Science and Technology to Enhance Weightlifting Performance: The Olympic Program

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THE QUEST TO COMPETE IN the Olympic Games requires an incredible amount of focused preparation time and effort on the part of the athlete. The coach makes most of the decisions concerning how to prepare the athlete for the highest levels of performance in competition, but coaches sometimes need help to increase the likelihood of success. The Sport Science & Technology (SS&T) Division of the U.S. Olympic Committee is one resource coaches can draw upon to help maximize their athletes' potential.

■ Overview of Sport Science & Technology Division

The mission of the SS&T Division is stated as follows:

- To provide leadership in the application of science to Olympic sport.
- To anticipate and meet the sport science and technology needs of Olympic sports in their quest to maximize the performance of athletes.

The SS&T Division supports programs in biomechanics, physiology, psychology, strength and conditioning, computer science, and engineering technology. All staff members in these programs can provide information that will benefit coaches and athletes as they strive to optimize athletic performance.

The three primary ways in which program areas can have an impact on sport performance are through (a) specifically designed sport testing sessions, (b) research and development projects, and (c) dissemination of testing and research results to coaches, athletes, and appropriate national governing body (NGB) staff.

National governing bodies, through resident programs or short-term camps at Olympic training centers (OTCs), decide how SS&T staff will become involved with their athletes. The NGBs establish resident programs so that athletes can live and train at an OTC for an extended time. Coaches selected by NGBs plan and supervise the training for these resident athletes. In contrast, athletes attending NGB training camps are housed at an OTC for a short duration varying from several days to a couple of weeks.

Coaches in both the resident and training camp situations can consult with SS&T staff in planning which programs are most relevant to their particular sport. Because of the different needs of individual athletes, SS&T program involvement varies. Some sports incorporate all the SS&T program areas into their training, others incorporate a few, while still others may use only one.

There are two additional aspects of the SS&T program offerings. Under certain circumstances, SS&T staff may conduct testing sessions in locations other than an OTC or accompany athletes to actual competition sites. The other important aspect is the SS&T Division's commitment to help

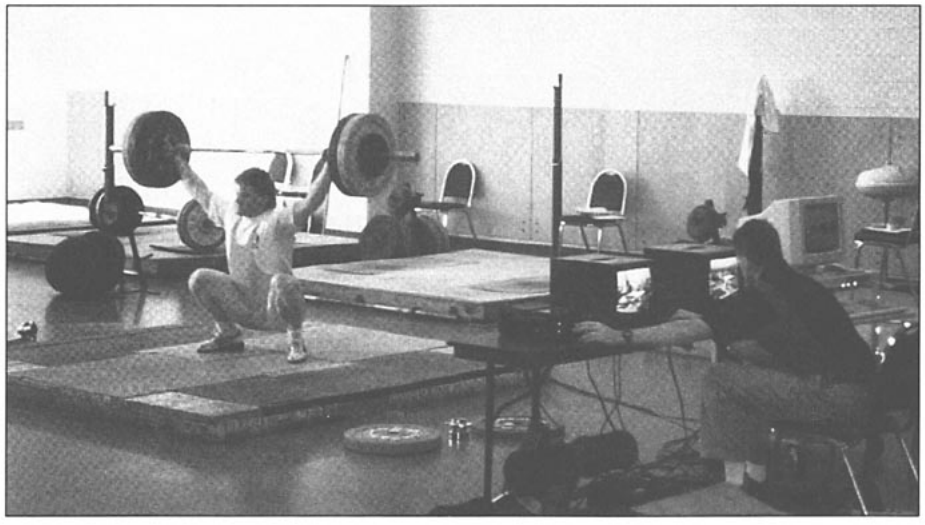


Photo 1 **Biomechanical data collection equipment with athlete lifting on the modified platform.**

Photo 2 **Rear view. Note the force platforms, one under each foot, and the cameras stationed obliquely off to the sides of the lifter; no additional lighting or markers are needed, so as not to interfere with the lifter's performance.**

improve athletic performance, as shown in the operation of the SS&T Grant Program. Funding is available to qualified researchers who collaborate with an NGB to address areas that are critical to performance in a particular sport.

■ Weightlifting: A Specific Example

Weightlifting is an excellent example of a sport getting integrated SS&T help because of the requirements of strength, power, technique, and concentration. This article describes program services in biomechanics, physiology, and psychology. Since technique is such a critical aspect of weightlifting performance, the request for biomechanics services is predominant. Therefore this article will focus mainly on the services provided by sport biomechanists.

■ Biomechanics

The involvement of the biomechanics program is primarily service oriented, providing detailed technique analysis for resident and visiting athletes. The analysis is a time-consuming process that allows for in-depth examination of a lift so that improper technique may be brought to light. This service is performed for resident weightlifters 4 times a year; additional analyses are conducted if necessary.

Analyses of both the snatch and clean & jerk lifts during competition has been the focus of the research aspects of the biomechanics effort. Results from competition allow coaches and athletes to make several important comparisons. Differences and similarities between training and competition lifts are noted so that coaches and athletes can focus on making the necessary corrections. Also, athletes get a chance to compare their techniques with the world's best lifters in their respective weight class.

Data Collection

In the Colorado Springs OTC weightlifting gym, data collection occurs on a modified lifting platform. The platform has two force platforms mounted flush to the surface so that ground reaction forces can be measured for each foot. Two video cameras capture barbell and athlete segment motions. The cameras are time-synchronized with the platform

acquisition computer (Photo 1). Two cameras are used to reconstruct the movements in 3-D. Natural gym lighting is sufficient, thus athletes are able to lift in a relatively normal setting. The camera positions allow two front diagonal views and are not in the lifter's normal line of sight (Photo 2).

During a data collection session, lifters generally perform 3 snatches and 3 clean & jerks. The weight lifted is usually 80% of their maximum, which is representative of the loads used in training. The exact number of attempts and amount of weight lifted is determined by the coach. For meaningful analysis, heavy weights are used since an athlete's technique may change as heavier weights push the limits of his or her ability.

Data Processing and Analysis

A copy of the video is made available to the coach and athlete immediately after data collection. The video is processed in the biomechanics laboratory by digitizing the movement sequence from two camera images to construct a 3-D figure and synchronizing the force data.

For analysis purposes, approximately 1 sec of videotape is recorded for each type of lift. A lift begins just prior to the barbell leaving the platform and ends when it is caught overhead with the elbows locked in the snatch, or when the barbell touches the front of the shoulders in the clean. Digitizing and 3-D reconstruction takes approximately 3 hrs per lift when the movements are recorded at 60 frames per second.

Detailed technique analysis normally produces one reconstructed lift per athlete; the coach determines which lift to examine. This one-lift-per-athlete approach is

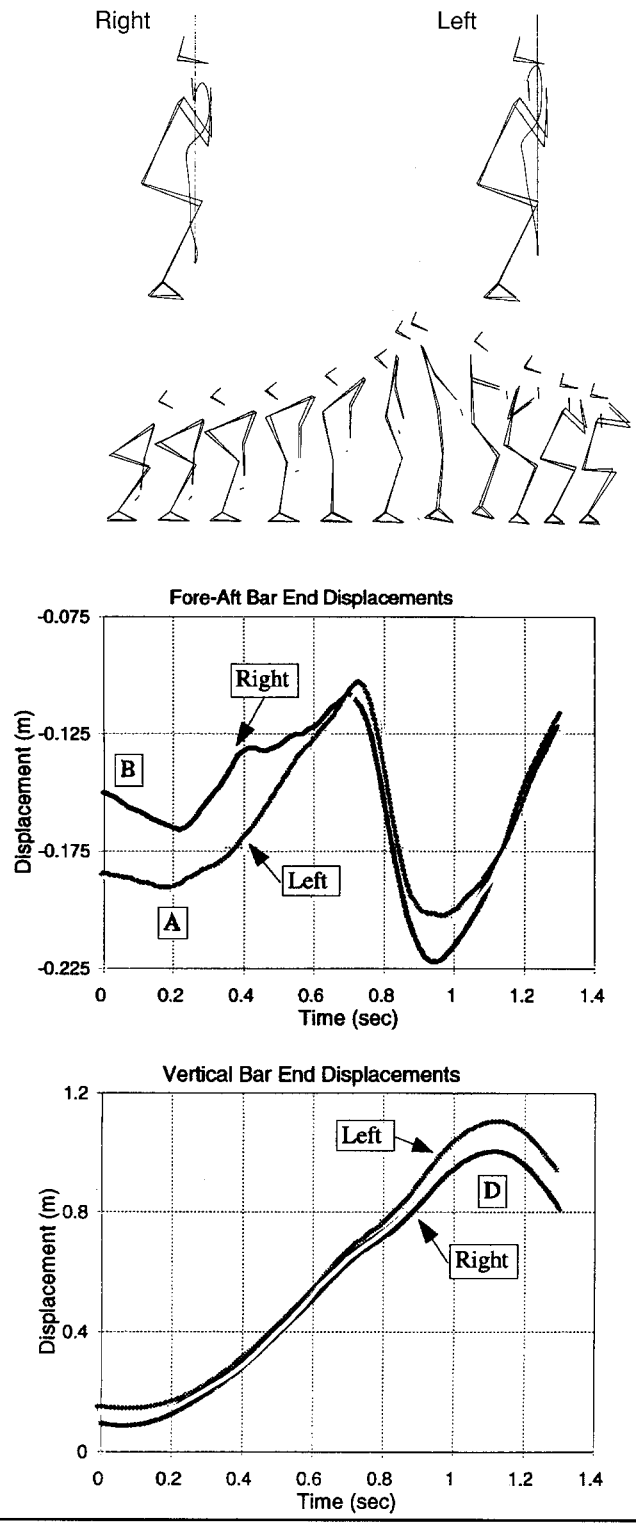


Figure 1 **Right and left bar end trajectories of a clean from just before liftoff until first touch on front of shoulders, followed by fore/aft and vertical bar end displacements with respect to time for the same duration. These displacements are referenced to an axis system passing through the ankles with forward movements in the negative direction.**

most effective given the time-consuming nature of technique analysis and an elite lifter's overall technical consistency. Occasionally, additional lifts are digitized if the athlete attempts slightly different techniques to correct an identified flaw.

Feedback

Feedback is usually given during a data return session within 1 week of data collection. During this session the coach, athlete, and biomechanist discuss various aspects of the lifts. Stick figure diagrams and plots are given to the coach and athlete to take with them for further study.

The diagrams include both a kinematic (motion-based) and a kinetic (force-based) analysis of the barbell and lifter. The kinematic portion contains barbell trajectories in the sagittal plane and includes both the vertical and horizontal displacements (Figure 1). It also provides vertical velocities and accelerations of the ends of the barbell as well as specific joint/segment angles (Figure 2). The kinetic portion includes the vertical ground reaction force of each foot (Figure 2) and, most recently, ankle, knee, and hip moments (torques) of each leg in the sagittal plane (Figure 3). For each parameter, specific maximum and minimum values are noted (Table 1).

The conference between coach, athlete, and biomechanist allows further examination of the lift beyond what is shown. At this time the stick figures, video, and diagrams may be visualized one frame at a time to highlight the characteristics of any incorrect movements. The parameters examined depend on what is perceived as the source of the problem.

If necessary, the analysis may be expanded to include additional parameters such as horizontal barbell velocities and accelerations, joint/segment angular velocities and accelerations, fore/aft and medial/lateral ground reaction forces, forces imparted on the bar, instantaneous power applied to the bar, and joint moments outside the sagittal plane. After the coach, athlete, and biomechanist have discussed the lift and determined what steps to take to correct the fault, the coach and athlete return to the gym for more technique sessions.

Data Interpretation: An Example

It is primarily the coach who determines proper technique and detects faults—with assistance from the biomechanist to ensure accurate interpretation of results.

With proper technique, for both the snatch and the clean of the clean & jerk, two pulling sequences are evident. In each instance the lifter must place great force on the barbell in a coordinated manner in order to raise it high enough to get his or her body under the weight and catch the barbell.

The first pull begins when the barbell leaves the floor and continues until it passes knee height. At this point the lifter repositions the body by flexing the knees forward relative to the barbell. The lifter has now assumed a position that allows him or her to exert more force on the barbell and initiate the second pull. This propulsion of the barbell, which is accomplished through forceful knee and hip extension, brings the barbell to an adequate height for the lifter to catch it.

In the clean lift illustrated in Figures 1–3 with summary values reported in Table 1, the following errors would be addressed:

1. The barbell moves forward immediately after it leaves the floor (Figure 1: fore/aft bar end displacements, Region A). Proper technique would have the barbell moving straight up or slightly rearward. Most likely this forward movement was caused by the shoulders being ahead of the barbell at liftoff.

2. The barbell is not aligned parallel with an imaginary axis passing through the ankles at liftoff (Figure 1: fore/aft bar end displacements, Region B). Through the first 0.7 sec of the lift, the left bar end is in front of the right bar end.

This could be caused by muscle imbalances in the lower extremity that have manifested themselves by an incorrect starting position. There are uneven ground reaction forces present at liftoff (Figure 2: vertical ground reaction forces, Region C) as well, which might also suggest differences in leg strength. Since the forces become equal midway through the first pull, however, this is most likely caused by the improper starting position and uneven weight distribution. This error should be corrected by monitoring barbell alignment at the start.

3. In the vertical direction, the left end of the barbell is moved higher than the right end during the second pull (Figure 1: vertical bar end displacements, Region D).

This is often caused by one leg acting more forcefully than the other, but in this case it is most likely due to uneven transfer of force production from the lower extremity to the upper extremity. The legs produce equal ground reaction forces during the second half of the clean when the vertical displacement difference begins to be apparent (Figure 2: vertical ground teaction forces, Region E). A shoulder injury, past or present, could cause such a problem. This

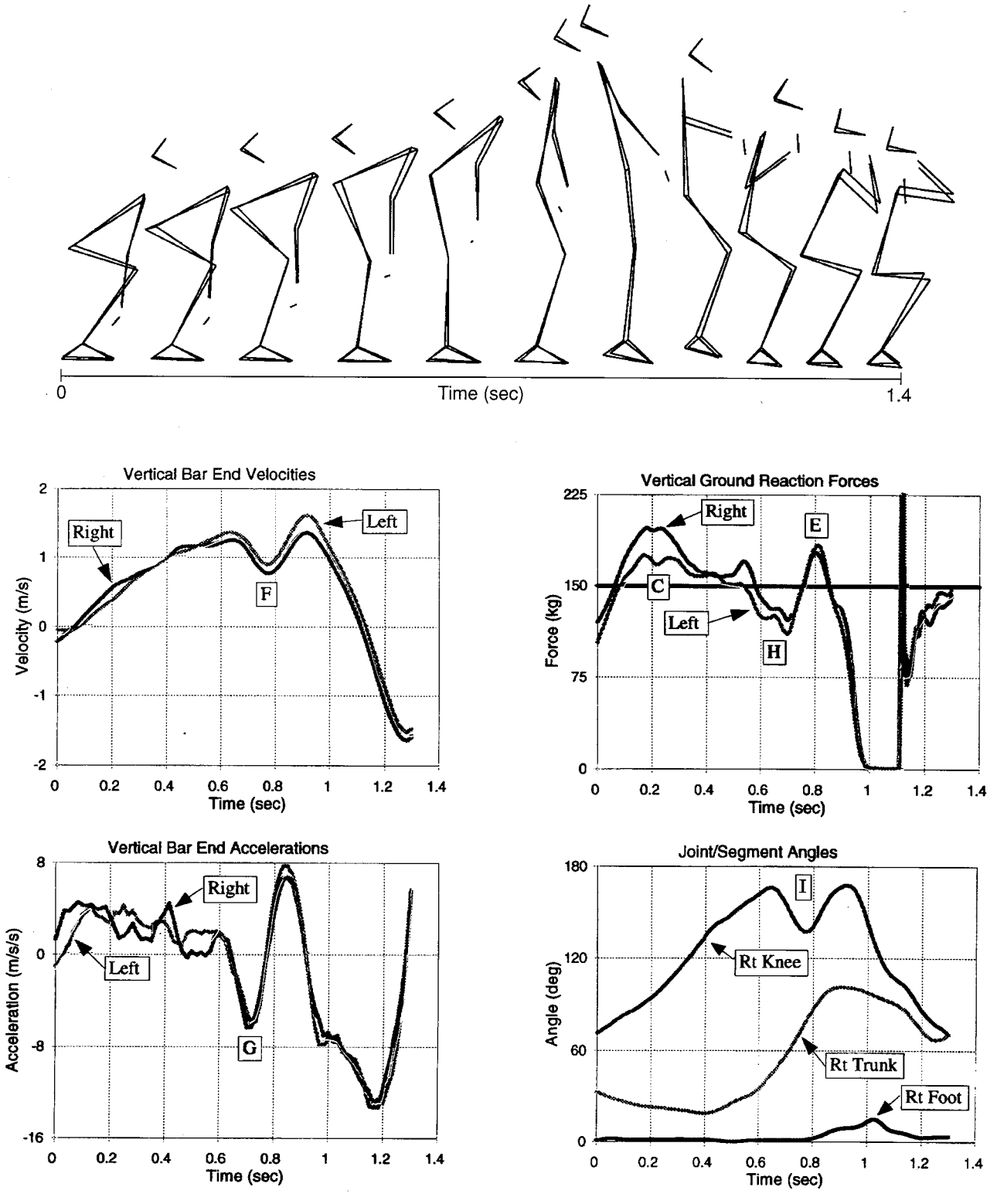


Figure 2 **Additional kinematic and kinetic information returned to the athlete includes vertical bar end velocity and acceleration, vertical ground reaction forces, and selected joint/segment angles. Vertical ground reaction force values are given in kilograms. Reference line represents half of combined lifter and bar mass (~150 kg).**

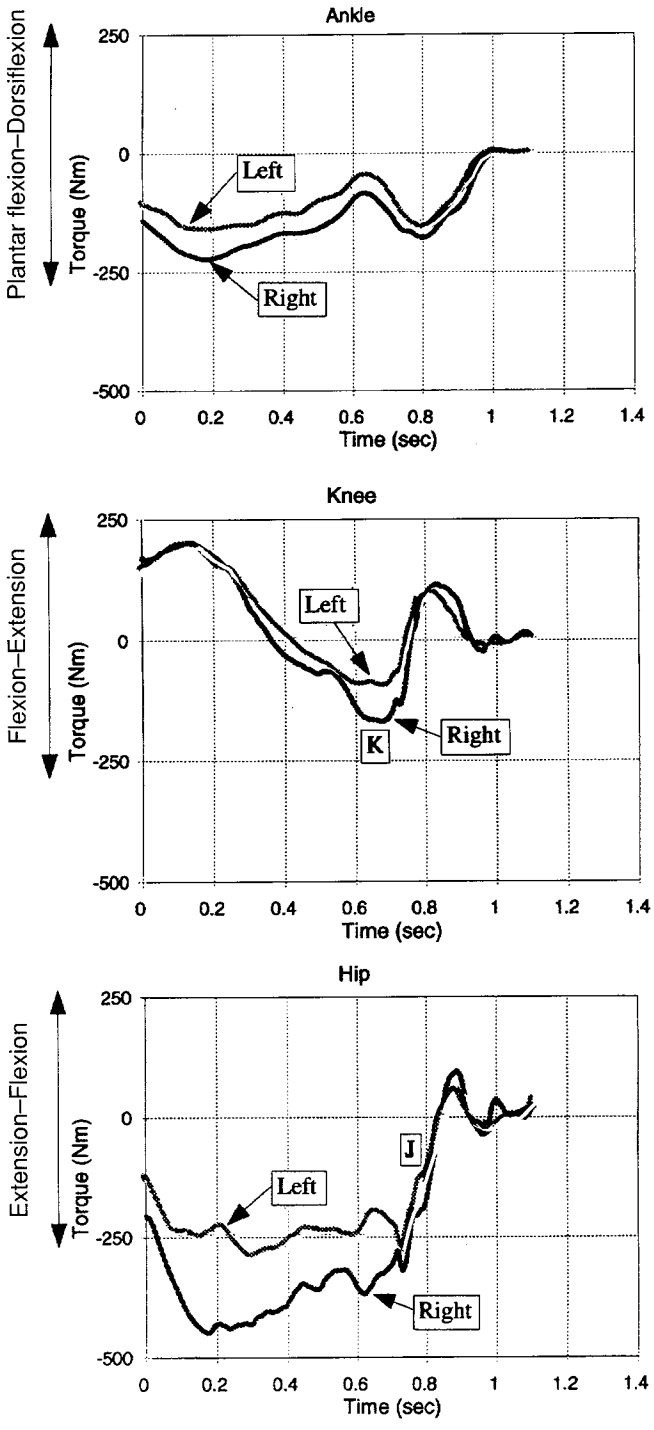


Figure 3 **Joint moments about sagittal plane for left and right lower extremities from just before liftoff until just before lifter's feet land on force platforms after leaving platform during second pull. The sudden impact on force platforms causes a force output overshoot (see Figure 2: vertical ground reaction forces, at ~1.1 sec) which leads the system to calculate incorrect moments. Joint moments are terminated before foot impact so as not to confuse the coach or athlete with incorrect results.**

error may be corrected by increasing shoulder stabilizing muscle strength.

4. There is a large decrease in vertical barbell velocity between the first and second pulls (Figure 2: vertical bar end velocities, Region F). The barbell velocity achieved in the first pull should be maintained into the second pull.

The loss of barbell velocity is evident also in the large decrease in vertical barbell acceleration (Figure 2: vertical bar end accelerations, Region G) and in the ground reaction forces at the same time (Figure 2: vertical ground reaction forces, Region H). The vertical barbell acceleration should decrease to near zero as the ground reaction forces of each foot fall to almost half of the combined lifter and bar mass (150 kg). These large decreases in vertical barbell velocity, acceleration, and ground reaction force are common when the transition from first pull to second pull is inefficient.

After the first pull, the knees are flexed to prepare for the second pull (Figure 2: joint/segment angles, Region I). During this period of knee flexion the hips must undergo a powerful extension in order to maintain vertical barbell velocity. Even though the knees are flexing, a knee extensor joint moment should be present to accompany the rapid hip extension and produce a ground reaction force that will help maintain barbell velocity. In this case the hip extension moments drop off during the transition (Figure 3, hip, Region J); this necessitates a knee flexion moment to flex the knees in preparation for the second pull (Figure 3: knee, Region K).

The magnitudes of the knee and hip moments at the beginning of the lift suggest the lifter is strong enough to execute the proper transition from first to second pull. It

Table 1
Noted Values

Parameter	Right	Left
Horizontal bar displacement (cm)*		
-Forward displacement off floor	0.79	0.30
-Backward displacement between pulls	-4.87	-8.45
-Forward displacement second pull	6.43	1.48
-Backward displacement at catch	-0.87	-4.90
Vertical bar displacement (cm)		
-Crash distance	6.58	4.60
Vertical bar velocity (m/s)		
-Maximum first pull	1.25	1.34
-Minimum between pulls	0.77	0.88
-Maximum second pull	1.36	1.59
Vertical bar acceleration (m/s/s)		
-Maximum off floor	4.58	4.17
-End of first pull	2.00	1.74
-Minimum between pulls	-6.33	-6.00
-Maximum second pull	6.76	7.62
Vertical ground reaction force (kg)	(foot)	(foot)
-Maximum off floor	197.4	174.0
-End of first pull	170.1	150.8
-Minimum between pulls	121.9	109.3
-Maximum second pull	176.5	183.5

*A positive value denotes a distance in front of the starting position.

is the neuromuscular control that probably needs fine-tuning to correct this fault.

Additional Biomechanical Assessment Systems

The biomechanical analysis process described above yields data 1 or more days after the lift, except for the force platform results which may be examined immediately after the lift. However, there are more immediate biomechanical feedback systems that can be incorporated into a weightlifter's training. If the lifter is videotaped in the sagittal plane only, qualitative evaluations of technique can be made almost immediately.

This process allows the coach to examine aspects of the lift through slow-motion replay which may be missed by the naked eye, and allows the athlete to see himself or herself immediately after the lift is completed when the "feel" of the lift is still fresh.

This one-camera process is simple and relatively inexpensive but should be employed with extreme care. One camera can only capture information about one side of the barbell and lifter. For a lifter who is still attempting to develop proper technique, the opposite side of the barbell and body may well display slightly different actions. In fact even elite lifters exhibit substantial asymmetry, and thus the single-camera process is generally discouraged.

Other than force platforms, there are no viable means for measuring ground reaction forces and computing individual lower extremity joint moments. Diagnosing leg strength asymmetries can be partially accomplished using the kinematic data. For example, a leg strength discrepancy may be apparent if (a) both feet do not leave the platform simultaneously after the second pull of either the snatch or the clean, (b) uneven foot placement occurs when the feet are repositioned on the platform for the catch, (c) uneven foot placement occurs during squatting exercises with excessive leaning to one side during the movement, and/or (d) there is rotation of the upper extremity and barbell around a vertical axis during lower extremity extension.

Biomechanics Research and Development

In addition to technique analysis, research is being conducted and alternative analysis methods and procedures are being incorporated to improve our understanding of optimal lift performance. The most recent project was the development of algorithms and software to compute individual joint moments for each ankle, knee, and hip. Joint moments provide information as to where and when forces internal to the musculoskeletal system are being generated.

Although joint/segment angles, velocities, and accelerations give a general idea of force production, the complexity of the skeletal system often masks critical features associated with force and power production.

Other biomechanical research projects have involved assisting with the production of educational/coaching videotapes, kinematic analysis of weightlifting competitions (to gain information on lifters from other countries), and the evaluations of weightlifting as a strength and conditioning modality for multisport training.

Physiology

Historically, the physiology program has had major involvement with weightlifting. Presently, weightlifting uses physiology services on an as-needed basis, for body composition, vertical jump, lower back/hamstring flexibility, and right and left hand-grip strength tests. These are quick tests that yield a wealth of information about the status of a lifter. For example, body composition tests monitor gains/losses of lean body mass and fat. A body composition test may provide additional information relevant to a lifter for weight class selection.

Most of the involvement by the physiology program has been to assist in USOC funded research projects. These studies have typically assessed the merits of different training programs. Weightlifting programs were developed to test the effects of manipulating training volume and intensity on various blood markers. The effects of protein supplementation and different tapering regimens on blood markers and performance have also been studied.

Physiology staff examine blood markers such as testosterone, growth hormone, sex hormone-binding globulin, cortisol, ammonia, hemoglobin, and hematocrits at regular intervals during the studies. The levels and trends of these markers yield information about adaptations to training, ability to recover from strenuous workouts, potential for illness and injury, and presence of overtraining.

Elevated levels of testosterone, growth hormone, and sex hormone-binding globulin indicate skeletal muscle synthesis and repair. Elevated levels of cortisol and ammonia indicate skeletal muscle breakdown. Hemoglobin and hematocrits are markers of the oxygen carrying capacity of red blood cells; while not relevant to a weightlifter's training, these do provide reference values for fluid movement in the vascular system.

Psychology

U.S. Weightlifting's National Resident Program has been one of the most progressive users of SS&T sport psychology services. USOC sport psychologists have worked with weightlifters in both group and individual contexts. Group work has primarily focused on identifying and preventing overtraining syndromes in junior-elite lifters and thereby reducing attrition from the national resident team. The process of monitoring junior lifters for signs of overtraining involves 3 steps:

1. Educating weightlifters about the signs and symptoms of overtraining syndrome;
2. Monitoring psychological symptoms of overtraining through mood evaluating tests;
3. Increasing communication between athlete and coach as well as coach and psychologist regarding overtraining issues.

This emphasis on overtraining syndrome is intended to prevent full-blown syndromes before they occur, thus reducing the number of days lost to injury and attrition from the resident program.

Individual sport psychology consultation with weightlifters occurs every week and topics of discussion vary widely. Among the themes that tend to surface consistently with weightlifters are relaxation training, visualization/imagery to assist technique development, visualization/imagery to prepare for the stress of competition, goal-setting principles, improving self-talk, adjustment issues (either adjustment to the OTC or to retirement from sport), and working on exhibiting positive responses (behaviors) in place of negative behavior during the inevitable frustrations in training and competition.

Sport psychology consultation also occurs every day. The sport psychology program's on-site presence gives weightlifters a chance to discuss issues as they occur during training. Routine observation of weightlifters' behavior and performance is also a very important element in monitoring for signs of overtraining and in establishing a rapport with athletes. Sport psychologists have found that on-site observation of training behaviors is an indispensable means of establishing effective sport psychology regimens.

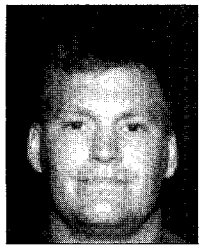
Results

The SS&T staff has played an active role in supporting scientifically based training for the athletes in the U.S. Weightlifting Federation. It is difficult to measure the impact of the SS&T Division on the resident weightlifter's performance, but the results are very encouraging.

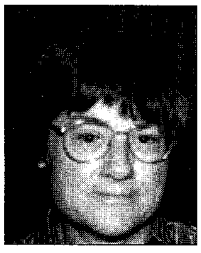
Senior weightlifters who have been involved in the resident program presently hold 25 of 30 national records. Since the new bodyweight categories were introduced a few years ago, resident weightlifters have broken over 100 American records. Internationally, it is hard to compare the U.S. weightlifters with those of other countries due to rapidly changing drug testing policies and procedures. However, at the 1995 Pan American Games, U.S. Weightlifting had its best showing in recent history with resident weightlifters winning 4 gold medals.

Weightlifting is just one example of many integrated SS&T programs. Staff members in the SS&T Division will continue to serve weightlifting and will continue working with other sport federations in an effort to improve athletic performance. ▲

Note. For more information about the SS&T Division, contact Programs Manager Martha Ludwig, PhD, One Olympic Plaza, Colorado Springs, CO 80909.



Reiser



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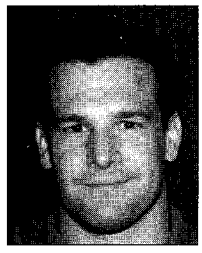

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