Newton And Dyson Pumped-Up On Hill And Cavagna

This is simply an outstanding biomechanics presentation! McDonald has taken some critical lines from Geoffrey Dyson's book, lines which have troubled me for 20 years, and he has lifted the veil. Thanks to McDonald for his effort in bringing the Dyson text into agreement with the science of the 90's. There are some good suggestions at the end of the article. The closest thing we have to a repository for videotapes is Lyle Knudson, who has sent out thousands of videos over the years. McDonald is suggesting additional steps that would certainly help educate coaches in the U.S.

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A few years ago, Dr. Harmon Brown posed some interesting questions concerning Geoffrey Dyson's application of Newtonian physics to track and field (Brown, 1992). Brown noted "in recent years a number of scientific findings, as well as successful coaching techniques, have suggested that learning methods based upon classical Newtonian mechanics must be reevaluated, since these principles neglect the contribution of the visco-elastic and neuro-muscular reflex elements in the muscle itself."

The original text of Dyson in *The Mechanics of Athletics (1973),* page 36 follows:

"The change in speed of an athlete, discus, shot, javelin or hammer does not merely depend upon the force applied, but also upon the *time* for which it operates, its *impulse*. In the starting blocks, for example, an athlete should adjust his position not only to increase his driving force but also to lengthen the time during which it is exerted, thus increasing his staring velocity. And in the throwing events, also, **the best techniques are those in which the maximum muscular force is exerted for the longest possible time** [emphasis mine].

"The same change in speed (and, therefore, the same impulse) can be produced by a small force acting for a long time, or a very large force acting for a short time. **However** [emphasis mine], in athletics, an increase in force often requires a more rapid action, resulting in a decrease in time of operation—unless the distance over which the force operates is increased."

Dyson continued on page 37:

"In track and field athletics there are many examples of the impossibility of exerting full force against a fast-moving object, for the feet (in running) and the hand (in throwing) cannot be moved fast enough. In such cases, the speed of movement of the source of resistance reduces not only the ability to apply muscular effort, but also the time for which that effort can be applied."

Newtonian mechanics have not changed and are still valid. A force is still a force, although our understanding of how it is produced by muscles has been refined since Dyson first published his text in 1962. Cavagna, Dusman, and Margaria as early as 1968 determined that muscle force production was dependent upon the prior

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conditions of the muscle. Prior conditions included eccentric (attempting to shorten, while length is increased), isometric (attempting to shorten, while length remains constant) or concentric conditions (able to shorten). Dyson probably meant, regardless of prior contractile condition, a muscle is capable of making a peak maximal force for the conditions in which the muscles are currently acting.

Insight into muscular force production during athletic events can be gained by: a) using Newtonian mechanics to analyze and understand the kinematics and kinetics of events, and b) better understanding how muscles produce force. Coaches need an understanding of these two fundamentals in order to properly coach track and field events. My goal in this article is to synthesize some of the aspects of these two fundamental concepts.

Dr. Brown posed several questions:

1. If this general concept (of muscle force development) is valid, should not currently known information be summarized for the coaching and athletic science community? Yes.

THE CONCEPT OF IMPULSE

Rather than speculate what Dyson meant, it is best to take a look at how impulse can be conceptualized, what the current understanding of muscle force production implies, and how mechanical aspects of a technique aid muscular force production.

The linear impulse exerted on an object determines the change in speed of that object. For a constant force, linear impulse can simply be defined as force multiplied by the time (duration) of application of the force. The amount of impulse for a constant force can be represented as the area of a rectangle as shown in Figure 1. Constant muscular force vs. time does not usually occur in athletic events, but this is an example in which impulse can be easily conceptualized as area under a graph. Forces produced by human muscle generally are not constant with respect to time.

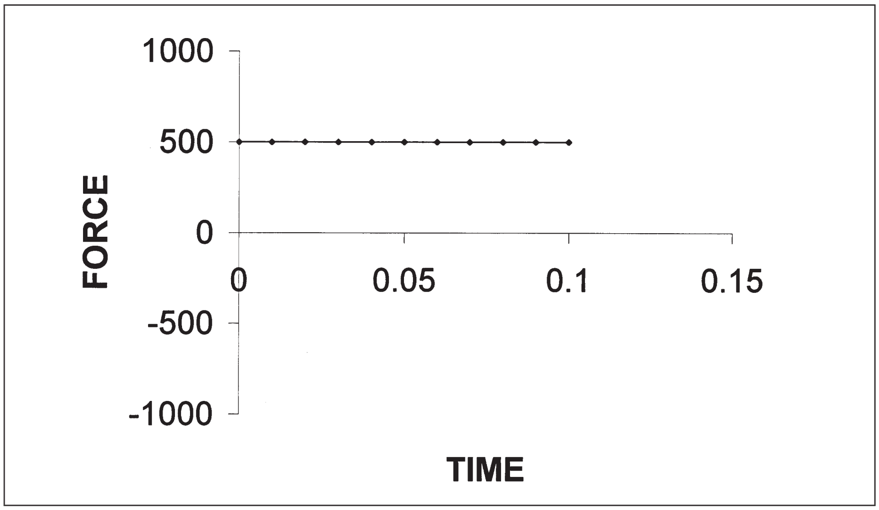

Figure 1

Figure 2 shows a typical force produced by human muscle. The linear impulse exerted is still the area under the force vs. time curve. You can also think of the linear impulse as the ***average* force** exerted, multiplied by the time during which that average force is exerted, which would appear similar to Figure 1.

To generalize one step further, there are both positive and negative impulses. For example, when sprinting at maximum speed, there is an initial negative (slowing) impulse caused by landing on the ground (an area below the time axis).

To recover the velocity lost, this negative impulse must be overcome by a subsequent positive impulse created by muscular effort (an area above the time axis) as in Figure 3. The net impulse is the sum of the negative and positive impulses (areas). After 50 or 60 meters the negative impulses become larger than the positive ones due to fatigue, and the sprinter begins to lose velocity ever so slightly.

PRODUCTION OF IMPULSE

Production of impulse has different requirements from event to event. In throwing and jumping events, the desire is to maximize the area under the force vs. time graph, with no restriction on the amount of time. In contrast, while sprinting at maximum speed, time is of the essence, and the size of the positive impulse need only be large enough to overcome the earlier negative impulse.

Fast (elite) sprinters, similar to those in Mann's study mentioned by Dr. Brown, are stronger than slower sprinters when very rapid contractions are required, but they are not using a different muscle force production method than a slower sprinter.

The force produced by both the fast and slow sprinters is undoubtedly a result of contributions of contractile, viscoelastic, and neuromuscular (stretch) reflex elements. The difference is that the fast sprinter has more of all contributions, and can produce the required impulse in less time. As a result, faster sprinters spend less time per stride on the ground as compared with slower sprinters.

In the throwing and jumping events a maximal impulse is needed, but minimal time is not. The amount of time that a force can be applied to an object (shot, discus, or ground) is related to the range of motion of the arm or leg. The amount of time that a force can be applied is *inversely* related to its size—the bigger the force the shorter the time. It would be nice to maximize both force and time of application, but large forces minimize the possible time of application of the force. For example, if the arm imparts a huge force to an object, the change in velocity is rapid, and the duration of the motion is brief.

MUSCLES, MECHANICS AND TECHNIQUE

The research by Hill (1922) has shown that muscles can make larger forces in slower concentric conditions (when the muscles are shortening more slowly). Also, Cavagna, et al. (1968), found that muscles in concentric conditions that were previously in eccentric conditions (the muscles were previously lengthening while trying to shorten) are capable of making larger forces than if not previously stretched.

These properties of muscle reflect the viscoelastic and neuromuscular reflex elements and enhance force production. These elements of force production are probably trained and developed by weight training and plyometric exercises.

In order to maximize force production, techniques that require muscles to be in eccentric conditions prior to concentric conditions are best where feasible. Also techniques that allow muscles to be in slower concentric conditions are best where possible.

MUSCLE FORCE AND ROTATION

In addition to understanding the concept of impulse and how muscles produce force under different conditions, the role of rotation (angular impulse and angular momentum) must be considered. Rotation is created by a force that is not directed toward the center of mass of the system (the human body alone or the human body plus the implement).

To better understand how rotation of an object is produced by a force, you can do a simple experiment. Push with your finger on a blackboard eraser or block of wood placed on a smooth surface. If the object only slides, you are directing the force of your finger through the center of mass of the object. If the object turns or tips (rotates) while sliding, the force is off-center, that is, not directed through the center of mass.

During athletic events, reaction forces from the ground acting for a period of time create an angular impulse, which produces angular momentum and therefore rotation of the human body or body plus implement. Such rotations give the system angular momentum.

Unlike the rigid eraser or block of wood, the human body has arms, legs, and a head-trunk that are free to move around the center of mass. As a result, rotation (angular momentum) of these body segments can be used to take advantage of the conditions under which muscles are able to produce larger forces and to increase the linear velocity of the implement.

Dapena (1993) is a prime example of how angular motion (rotation) aids maximal force production and maximal velocity of the discus. To summarize the article, the human body plus the discus make up a system, which not only receives a linear impulse, but also an angular impulse that causes the rotation of the system. See Dapena (1993) Figures 6,7 and 8.

Blocking techniques (stopping rotation of selected body parts) are a method of using angular momentum to increase the velocity of an implement. Blocking of limbs other than the throwing arm slows down or stops the rotation of these system parts, so that the trunk speeds up its own rotation.

In turn, this makes the muscles that connect the trunk to the throwing arm stay in slower concentric conditions which allow the thrower to make

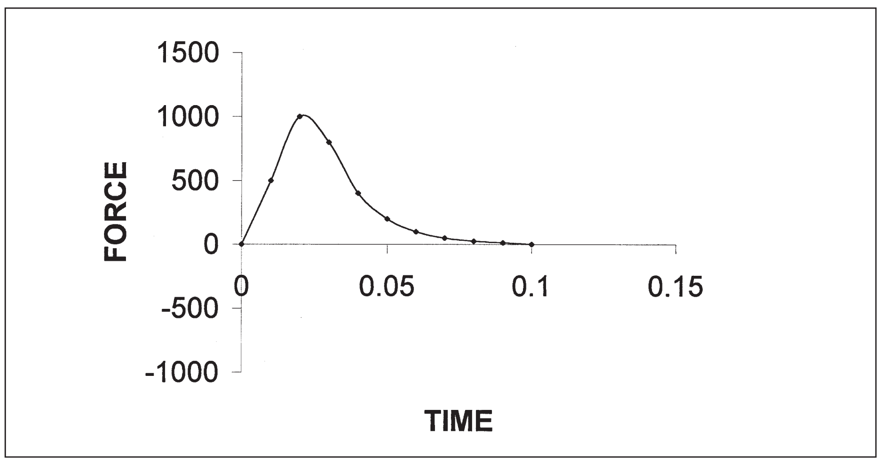

Figure 2

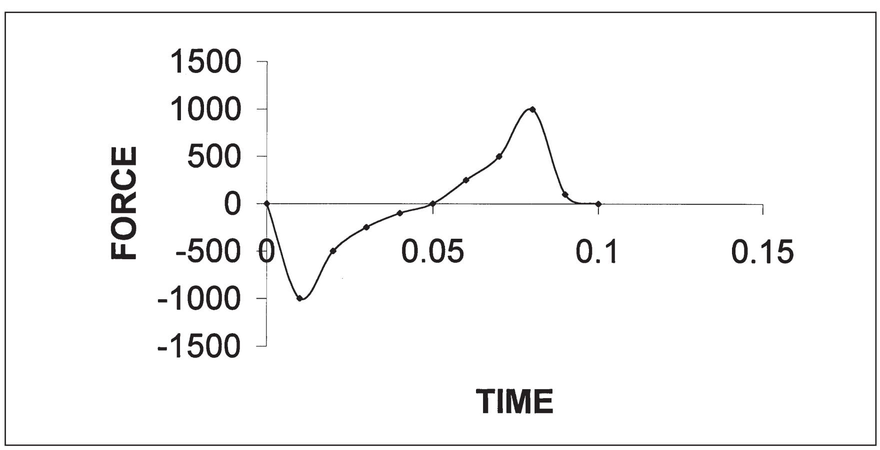

Figure 3

bigger forces for a longer time on the implement.

Blocking techniques also can involve the pulling in toward the midline of the body (closer to the trunk) of arms and legs in order to increase the rotational velocity of the whole system (the effect seen when an ice skater pulls in the arms during a spin). Such a technique does not put muscles into slower concentric conditions, but it does add velocity to the implement.

Angular momentum and muscle mechanics are also important to the mechanics of sprinting, an activity not as obviously rotational as the discus event. For example, the non-support or recovery leg during its forward swing has angular momentum, which by reaction causes the rest of the body to rotate in the opposite direction. This rotational action-reaction pushes the support leg backward against the ground.

Similar to the discus thrower's arm, the reaction keeps the muscles of the sprinter's support leg in slower concentric conditions. The result is larger forces and a faster race time.

Such an analysis implies that sprinters should strengthen the hip flexors which are required to rapidly rotate the non-support leg forward. Here's another experiment you can do. Stand on a bathroom scale, and swing up one leg rapidly at the hip, similar to the motion of the recovery leg of the sprinter. Watch the reading on the scales increase. Momentarily, you were making larger forces on the scale.

SUMMARY

The maximum force that a muscle is capable of making is dependent upon the velocity of the contraction. The previous condition of the contraction also influences the maximum force the muscle is capable of making. Linear and angular momentum can be used to put muscles in advantageous conditions that allow the muscles to produce greater forces.

2. If further validation is needed, in what direction should research inquiries proceed? What further questions need to be asked?

In order to understand contemporary technique, there is no need to throw out Newtonian mechanics. However there is a need for coaches to more fully understand mechanics *and* how muscles produce forces under different contractile conditions.

Additional research is needed to better understand muscle force production, and also the mechanical aspects of many track and field events, which are only qualitatively understood. The measurement of angles and body positions of elite athletes is incomplete research. Understanding of an event requires kinematic (velocity and position) and kinetic (force and angular momentum) data. Armed with a better understanding of how events work, coaches can better understand how to coach events.

Some possible future questions:

- What is the role of angular momentum in sprinting? How does arm action influence sprint performance?
- What is the role of angular momentum in the spin shot technique? Why has it not been superior to the traditional technique?

Force plate studies are still needed in most events. Combining force plate data with filming/video would vastly increase our understanding.

3. How best should information be "translated" and disseminated to the coaching community?

Coaches at all levels must have a means of acquiring a minimum of understanding of muscle mechanics, Newtonian mechanics, exercise physiology, and psychology. I would encourage any coach who has not attended the USATF Level 1 and Level 2 schools to do so.

Although many commercial products are available, videotapes should be made when the event experts convene to share information. USATF could serve as a repository of videotapes of clinics, presentations of papers, and other media for loan.

Improved coaching will result in better performances and will tend to generate interest in track and field by athletes (who may have opted for another sport), parents, and the general public.

To increase interest in track and field, the effort must be at the "grass roots" level, in grade schools, middle schools, and high schools. I would encourage USATF to do a nationwide mailing to all high schools with track and field programs: 1) inform and invite coaches to Level 1 schools in their area; 2) invite articles for publication in *Track Coach* in return for a free year of *Track Coach* and tee-shirt with the slogan across the back, "Read my article in Track Coach"; 3) most high schools are linked to the Internet; supply links to web sites where useful track and field books, videotapes and information can be found.

ACKNOWLEDGMENT

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