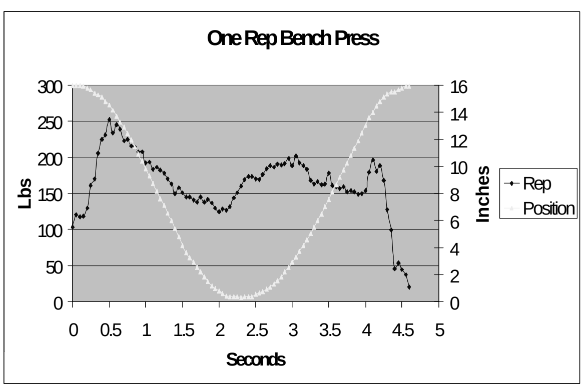

Fig. 7

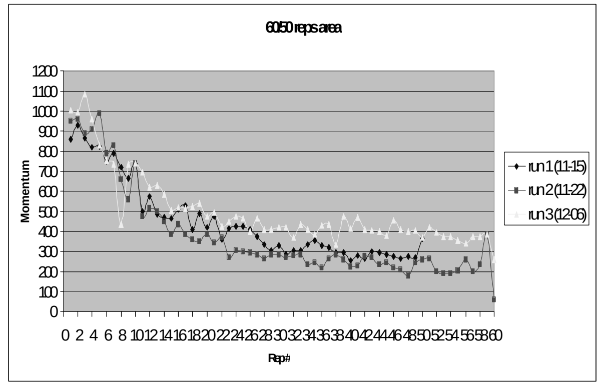

Fig. 8

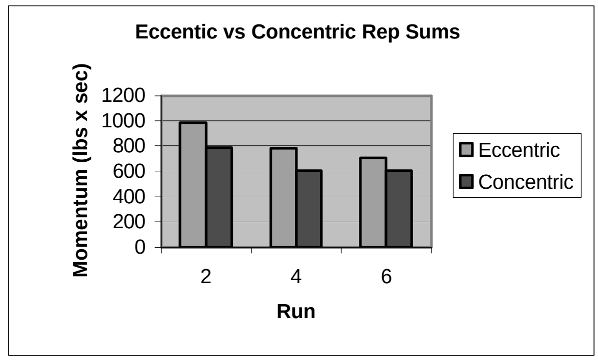

Fig. 9

DISCUSSION

The original intent of this study was to compare exercise on the machine to weight lifting. However, due to time constraints and the need for exercise machine recalibrations, the study was changed to lay the groundwork for other students who decide to work with the machine. The goal of this study was to find a way to recalibrate the machine and show different ways that the data could be used to assess human performance. Generated momentum was calculated, using raw sensor voltage, time data, and calibration curves. This gave an area for one rep, or for a whole run, and the data was compared to data for other reps or runs. Data could also be used to determine fatigue and to compare eccentric to concentric exercise.

The recalibration process progressed from a fulcrum method, to weights hung on the bar, and culminated with a direct method. The fulcrum method did not work well because the bar was unable to go up and down easily, as the weight on the end of the bar not only applied a force up, but also across the bar, restricting its movement. Hanging weights on the bar might have been the best method, but the starting voltage drifted; thus, the polynomial fitting equations used for both right and left sensors were inaccurate. The successful method used 2 scales, allowing weight to go over 400 lbs combined; force was then applied and measurements were read. Unfortunately, there is a significant error of +/- 17 lbs on average for both sensors, so the results given are slightly off.

As shown in Fig. 8, the subject did 50 to 60 interval reps after completing 1 set of 15 reps on bench press, followed by 5 sets of 10 reps on bench press, and 5 sets of 10 pull downs. The data shows a gradual decrease in momentum from rep 1 to 22; at rep 23+ the subject shows a fairly linear momentum generation, indicating the point where fatigue basically set in.

Comparison of eccentric and concentric generated momentum, which can be seen in fig. 9, was made by using data from a position sensor to determine the location of the bar. Motion of the bar from top to bottom position represented the eccentric (antagonist) half duty cycle of exercise for one rep, while bottom position to top position motion represented the concentric (protagonist) half duty cycle of exercise. Half duty cycle force data was integrated over time to obtain protagonist and antagonist generated momentum. This was done for one set of data taken at the midway point of the exercise sessions and was only done for runs 2, 4, and 6 and reps 1, 5, and 10. As can be seen in the figure, the total momentum of the eccentric portion was always higher, but gets closer to the concentric after each run. Further study will need to be done to see if the concentric ever became greater than the eccentric.

All data collected showed an increase in generated momentum over a period of time, in comparison to the first exercise session. These results can be seen in fig. 4 and fig. 6, which show 15-rep bench presses taken weekly, as the first exercise performed each week. An incremental increase can be seen from runs 1 to 2 to 3. However run 4 drops down to approximately the same momentum as run 2. This may be due to the fact that the subject did not exercise with the machine from 11-23-04 to 11-30-04, and even then, he did not do the 15-rep exercise on the bench press until 12-6-04. However, fig. 8, recording the bench press for 50 to 60 interval reps, shows that run 2 actually drops below run 1 after the seventh rep, but run 3 is better than both runs. This may be due to the fact that a week elapsed between run 2 and run 3. Further study will have to be done, but best results would probably occur if the subject did only 50 to 60 interval reps every other week.

The data collected was taken using the bench press only; so further studies could determine differences among other exercises, finding which exercises produce greater generated momentum. The key finding in this study was the correspondence between weight lifting terminology and physics terminology of exercise, as seen in figure 10. The major result of these new definitions was determining that effort in a weight lifting sense is better defined as generated momentum. To our knowledge, this correspondence has not been established in other exercise studies. Data was taken from only one subject, and therefore it has no real statistical significance. However, showing various ways the data can be used and defining terminology in a technical fashion will have significance for others who continue on with this study.

Terminology

Non-Technical	Technical
Strength	-Peak force at "sticking" point of exercise
Performance	-Peak/Average Power
Effort	-Generated Momentum
Fatigue/Recovery	-Change in generated momentum per cycle

Fig. 10

ACKNOWLEDGEMENTS

I would like to thank Dr. Noffsinger for his guidance and assistance in the completion of this project.

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