Applied Video Analysis For Coaches: Weightlifting Examples

by

John Garhammer and Harvey Newton

Reprinted from

International Journal of
Sports Science & Coaching

Volume 8 · Number 3 · 2013

Applied Video Analysis For Coaches: Weightlifting Examples

John Garhammer[1] and Harvey Newton[2]
[1]Professor Emeritus, Department of Kinesiology,
California State University, Long Beach, CA, USA
[2]Newton Sports
PO Box 1453, Ormond Beach, FL 32175, USA

ABSTRACT
The following article presents a reasonably detailed introduction to video analysis, as can be used by coaches in many sports for both qualitative (subjective) and quantitative (objective) evaluation of their athletes from a two dimensional (2D) point of view. Video cameras and their set-up to capture video records of training or competition performances of athletes are emphasized, along with a review of five video analysis software programs, two of which can be obtained free of charge. Examples from the sport of Weightlifting are provided, but similar applications can be made to other sports. A brief general history of cimematographic (film) and video analyis is given, in addition to a history that is more specific to Weightlifting.

Key words: Calibration, Qualitative Biomechanics, Video Analysis Software

INTRODUCTION

The use of photographic methods in the analysis of animal and human movement began in the late 19th century. In a book published in 1882, Eadweard Muybridge provided details of the running mechanics of horses using sequential photographs. Wilhelm Braune and Otto Fischer made important contributions to the study of human gait around the same time. When motion picture cameras were developed in the early 20th century, the use of cinematography in basic human movement and sport analysis began to increase. Early film cameras had many limitations, such as a single slow frames per second (fps) rate (32 fps became an early standard), spring wound motors, and film that required high light levels. By the 1970s, cinematographic analysis capabilities had improved substantially. Cameras had electronic motors that could be run on batteries, and a variety of frame rates (up to about 400 fps) were available on higher quality 16mm cameras. Film with greater light sensitivity was available, making indoor light levels usable for filming even without special lighting equipment. By far the greatest advance at this time was the availability of "digitizing" equipment that interfaced directly with early desktop computers. Rather than the hand tracing of images frame by frame, this new equipment permitted frame-by-frame manual measurement of the location of

Reviewers: Loren Chiu (University of Alberta, Canada)
Andrew Fry (University of Kansas, USA)
Greg Haff (Edith Cowan University, Australia)

objects or points on the human body, such as the hip, knee and ankle. When these locations were converted to digits (digitization) in the form of horizontal (x) and vertical (y) coordinates at known time intervals, such as every 1/32 second, the path of motion and the object's velocity and acceleration could be calculated, as could joint angles and body segment orientations. Initial analysis work of this type was two dimensional (2D), but 3D analysis capabilities were rapidly developed using two or more cameras simultaneously, along with more powerful computers and sophisticated software. By the early 1990s, video cameras had largely replaced film cameras, making video analysis available to many more individuals and institutions than ever possible with film due to lower costs and much less technical know-how for camera set-up and video data collection. The most significant advance associated with video techniques was that the slow and tedious manual digitization of film could, in many situations, be replaced by automated digitization. Common computer monitors could be used for video display and digitizing, and since video images were electronic displays, contrasting areas of color or shades of gray could be tracked automatically using specialized software. This capability is extremely valuable since days of manual work can be reduced to hours of mostly automated work done by computer software. Commercial software packages to perform 2D and 3D video analyses were initially very expensive, but gradually prices decreased due to competition, especially for 2D analysis programs. Today powerful video and computer equipment is readily available at low cost, and a number of 2D video analysis programs can be acquired from no cost to just a few hundred dollars. More details related to some of the ideas and concepts mentioned above will be given in later sections of this article, and the final section presents a short discussion of much more expensive and sophisticated 3D video analysis equipment and techniques. 3D analysis methods are only needed for sport activities that cannot be reasonably approximated as a 2D movement pattern, such as a side view (versus overhead view) of a discus or hammer throw. The bottom line is that 2D video analysis is now readily available for all coaches at very low cost.

VIDEO CAMERA SPECIFICATIONS

A video camera is the one essential piece of equipment that every coach needs to analyze athletes in training and competition. Fortunately, there are many quality video cameras available at prices ranging from about $100 US to over $1000 US. The higher priced cameras are generally high definition (HD), which typically means 720 to 1080 horizontal lines are used to form each video picture. The intersection of these lines with a series of vertical lines can form millions of pixels or picture elements, each of which can be assigned a large range of colors. Thus, picture "resolutions" are given as 1920 x 1080 or 1280 x 720 to indicate the number of vertical and horizontal lines used to create a video image. 1920 x 1080 = 2,073,600 or 2.07 mega pixels. Older standards such as Super VHS (S-VHS) and Hi-8mm were 640 × 480 pixels, and this resolution is still fine for almost all video analysis work with athletes. Many newer cameras permit a selection of video resolutions, and resolutions below HD levels save considerable video memory storage space while still providing high-quality images. The fps choice used to record video may limit the types of analysis software that can accept it, as can the storage format, as discussed below.

There are other important considerations related to resolution choices. Some video cameras provide only 30 fps at HD resolution, but 60 fps at one or more lower resolutions. This can be very important when performing any type of video analysis, because the fps value indicates the number a pictures taken per second and thus, the number of samples of position every second during a movement activity (fps can be called sampling rate for analysis purposes). A sport like weightlifting, where maximal barbell speed is between 2 and 3 m/s, can be analyzed clearly and accurately at 50 to 100 fps. For fast events like foot contact during sprinting, or ball contact during a tennis or golf swing, a much higher sampling rate is needed to clearly see the details of the event of interest. Some reasonably priced cameras have an option for high sampling rates of 100 to 500 or more, at least for short durations of a few seconds at most. Higher quality video analysis software can separate the odd and even numbered horizontal lines that form each video image in standard 30 fps video formats, such as audio-visual interleave (AVI), and create two images. This methodology essentially converts 30 fps to 60 fps video for analysis purposes.

A very important setting for all cameras is the exposure time. This is the amount of time a camera's shutter is open to allow light from the object(s) of interest to enter the camera to form each picture. The faster the movement of interest the shorter the needed shutter setting to avoid a "blurry" picture. Most modern video cameras have a shutter selection button to choose from a large range of shutter (exposure) times, typically from about a second to just a few thousandths of a second. Indoor video data collection may limit how short an exposure time can be used due to available lighting.

Another factor to consider in a video camera's specifications is the file format it uses to store the recorded video, and how it is stored (tape cassette, flash memory card, internal hard disk). When video data files are downloaded to a computer, the computer must have the appropriate software to play any given file format. The original standard file format for video was AVI and it is still used as the video file storage format for some cameras. There are many other storage formats used by various cameras today, such as MOV (Movie format used in Apple company products), WMV (used in the Microsoft Windows environment), and MP4. Video file format is very important to consider if a coach is planning to use video analysis software for a quantitative analysis, since such software may only accept a limited number of formats. The most recent versions of many analysis software programs accept a large variety of video formats. Fortunately, several software programs are available that can convert video files from one format to another.

Final considerations include camera batteries and storage media. If day-long video data collection is sometimes performed "in the field" away from a power source, then several long-life batteries may be needed. Such batteries can be expensive, so the price and availability should be considered if a new camera is to be purchased. The capacity of a camera's storage media is also important. Video cameras that use a fixed hard disk are limited to that disk's capacity before the contents must be transferred to a computer or other storage device. Cameras that use video cassettes, such as 8mm or mini-DV tapes, may be limited to one or two hours of recording per cassette. Flash memory cards for video cameras come in a variety of storage sizes, such as 2 and 4 GB, and can be easily exchanged when needed. One camera design issue to consider is whether or not a battery, memory card or tape cassette can be changed without removing the camera from its support tripod. For quantitative analyses, calibration for real world size in each picture is important (as discussed below) and any change in camera position or focus, as may occur with camera removal from a tripod, requires a new calibration. Some video cameras permit battery and storage media changes without removing the camera from the tripod.

QUALITATIVE ANALYSIS CONSIDERATIONS

Qualitative analysis of sport activities involves no measurements, only subjective evaluation by the observer. This type of visual analysis has surely been done since competitive sports began. In an explosive event like weightlifting, athletes rapidly move through a series of key positions while elevating the barbell. For the novice eye, much of what an elite weightlifter does while executing the snatch or the clean & jerk remains a mystery. Without fail, if given a dowel and asked to imitate what has just happened, a newcomer invariably swings the "bar" overhead or to the shoulders with little, if any, evidence that the technical nuances of proper weightlifting were seen, understood, or duplicated. A novice coach or athlete can learn about proper technique in weightlifting and other sports in a relatively short time if qualitative video analysis techniques, such as slow motion and stop-action viewing, are utilized. With modern technology, the options available for dissecting sport techniques are many. The following paragraphs review some history and current options available for use by weightlifting coaches and strength training professionals relative to qualitative analyses.

Historically, the Olympic sport of weightlifting was one of the early subjects to receive serious scrutiny from what we today call the field of sports science. This began during the Cold War era of the 1950s and 1960s, as both the sport and sports science began to evolve into more sophisticated practices. The main players involved in weightlifting at this time were locked in serious competition to improve performance. Many think of the Cold War only in terms of a military arms race, but there was also a propaganda war to be waged. Sport was a key weapon in this war and weightlifting factored heavily into the strategy.

At the end of World War II, the USA emerged as a strong player in international weightlifting (and other sports). USA emerged from the war relatively unscathed, certainly compared to Europe, and their role as a strong leader is reflected in the 1948 Olympic Games in London. Here USA's eight team members garnered four gold, three silver, and one bronze medals. Egypt, a strong force prior to the war, scored the second highest number of medals with two gold and one silver. The Soviet Union did not compete in the Olympics until 1952, when they performed strongly, but were outscored by the USA by one point.

The USA weightlifting team, sponsored by the Department of State, toured the Soviet Union in 1955, the first-ever American team to conduct such a sporting exhibition in the country. The Soviets were in awe of American champions Tommy Kono, Isaac Berger, Chuck Vinci, and particularly, Paul Anderson, dubbed by the press *Chudo Pirody* (A Wonder of Nature) [1, p. 162]. It was quickly determined that competing against and/or beating the Americans, especially in the so-called combative sports (boxing, wrestling, weightlifting), was of high propaganda value. "In order to beat them one had to be superior in all departments: physically, technically, psychologically, and tactically" [2, p. 80].

Initial attempts at technique analysis involved cinematography. Only occasionally did such images make it into mainstream periodicals, such as *Strength & Health* where the average American lifter or coach could benefit [3]. Among the first evidence of the Soviet Union's scrutiny of weightlifting was an 18-frame sequence (taken from film) of a USSR lifter performing a split snatch from blocks that was published some years later in the same publication [4].

In the early 1960s, David Webster, Scotland's National Coach, painstakingly traced 16mm film to paper, then measured angles and positions. This early step into quantitative analysis was presented in English-speaking publications. Both sides of the international battle for weightlifting dominance benefited from Webster's work. In his book, *The Iron Game*, Webster is shown receiving awards from a leading Soviet sport scientist [5].

Motor driven photography quickly became the state of the art means of conveniently capturing technique images. The challenge was to use a sufficiently high sampling rate (fps) to accurately see the fine details of technique, so called high-speed cinematography. Even with this more advanced practice, film had to be developed and images printed, all of which greatly delayed the feedback process. During this time the Super 8mm movie camera and film became a popular means for club-level coaches and lifters to record weightlifting technique on a low budget.

Soon thereafter, relatively bulky videotape recorders were introduced. Now, instead of having to send film off to be developed, coaches simply captured a lift and played the tape back for nearly immediate feedback. Doing so at various speeds and in stop-action provided excellent and immediate feedback. Videotape certainly made capturing weightlifting images easy and inexpensive. Sixteen millimeter high-speed film remained the standard for serious scientific research well into the 1980s, with frame speeds typically at 50 frames per second. During the U.S. Olympic Committee's Elite Athlete Program (1982-84), one author routinely hand digitized high-speed film to thoroughly analyze top American lifters. The transition from the laborious manual process with film to more automated methods with videotape allowed analyses to be performed much more quickly. Accurate, real-time visual feedback is very valuable in the process of learning and refining various technical characteristics of the lifts. But again, the lifts are executed in less than one second, so the ability to see detail is limited. Therefore, in addition to real-time replay it is also crucial to have access to slow motion, frame-by-frame, and stop action viewing. It is only with this slowed down playback that the lifter and the coach can be more certain how minute technical issues may contribute to the success or failure of a particular lift.

At the beginning of the 21st Century software to measure and quantify weightlifting, and other sports performances, continued to evolve. Popular applications such as Dartfish allowed for video capture, along with drawing tools to track trajectory and data tables to reflect bar velocity, along with a convenient means of communicating such results over the Internet for those engaged in distance coaching. With the advent of "smart phones" and other mobile devices, we now see a number of affordable "apps" that allow coaches to capture and immediately show athletes their performance, all on a simple, handheld device.

Due to advances in technology, qualitative motion analysis today is relatively simple. Remaining questions are, what angles, how many cameras, what details to capture, etc. This is a nice problem to have, especially compared to earlier years.

THE VIEWING ANGLE FOR QUALITATIVE ANALYSIS

During training, most weightlifting coaches watch their charges from a frontal angle, 30 to 60 degrees forward from a side view (Figure 1). This allows for some viewing of the lumbar spine, most of the frontal plane, and the all-important lower body kinematics. When utilizing only one camera this view probably provides more technique details than any other, at least from a coaching point of view.

In most competitions, however, coaches actually view performances from an angle behind the lifter. This is due to the orientation of the warm-up room and competition platform, along with the expected role of the coach accompanying the lifter to the stage. This is not an angle from which many coaches would choose to film a lift. For the trained eye, however, either of these two orientations allow for a reasonable observation of the lift.

One author has found viewing from the front and from a front side angle helpful, especially for observing errant foot movement when the bar is at approximately knee height. This undesirable trait, not uncommon in novices, frequently results from getting one's bodyweight too far back onto the heels and/or a proprioceptive need to execute the second pull with the feet in a different orientation than the first pull. But at the same time, the coach has little if any feedback relative to barbell trajectory when viewing from this angle. It is a wise coach who varies viewing positions and requests different angles be filmed for technique analysis.

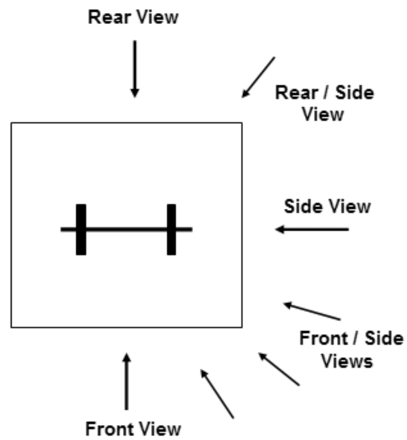


Figure 1. Commonly Used Camera Recording Positions

With a single camera, a side view directly opposite one end of the barbell permits excellent feedback on trajectory. But since much of the viewing area is blocked by the 45 cm diameter discs loaded on the bar, many key joint movements are blocked. This location, however, remains the norm for quantitative scientific study involving one camera due to the ability to determine barbell kinematics, such as barbell trajectory, velocity, and acceleration.

At major broadcast opportunities, such as the Olympic Games, we see cameras placed elsewhere. An overhead view permits rare looks at rotational asymmetries and balance positions. Should the media choose to focus on the strain of a lifter's face with a frontal shot, very little meaningful lifting technique information is captured. Two other favorite camera locations at the Olympics are one camera directly behind the lifter and one embedded into the platform, showing the lifter's face just prior to lift-off. Such angles have little, if any, use for weightlifting coaches.

In recent years, 3D video analyses have been performed on weightlifters in order to obtain a more thorough understanding of what is happening that remains largely unseen in a 2D or naked eye viewing. Here data are gathered on left versus right side barbell discrepancies, blended front and side views, tilted barbell elevation, or other such individual quirks. Often coupled with 3D recording is the use of a force plate in order to determine if certain ground reaction forces are related to idiosyncratic lifting style. These topics are briefly discussed again below, but are well beyond the purview of most weightlifters and their coaches.

CAMERA SET-UP FOR QUANTITATIVE ANALYSIS

Quantitative 2D analyses are based on the assumption that some movement patterns have symmetries that permit key aspects of the real 3D motion to be evaluated from a single 2D view. A classic example is the analysis of gait (walking), where many of the most important parameters defining this locomotion skill can be measured from a side (sagittal plane) view. Right and left side movements during Weightlifting are also mostly symmetrical and many useful parameters characterizing the lifts can be determined using a side view video camera and subsequent use of appropriated computer software. To be able to take accurate measurements from a single video camera view, the camera must be level horizontally and the optical axis of the camera (line of sight through the camera lens) must be perpendicular to the plane of motion. The camera axis should also be centered within the range of motion to be analyzed. During the pulling motion for the Snatch and Clean & Jerk in Weightlifting, the barbell moves upward from the platform about 100 to 120 centimeters (3 to 4 feet). Since the center of the barbell is 22.5 cm above the platform before lift-off, an ideal height for the camera axis above the platform would be about 65 to 70 cm (half of 110 + 22 = 132 /2 = 66 cm). The camera should be as far from the center of the lifting platform as is reasonable. 10 meters (33 feet) is the minimum camera distance that should be used for accurate 2D measurements of the barbell motion. If the camera is closer, the 2D motion assumption is less valid since the effects of distance variation (such as the outer barbell plate being about a half meter closer to the camera than the head and feet of a weightlifter) will affect measurements and accuracy of the calibration scale. The zoom lens on the camera should be manually focused and adjusted so that the total field of view includes the barbell plates on the platform and will be large enough vertically to see the barbell overhead. Modern video cameras have zoom lenses that cover a large range of focal lengths (10 – 100+ mm). Longer focal lengths are used when the camera is a "longer" distance from the subject, and provides an image that looks "flat" (more 2D than 3D). Once the camera is leveled and set up with the proper height and field of view, it cannot be moved or adjusted in any way (otherwise calibration must be re-established). Calibration is performed using either a square of known dimensions or a stick or ruler of known length held vertically above the barbell plates closest to the camera (this is the plane of motion for analyzing barbell motion, most of which is in the vertical direction (see Figures 2 and 3). If the overhead portion of either type of lift is to be included in the analysis, then the field of view must be made large enough to include the overhead position, and the camera height should be increased from that estimated above. The calibration object used should be reasonably large (50 to 100 cm or more) and be videotaped while being held over the plates in the center of the range of motion to be analyzed. At major competitions, it may be impossible to get to the platform to hold a calibration object in the position needed. In this case, the vertical diameter of the largest plate (45 cm) can be use for calibration if measured from a video image when the plate is about halfway through the vertical range of motion. This is easy to do with all video analysis software compared below, except Ariel Performance Analysis System (APAS), which requires a more specialized method for calibration using a square object (the top, bottom, right and left center edge of the plates can be used in this case if a square object cannot be held in the proper calibration position).

QUANTITATIVE ANALYSIS METHODS

Digitization is the primary method used for quantitative 2D video analyses related to human movements in sport. It is done using specialized software running on a desktop or laptop computer. The process involves displaying the video record of the movement of interest, appropriately recorded as discussed in the previous section, one picture at a time. For each picture, one or more points of interest (knee, hip, center of a barbell plate, etc.) are registered by moving a crosshair over the center of the object of interest by moving the computer mouse and clicking the appropriate mouse button. This action registers the 2D (x,y) coordinates of each point digitized. When the points of interest are digitized for all pictures of the movement sequence, parameters such as displacement, path of motion, velocity, joint angles and angular (rotational) velocities can be calculated by the computer program being used. This is possible because the pictures in the sequence are taken at a fixed time interval which depends on the camera used and its settings. Typically pictures are taken every 30^{th} or 60^{th} of a second, so it is said that the sampling rate of the camera is 30 or 60 hertz (Hz), same as the fps. The digitization process can take considerable time and patience, especially for

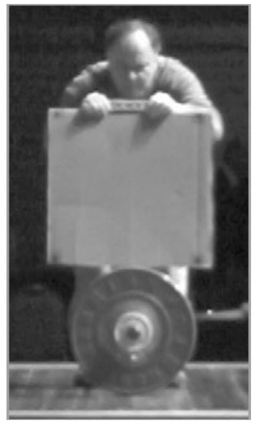


Figure 2. Calibration Using a Square of Known Dimensions

Figure 3. Calibration Using a Frame of Known Dimensions

longer video segments and/or multiple points of interest in each picture. Automated digitization can greatly reduce the time and effort involved in any quantitative analysis, and this option is available on many video analysis programs, including four of the five programs reviewed below. The automated process begins by manually digitizing the first one or two pictures, setting a few parameters, and starting the automatic process which continues to digitize each remaining video picture frame by frame to the end of the sequence. The success and accuracy of the automatic process depends on the points of interest being distinct relative to the surrounding background. This is usually possible due to a distinct shape or due to good color contrast. In the laboratory or during practice, contrast may be enhanced through the use of colored tape or markers placed on clothing or on the skin. In competition situations, it may not be possible to enhance the contrast of points of interest so, in some cases, manual digitization may be needed for at least some of the points or video images.

SOFTWARE COMPARISONS

For this article, five video analysis programs were used to evaluate a gold medal performance in the snatch lift, performed at the 2009 Pan American Championships. As can be seen in Table 1, the analysis data obtained for this evaluation included maximum bar height (Ymax), horizontal displacement of the bar at Ymax relative to the start or “lift-off” position, and maximum vertical barbell velocity (Vymax) during the lifting movement. The time (t) after the start of the lifting motion when the listed parameters were obtained is also given. The values obtained using the Ariel Performance Analysis System (APAS) are considered correct or "Gold Standard" values due to the use of ever improved revisions of APAS for detailed scientific research and publication in the study of human movement for over 40 years. If differences of 1% or less were found for Ymax or 2% or less for Vymax when parameter values from the four other software packages were compared to APAS values, then they were considered equivalent in accuracy since such small differences may occur if a given person analyzes the same video two or more times. The vertical (y) coordinates obtained during analysis with each program were also used to calculate vertical velocity with the simple and commonly used Central Point Finite Difference (CPFD, Vymax2) method (see equation below), and the more involved Five Point Moving Arc method (5 Pt MA, Vymax3) [6], to double check the velocity values determined by the software itself (Vymax1). Detailed help screens and/or online manuals are provided for all the analysis programs discussed below to aid in learning how to use the software. If coaches are not comfortable learning and working with video analysis software, they may likely find that one or more of the athletes they coach are very computer literate and can assist in learning and using the software.

Table 1. Video Analysis Software Comparison

Software	X (cm) @ Ymax	Ymax (cm)/t(s)	Vymax1 (cm/s)/t(s)	Vymax2 (cm/s)/t(s)	Vymax3 (cm/s)/t(s)
APAS (60 Hz)	–11	106/1.08	202/0.83	202/0.83	202/0.83
Dartfish (60 Hz)	–10	102/1.08	221/0.80	221/0.80	217/0.80
Kinovea (30 Hz)	–11	105/1.07	*	212/0.80	208/0.80
Logger Pro (10 Hz)	–12	105/1.07	202/0.80	206/0.80	203/0.80
Tracker (30 Hz)	–11	105/1.07	214/0.80	214/0.80	207/0.83

APAS is the only program used in this comparison that utilizes a method of data smoothing. Smoothing is a mathematical process used to minimize the effects of measurement error, which always occurs during the digitization process. Its benefit can be seen in the vertical velocity graph for the lift analyzed in Figure 4 with no smoothing, and Figure 5 with smoothing.

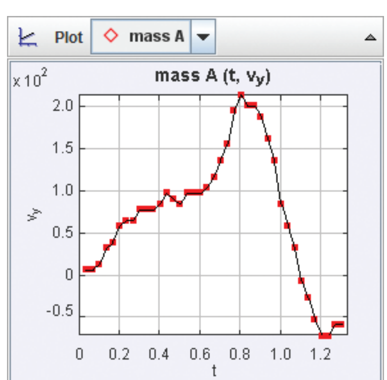


Figure 4. Vertical Velocity Graph for Lift with No Smoothing

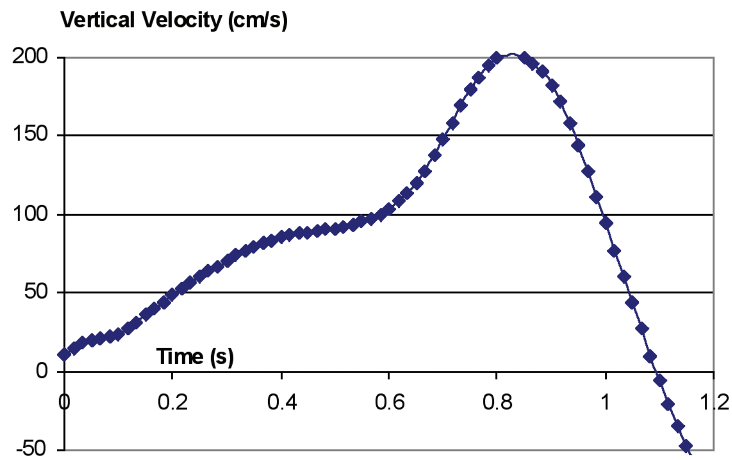


Figure 5. Vertical Velocity Graph for Lift with Smoothing

APAS {REVISION 3.7}

This is a widely used video analysis package throughout the world (also see the above comments on APAS). It can perform 2D and 3D analyses, and can also incorporate electromyographic (EMG) and force plate data. It is more difficult to learn to use than the other four packages, but is much more powerful. It includes sophisticated data-smoothing capabilities. The complete APAS package can be expensive (See *www.apas.com*).

DARTFISH {VERSION 4.5.2.0}

This software package is very powerful for qualitative analyses and comparison of multiple trials of movement activities. It also permits a variety of quantitative linear and angular measurements. The website (*www.dartfish.com*) should be consulted for detailed information about its capabilities and prices for lower versus higher powered versions of the software. In the current comparison of results Dartfish was about 4% low for Ymax and about 9% high Vymax. The reason(s) for these differences are unknown.

Figure 6 shows a two window comparison in Dartfish of two lifters in the lift-off position for a power clean. Vertical and horizontal reference lines are shown along with the back angle relative to the horizontal. Figure 7 shows the same two athletes in the catch position. Bar trajectory and height are shown, along with a timing clock and the 0.45 meter reference scale on one barbell plate.

KINOVEA {VERSION 0.8.15}

This video analysis program can be downloaded for free from the website (*www.kinovea.org*). The organization behind this program is focused on the study of movement. One shortcoming is that it does not calculate horizontal and vertical velocities separately. It only provides speed values for points of interest (magnitude of the total velocity). However, the vertical coordinates of motion can easily by pasted into any spreadsheet, such as Microsoft Excel, and used to calculate vertical velocity with the CPFD method, where Vy2 = (Y3 - Y1) / (2 x t), Vy3 = (Y4 - Y2) / (2 x t), and so on for each data point other than the first and last. "t" is the time interval between video pictures digitized, usually 1/30 or 1/60 second.

Figure 6. Two-Window Comparison in Dartfish of Two Lifters in The Lift-Off Position

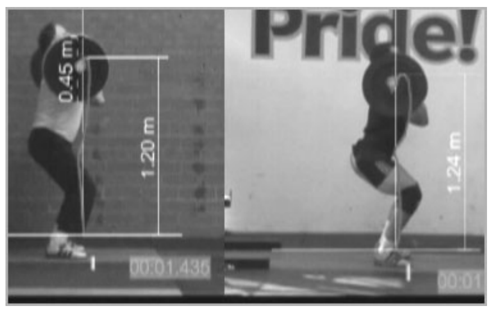


Figure 7. Two-Window Comparison in Dartfish of Two Lifters in The Catch Position

LOGGER PRO {VERSION 3.8.4}

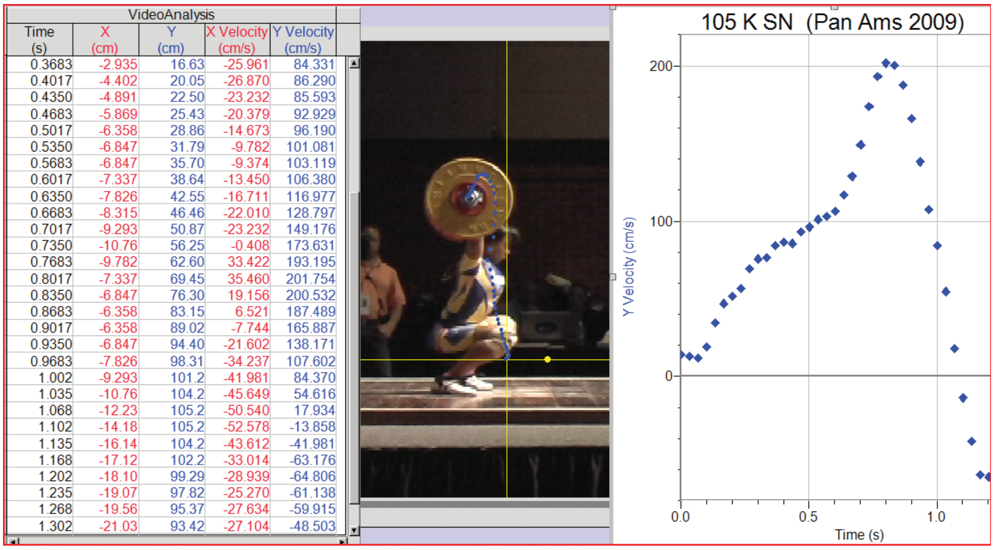
This program is sold at the website, *www.vernier.com*, which specializes in high-school science lab equipment. The video analysis capability is just one component of what Logger Pro can do. It is an inexpensive (~ $150) program that controls many pieces of equipment that the company sells, such as force plates and accelerometers. Purchase includes a "site license" so all members of purchasing group (students, team members) can load and utilize the program. It is probably the easiest of the programs evaluated to learn and use for basic video analysis. Results are very accurate and the display of data and results within the program is excellent, as shown below in Figure 8 below.

TRACKER {VERSION 4.62}

This program is distributed at no cost by a physics educational group at the website (*www.cabrillo.edu/~dbrown/tracker*). It has numerous analysis capabilities, but is relatively easy to learn and use, and includes a substantial on-line manual for download. In the software comparison its Ymax value was good, but the vertical velocity value was about 6% high. The auto-tracked bar trajectory obtained using Tracker is shown to the left in Figure 9.

OVERVIEW OF 3D ANALYSIS AND MOTION CAPTURE LABORATORIES

Coaches may hear the terms "Movement Analysis Laboratory" or "Motion Capture." The former is a specialized laboratory often found in major hospitals, physical therapy programs and at major universities. It typically consists of four to eight specialized cameras which are located in fixed positions around an area used for 3D analysis of movements, such as gait and running. Such evaluations are common with amputees as part of artificial limb fittings,



VideoAnalysis

Time (s)	X (cm)	Y (cm)	X Velocity (cm/s)	Y Velocity (cm/s)
0.3683	-2.935	16.63	-25.961	84.331
0.4017	-4.402	20.05	-26.870	86.290
0.4350	-4.891	22.50	-23.232	85.593
0.4683	-5.869	25.43	-20.379	92.929
0.5017	-6.358	28.86	-14.673	96.190
0.5350	-6.847	31.79	-9.782	101.081
0.5683	-6.847	35.70	-9.374	103.119
0.6017	-7.337	38.64	-13.450	106.380
0.6350	-7.826	42.55	-16.711	116.977
0.6683	-8.315	46.46	-22.010	128.797
0.7017	-9.293	50.87	-23.232	149.176
0.7350	-10.76	56.25	-0.408	173.631
0.7683	-9.782	62.60	33.422	193.195
0.8017	-7.337	69.45	35.460	201.754
0.8350	-6.847	76.30	19.156	200.532
0.8683	-6.358	83.15	6.521	187.489
0.9017	-6.358	89.02	-7.744	165.887
0.9350	-6.847	94.40	-21.602	138.171
0.9683	-7.826	98.31	-34.237	107.602
1.002	-9.293	101.2	-41.981	84.370
1.035	-10.76	104.2	-45.649	54.616
1.068	-12.23	105.2	-50.540	17.934
1.102	-14.18	105.2	-52.578	-13.858
1.135	-16.14	104.2	-43.612	-41.981
1.168	-17.12	102.2	-33.014	-63.176
1.202	-18.10	99.29	-28.939	-64.806
1.235	-19.07	97.82	-25.270	-61.138
1.268	-19.56	95.37	-27.634	-59.915
1.302	-21.03	93.42	-27.104	-48.503

Figure 8. Data Table, Image of the Snatch Catch Position with Bar Trajectory, and Vertical Velocity Graph from the Logger Pro software

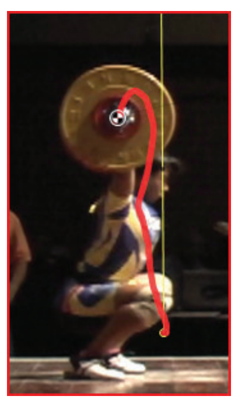


Figure 9. Auto-Tracked Bar Trajectory Using Tracker

and during rehabilitation programs after injury. Subjects wear numerous reflective markers, which permits much of the movement analysis process to be automated. Such facilities are very expensive to set up and maintain, and must be utilized on an almost daily basis to be economically feasible. The size and shape of the area for movement analysis is generally too small for many types of sport analyses, and floor strength may not permit the use of heavy weights.

Motion capture is an advanced form of video analysis, and the equipment used has many similarities to that of the laboratories discussed above, but the movement area is usually larger. The techniques involved are most often used in the production of video games and motion picture special effects, but are also used to evaluation some sport activities, such as golf club and tennis racket swings. As above, much of the process is automated and the equipment involved is very expensive. More types of sport activity can be analyzed in a typical motion capture facility, compared to a standard motion analysis laboratory, due to the larger areas available for movement and stronger (often concrete) floors.

ACKNOWLEDGEMENT

The authors would like to thank Aaron Cunanan, at Louisiana State University, Shreveport, for his assistance in double checking some of the software comparison values.

REFERENCES

1. Fair, J.D., *Muscletown USA: Bob Hoffman and the Manly Culture of York Barbell*,The Pennsylvania State University Press, University Park, Pennsylvania, 1999.
2. Williams, J. (Trans.), *USSR-USA Sports Encounters*, Progress Publishers, Moscow, USSR, 1977.
3. Anon, Learn to Lift by Looking, *Strength & Health*, 1956 (February), 12-13.
4. Anon, If You Want to Beat the Russians, *Strength & Health*, 1963 (May), 14-57.
5. Webster, D., *The Iron Game*, John Geddes, Irvine, Scotland, 1976, 133.
6. Wylie, C.R., *Advanced Engineering Mathematics,* 3rd edn., McGraw Hill Book Company, New York, 1966.