The Application of Biomechanical Technology in Sports

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Abstract

Technology in biomechanics encompasses eight major categories: artificial optical devices, anthropometry, timing devices, electrogoniometry, electromyography, dynamometry, inertial tracking systems, and modeling and simulation. As technology improves and becomes more accessible to the general population, it becomes easier to implement biomechanical technology into sports. For each area of focus, biomechanical technology has numerous points of current application or potential application. This application has benefit in injury prevention, technique improvement, rule enforcement, performance optimization, overall health and condition analysis, sports timing, and product development and testing. This thesis examines each area in turn as well as the various tools implemented in order to provide an overview of how athletes, coaches, and trainers can benefit from their application.

The Application of Biomechanical Technology in Sports

Biomechanics is the area of study that examines and analyzes mechanical kinesiology within living organisms. It is the incorporation of both biology and physics, which combine to describe how the body moves and the forces that affect it. Within biomechanics, there are various forms of technology that assist with body and movement analysis. Eight major categories of technology in biomechanics include: artificial optical devices, anthropometry, timing devices, electrogoniometry, electromyography, dynamometry, inertial tracking systems, and modeling and simulation (Titcomb, 2017). As general technology improves and becomes more accessible, it becomes easier to incorporate technology within these categories into sports. The application of biomechanical technology into sports has great benefit in injury prevention, technique improvement, rule enforcement, performance optimization, overall health and condition analysis, sports timing, and product development and testing. This thesis will focus on examining each area of technology in biomechanics and how that technology can be implemented into the sports world.

Artificial Optical Devices

The first area of technology this thesis will cover is artificial optical devices. One major implementation of artificial optic devices in sports is the use of 2-D video analysis. 2-D video analysis is the use of cameras to film and study the kinematics and general motion within a video (Zult et al., 2019). In the past fifty to sixty years, there has been a drastic improvement in the quality of video cameras that has made 2-D video analysis possible. The first video cameras captured in very low frames per second, with the first home cameras in the 1940’s to 1970’s capturing in only 16-24 frames per second (Titcomb, 2017). In the 1980’s, cameras could shoot up to 60 frames per second, whereas today they can shoot as high as 6,000 frames per second

(Titcomb, 2017). With the advancement of the quality of video cameras, slow motion quality as well as frame by frame analysis has improved drastically. As the video camera has improved, it has also become more available to be used in the sports world. Nearly everyone has a smartphone with video quality of around 30-60 frames per second (Titcomb, 2017). There are apps for smartphones such as Hudl Technique or myDartfish Express which allow coaches and athletes to do video analysis almost instantly. It is an easily implemented biomechanical tool that has benefits in the areas of technique improvement, injury prevention, and rule enforcement.

According to William Bradford and the Institute for Law Teaching and Learning, about 65 percent of the population are visual learners (Bradford, 2011). Essentially every sport requires movements in which technique is incredibly important to optimize performance. Trying to explain these techniques with words, however, can sometimes be confusing or impossible to understand for the average athlete. For instance, the golf swing is best enacted when an athlete "increases thoracic rotation relative to pelvic rotation to preload the trunk muscles by accentuating their length and allowing them to use the energy stored in their elastic elements to produce more power" (Cole and Grimshaw, 2015). To the average athlete, this explanation would most likely not make sense. In this case, a coach could capture a video of the athlete's swing and analysis it side by side with a video of Tiger Woods, showing the difference in thoracic and pelvic rotation. This type of analysis can be used to improve technique in areas such as gait, diving, pitching, pole-vaulting, and so on.

Video analysis programs such as Dartfish are excellent for analyzing and improving technique. With Dartfish, athletes and coaches are able to take video of a movement and analyze still moments of that movement. One big area for technique improvement is the utilization of optimal body position and angles depending on what movement the athlete is performing. In tennis, an optimal stance for returning a serve is a crouched athletic stance with the belly button and heels forming a 50-degree angle (Sirola, 2015). The knees should be inside of the feet, and the chest should be forward to put weight over the front of the foot (Sirola, 2015). The reason for these body positions and angles is to create quicker reaction time and mobility, which is crucial in returning a ball travelling at over 100 miles per hour. Through video analysis and Dartfish, an athlete can take a still image of their return stance and actually check the angle of their belly button and heels or the positioning of their chest and knees to make improvements.

Technique improvement carries a great potential for injury prevention. Returning to the example of the golf swing, many golfers will laterally slide their pelvis towards the direction the ball will be traveling in order to generate more power (Cole and Grimshaw, 2015). This movement, however, produces a lot of force on the lower back that contributes to chronic lower back pain for golfers. Since most golfers might not understand the mechanics of their injury, video analysis can be used in slow motion to show exactly what portion of the swing is contributing to their back pain. From 2011 to 2013, a research group used video analyze to look at concussion injuries for youth under eighteen years old at a football tournament (Hendricks et al., 2016). Videos were captured of each incident resulting in a concussion, and analysis of these incidents showed that 60% of the injuries occurred when "players were unaware of the impending contact" (pg. 53). The majority of those players had their heads facing down when struck. As a result of the video analysis, players can be trained to have a higher degree of peripheral awareness while keeping their heads up to limit the number of concussions in football.

Another significant impact video analysis has in the world of sports in on enforcement of rules. In 2013, the British Journal of Sports Medicine published a study analyzing the injuries in Norwegian male professional soccer (Bjørneboe et al., 2013). The study showed that match referees could only identify “47% of all injuries and 40% of head injuries as foul play” (Bjørneboe et al., 2013). Using video analysis, Bjørneboe et al. compiled footage of incidents and injuries and presented them for discussion to re-evaluate the interpretation of certain rules. The end result of the discussions resulted in harsher repercussions for two-foot tackles and tackles with intentional high elbows. In 2017, the professional soccer world introduced VAR, or the video assistant referee. VAR allows for video to be analyzed by a team of professionals while the game is in progress to make sure that calls are being made correctly. For example, if there was a goal scored where it was questionable whether or not the striker was offsides when he scored, VAR can be used while the game is in progress to look at the positioning of the striker at the time of the pass. The head referee would then be notified via headset whether or not the goal should stand.

One of the sports where video analysis in rule enforcement can be seen the most is in American football. Advances in the quality of cameras and the ability to position cameras at different angles has greatly improved the ability of the NFL officials to make the correct calls on controversial plays. First introduced in the 1970’s, instant replay was established to allow referees to stop the play of the game and analyze the footage to review calls such as fumbles, interceptions, touchdowns, ball position, among other calls (Allen, 2010). Now with the use of skycam, the cable suspended cameras, nylon cameras, and numerous other cameras set up strategically around the field, officials can analyze the plays from almost every angle (Allen, 2010). The use of video analysis for rule enforcement can be seen in almost every sport, allowing officials to uphold the rules of the game and more easily prevent injuries.

Anthropometry

Another major area of study within biomechanics is anthropometry. Anthropometry consists of “quantitative measurements of the muscle, bone, and adipose tissue used to assess the composition of the body” (Casadei, 2020). One of the purposes of these measurements is to help determine potential risks to athletes in areas such as excessive body fat, not enough body fat, and low bone mineral density. Anthropometry also helps to give a general idea to coaches and athletes on the trends of the athletes’ body changes. For instance, a coach will be able to see the fluctuation in muscle mass surrounding an injury, and this will help him/her decide how to program resistance training for that athlete’s recovery process. In regard to nutrition, a coach or trainer can analyze fat-free mass and fat mass to determine the nutrients needed and a recommended energy expenditure (Moon, 2013).

A few of the basic pieces of technology in anthropometry are weight scales, stadiometers, and measuring tape. For each sport and positions in that sport, there are general trends of weight, height, and segmental circumference that correlate to the ideal body type for that position or sport. As a whole, elite runners are usually about 5’7” and weigh 140 pounds (McGinn, 2011). Elite bikers generally have a larger thigh circumference than the average person. Using tools such as weight scales, stadiometers, and measuring tape, coaches can determine how an athlete compares to the general elite body type of their sport in order to get a rough idea about future potential. Another benefit of the weight scale and stadiometers is to get a weight and height to determine the body mass index (BMI) of an athlete. BMI is a calculation done by dividing the weight in kilograms into the height of the athlete in meters squared. The resulting number can be categorized into groups ranging from underweight to class three obesity. While it is a very basic measurement of body composition and can be thrown off by a person who has a large amount of lean mass, BMI can be used for lower level athletes to help determine necessary gain or loss in body fat (Pilis et al., 2019).

While BMI is a very basic form of body composition, there are many pieces of technology in biomechanics that allow coaches and athletes to get a more detailed and accurate measure of body composition. One prominent piece is a bioimpedance device. A bioimpedance device works by sending electrical currents through the body in order to measure various factors such as resistivity and reactance to the current (Moon, 2013). Because of the different composition of fat, muscle, and water, bioimpedance is able to get a fairly accurate picture of the fat mass, fat free mass, and water content in the body.

Bioimpedance is a good option for measuring body composition in sports for several reasons. First off, a bioimpedance device can be purchased for a lot less than other devices designed to measure body composition such as Bod Pods and hydrostatic weighing tanks. While the measurements of both the Bod Pod and a hydrostatic weighing tank might be commonly be considered to be more accurate, the measurements obtained from the bioimpedance should be more than sufficient for most athletes (Schubert et al., 2019). Furthermore, bioimpedance devices come in all styles and sizes, with the smaller devices being handheld and easily portable. This would allow coaches and trainers to utilize bioimpedance during a training session no matter the location, rather than having to bring athletes into a lab for a more sophisticated measurement (Vasold et al., 2019).

Lastly, bioimpedance helps to accurately predict the fluid levels in the body due to the conduction of the electrolytes in bodily water (Moon, 2013). This is incredibly beneficial in sports where body weight is a major factor in either performance, like in gymnastics, or in placement, like in wrestling. In both sports, weight fluctuation is a common occurrence.

Gymnasts want to keep their weight lower in order to be able to perform their routines with ease. Wrestlers will fluctuate their weight in order to fit into a certain weight class during competition. One major area where weight is lost, however, is in water loss. A decrease in water weight is oftentimes not healthy and could lead to dehydration related symptoms. A study published in the Journal of Athletic training examined the fluctuation of weight in collegiate wrestlers a day before, and hour before, and 24 hours after a wrestling match (Ransone, 2014). Results of this study showed there were significant differences in the weight 24 hours and 1 hour prior to the competition compared to the weight 24 hours after the competition (Ransone, 2014). This weight loss was due in large part to water loss which, if prolonged, would lead to dehydration (Ransone, 2014). By utilizing bioimpedance, coaches and trainers can ensure their athletes are losing fat and not just cutting all their water, which could end up being harmful.

Another piece of technology used for anthropometry is the skinfold caliper. Just like bioimpedance, skinfold calipers are used to measure body composition, specifically body fat. The calipers are used to measure the folds of skin and fat at distinct locations on the body. By examining all these locations together, skinfold calipers can give a pretty accurate idea of the amount and percentage of body fat on an individual (Fernandes Filho et al., 2017). With that being said, skinfold calipers are an attractive option for coaches and trainers because of the relative cost and mobility.

In 2012, Jutte et. al. did a study using skinfold calipers to examine whether or not cryotherapy duration for athletes should vary depending on skinfold thickness (Jutte et. al., 2012). Cryotherapy is method used by athletes to recover after exercise or to provide therapy to an injury (Jutte et. al., 2012). The simplest forms of cryotherapy usually involve the “application of a cold pack or ice bag” (Jutte et. al., 2012). The recommended duration of a cryotherapy session varies depending on the source, with sources recommending from 20 up to 45 minutes with other sources not even stating recommended duration (Jutte et. al., 2012). Jutte et. al. wanted to discover whether adipose tissue levels at cryotherapy sites would have an effect on the cryotherapy and therefore warrant a change in time based off those levels (2012). It was concluded that adipose levels did affect the rate at which the cryotherapy was affective (Jutte et. al., 2012). With information like this, coaches and trainers can use skinfold calipers to get a better understanding on how to best facilitate recovery in their athletes.

A more expensive piece of technology that utilizes anthropometry is the hydrostatic weighing tank. Hydrostatic weighing tanks function by comparing an individual's mass in the air compared to his or her mass underwater. Using Archimedes' buoyancy principal, body fat percentage can be estimated due to the fact that fat mass has a higher buoyancy than fat-free mass (Han, Ko, and Cho, 2012). For athletes, hydrostatic weighing is considered to be one of the most accurate measures of body fat if performed correctly (Han, Ko, and Cho, 2012). However, in performing a hydrostatic weighing, the athlete must be comfortable with remaining still underwater for approximately ten seconds after complete exhalation of air. If an athlete was unable to fully exhale before going under the water, inaccurate measurements can occur.

Timing Devices

The next area of biomechanical technology that has application to sports is the timing device. Timing devices can be as simple as a clock or as complex as a radar gun or timing gates. The main purpose of a timing device is to determine the speed or rate at which some movement or event is being done. The most obvious application in sports would be in races; however, timing devices have uses in many sport settings. The first application of timing devices to modern sports occurred in horse races in 1731 in England (Serra, 2018). Timing devices were introduced to human races in 1850 (Serra, 2018). The timing device of the time was a chronometer, which was essentially a clock that could measure to the half second (Serra, 2018). As technology has continued to improve, so has the resolution to which timing devices can measure. An electric chronometer was developed in 1916 with an accuracy of 1/50 of a second. It was this device that was used to time races in the Olympics from 1920 to 1928 (Serra, 2018).

In the mid 1990's, races began to use a barcode system for timing (Serra, 2018). With this system, athletes would be given stickers or paper with a barcode on it that would identify that athlete to a time recorded by a separate person. This separate person would press a button each time an athlete crosses the finish line, and once that athlete scanned their code, they would be linked to the time recorded by that button. This method is still utilized at various levels of sports today, especially in sports such as cross country. The benefit to a barcode timing system is the cost. However, there are potential problems that could arise by using this system. For one, the system requires athletes to stay in order once they cross the line so that the barcode will link with the correct button press (Serra, 2018). Secondly, there is always the potential that an athlete could lose their barcode during the race, resulting in a voided run. Furthermore, the nature of the nature of the barcode system makes it more applicable to longer races where resulting times are more spread out and less frequently come within milliseconds of each other (Serra, 2018). For events such as 40-meter dashes or short swims, a barcode timing system would be impractical.

Another method of timing that is useful in longer distance events is radio-frequency identification. This method is more commonly used for upper-level marathons or biking races. Radio frequency identification functions by using tags or transponders that can transmit data to a collection device by use of radio waves (Perry and Kershner, 2014). The transponders are commonly worn on an athlete's shoe or placed on a bike. As the race progresses, there are antenna stations that will receive data from the transponder that will mark an athlete’s time at that given distance (Perry and Kershner, 2014). The finish line is also set up with an antenna that will record the time as the radio frequency of the transponder crosses. Radio frequency identification is beneficial because it is completely automatic and allows for a more accurate time measurement than a barcode system would. It also allows the times of athletes to be analyzed throughout a race as opposed to just at the end. However, radio frequency identification systems are more expensive and require the setup of antennas along the racecourse, making it a less practical option as a timing device for lower-level events (Perez-Diaz-de-Cerio et al., 2018).

In shorter distance events, where the results could be separated by milliseconds, automatic timing systems are beneficial in reducing human error. There are multiple methods used in timing shorter distance events, and oftentimes they will be used in conjunction to provide the most accurate readings. Some of these methods include high speed digital cameras, electronic touch pads, and infrared beams (Perry and Kershner, 2014). The Olympics uses these three timing devices in various combinations for a majority of their short distance races in order to provide the most accurate readings at the world’s most elite competitions.

For track events such as the 100 or 200-meter dash, the Olympics utilize infrared beams as well as high speed digital cameras. The starting gun is also integrated into the timing system and is used as the trigger that begins the automatic timing system (Perry and Kershner, 2014). In order to provide a level playing field for each athlete, speakers are arranged at equal distance from each athlete which project the gun sound (Perry and Kershner, 2014). This is done in order to prevent any one athlete from hearing the starting signal even ever so slightly before his or her competitors. Once the automatic timing system is triggered, times are recorded as athletes cross the finish line. The finish line is equipped with a laser timing gate. These gates operate by using lasers and sensor placed on either side of the track. As an athlete crosses the finish line, their body will break the infrared beam and a time will be recorded at that exact moment. High speed digital cameras are set up at the finish line which “scan up to 2,000 times a second” (Perry and Kershner, 2014). The cameras are also able to record the time a runner crosses the finish line by sending out an electric signal as a runner’s torso crosses the line (Perry an Kershner, 2014).

Aquatic races in the Olympics are timed in a similar way. However, instead of using infrared beams at the finish, aquatic sports utilize electronic touch pads. These pads are situated on the wall of the pool and record the time as an athlete touches it. In relay events, a teammates’ time will begin as soon as his or her previous teammate touches the electronic touch pad (Perry and Kershner, 2014). Just like in track races, the finish lines are equipped with high-speed digital cameras that can also record time based on when the athlete touches the wall.

Electrogoniometry

Another area of biomechanics in which technology is utilized is electrogoniometry. The purpose if electrogoniometry is to determine the angle of joints as well as range of motion. Before the development of electrogoniometers, goniometers utilized protractors to measure joint angle (Tesio et al., 1995). A tester would hold the goniometer at a joint using certain bony landmarks as reference points and the protractor would allow measurement to be taken along the whole range of motion. While goniometers are still used today, electrogoniometers are more adept at tracking the dynamic movement in sports (Tesio et al., 1995). Electrogoniometry is useful in the sports world due to the fact that range of motion is a great indicator of injury recovery. Furthermore, joint angle has a direct relationship to force output in many sports movements. Electrogoniometry allows for measurement of joints to determine necessary adjustments in stance or equipment in order to optimize performance.

There are various styles of electrogoniometers, but the most common style used is one which replaces the protractor of a goniometer with a potentiator (Titcomb, 2017). The electrogoniometer is placed around a joint so that an arm is attached to either side of the joint with the potentiometer attached to the point of rotation. Throughout movement, the potentiator senses angle changes and converts those changes to voltage output, which is sent to computer or phone (Titcomb, 2017). The computer and phone can interpret the voltage output changes and calculate the changes in joint angle throughout that movement. As discussed above, the ability to determine joint angle without the need for a tester physically moving or reading a protractor allows for more complex movements to be analyzed for athletes.

Just like video analysis can be used to determine joint angle and improve technique, electrogoniometry can also provide the same data without some of the disadvantages that video analysis presents. One major disadvantage of using video analysis for measuring joint angles is that the joint and markers used to measure the angle must be in view of the camera at all times. When performing dynamic athletic movements, it is very possible that those markers can get lost from frame to frame and throw off the accuracy of the measurements (Mercado-Aguirre and Contreras-Ortiz, 2017). Furthermore, video analysis programs such as Dartfish require users to measure individual angles in the desired frame, resulting in a more time-consuming approach to joint angle analysis. The ability to receive data in real time allows athletes and coaches to assess joint angles as the movement is being performed, making it easier to do adjustments as needed (Tesio et al., 1995).

While joint angle analysis occupies a considerably small niche in the world of sports performance, there are examples of electrogoniometry being uses in sports studies. In 2014, Lotfian et. al. examined intra-rater reliability of knee joint angles during a karate stance (Lotfian et. al., 2014). The study also aimed to see if electrogoniometry showed a correlation between knee joint angles through three phases of the stance amongst karate elites (Lotfian et. al., 2014). What Lotfian et. al. discovered is that electrogoniometry data showed acceptable reliability as well as a fair correlation of knee joint angles between the elites throughout each phase (2014). These results support the conclusion that certain joint angles create the optimal athletic movements, making electrogoniometers beneficial in giving athletes and coaches a quantitative approach to perfecting technique.

Another study utilizing electrogoniometry was done in 2012, where Harbili examined the kinematics of elite weightlifters during the snatch lift (Harbili, 2012). Harbili compared nine men and nine women to determine the efficiency of work across genders (2012). Using electrogoniometry, Harbili observed a greater maximal knee and ankle extension during the first pull of the snatch, as well as an average of 12 degrees of knee flexion during the transition phase for men compared to the 7 degrees of knee flexion for women (2012). These variations on kinematics assisted in a greater relative mechanical work output for men as well as more efficiency in the lift (Harbili, 2012). In elite sports, where every extra bit could mean the difference between winning and losing, electrogoniometers and joint angle analysis can provide a way to tweak stances and movements to optimize performance.

In addition to being useful for technique and performance improvement, electrogoniometry is also beneficial in injury recovery. With injury being commonplace in athletics, one of the main concerns with trainers is how to get athletes back into competition quickly and safely. For many injuries, range of motion is an impairment that is preventing return to play. In 2014, the International Journal of Sports Physical Therapy laid out a protocol for a five-phase rehabilitation for athletic pubalgia, or groin injury (Ellsworth et. al., 2014).

Throughout each phase, certain criteria need to be met in order for the athlete to proceed to the next phase. One of the main criteria is range of motion. For example, an athlete would need to achieve "full to functional range of motion for lumbar spine and increase hip ROM" in order to begin phase three (Ellsworth et. al., 2014). Joint angles and range of motion for recovery can be estimated visually by trainers, but electrogoniometers provide more validity.

Electromyography

Electromyography is the area of biomechanics that examines the electrical signal from the muscles through the use of electrodes (Clarys, 2000). Electromyography dates back to the 1770's, when researchers realized that an electric current could produce contraction in animal muscle tissue (Kazamel and Warren, 2017). This finding led scientists of the time to conclude that muscles and nerves could produce electricity, or action potentials, to stimulate contraction in living animals (Kazamel and Warren, 2017). In 1929, the first needle electrode was used to measure the action potential of a single motor unit (Kazamel and Warren, 2017). By the end of World War II, the technology was being used to examine action potentials of the muscles of wounded soldiers (Kazamel and Warren, 2017). As surface electrodes began to emerge on the scene, R.C. Davis created the first atlas for surface electrode placement on the body in 1952 (Cram, 2003). Today, there are two major categories of electrodes used in for electromyography: inserted and surface.

Inserted electrodes are broken up into two types: needle electrodes and fine wire electrodes. One major advantage that inserted electrodes have over surface electrodes is the fact that inserted electrodes directly contact the muscle that is being examined. Needle electrodes are used for more clinical procedures, given the fact that they have a much greater signal detection ability compared to both fine wire and surface electrodes (Jamal, 2012). However, needle electrodes require a larger needle diameter than fine wire electrodes, making them more painful and invasive. Fine wire electrodes, on the other hand, can be more easily inserted and withdrawn from a muscle making it a better option over needle electrodes for most non-clinical electromyography studies (Jamal, 2012).

Surface electrodes are less accurate than inserted electrodes but are much less invasive. Since they are attached to the outside of the skin, they are much more applicable in dynamic movement situations. For subjects with an aversion to needles, surface electrodes offer a good solution. However, due to the fact that they are placed on the outside of the skin, surface electrodes would mostly only examine superficial muscles (Jamal, 2012). Furthermore, it is much harder to isolate the action potential for a single muscle due crosstalk from other muscles (Jamal, 2012). Still, surface electrodes would be the most common electrode used in sport electromyography.

One of the areas related to athletics that electromyography can play a big role in is sports research. Kinesiological electromyography is the form of electromyography within sports research that examines fatigue, optimal training methods, the influence of equipment on muscle activity, and even sports rehabilitation (Clarys, 2000). While it is directly related to sports, kinesiological electromyography would most likely be used in research in a lab setting, with researchers seeking to optimize the performance of athletes. For certain areas of kinesiological electromyography, it is possible that an athlete could never be exposed to electromyography, but still benefit from the results of previous research.

Muscle fatigue is inevitable for athletes during training. Without the fatigue and stress on muscle fibers, the body could not push boundaries for improvement. However, muscular fatigue also leaves the athlete in a more vulnerable state, with less ability to protect against injuries such as sprains and strains. A major dilemma for coaches, trainers, and athletes is knowing hard the body can be pushed before serious damage happens. In 2019, Liu et. al. did a study on the use of electromyography to monitor muscle fatigue during exercise (Liu et. al., 2019). The team developed a system utilizing both surface electrodes and a BLE module, which was a signaling device that vibrated when the electrodes detected a certain level of muscular fatigue. (Liu et. al., 2019). The electrodes transmitted the amplitude of electrical activity in the muscles to a computer, which converted the amplitude to number of muscular contractions. These contractions were then used as a standard to measure muscular fatigue (Liu et. al., 2019). Results showed that the system was accurate in monitoring fatigue levels during exercise (Liu et. al., 2019). This technology is incredibly beneficial to athletes in all sports, but most specifically in steady-state sports such as long distance running or cycling. Athletes can wear the system during training and tune the settings to signal when muscle contraction output decreases to a certain level of fatigue. Signaling from the BLE module would give a good indicator of when the training session should come to an end to help prevent any injuries from occurring.

In addition to monitoring fatigue, electromyography can also be used to analyze optimal training methods. In order to develop the highest level of performance, an athlete wants to train efficiently and effectively. One aspect to optimal training is ensuring that the methods and exercises used are the most beneficial for the muscle or muscle groups being targeted. Electromyography provides a way to objectively rank certain variations of an exercise over another in regard to muscular activation. For example, Youdas et. al. published an article for the Journal of Strength and Conditioning Research in 2010 examining the electromyographic data of various pushup methods (Youdas et. al., 2010). One of the methods analyzed was the Perfect Pushup^{TM}, which utilizes hand grips as opposed to conventional hand placement on the floor.

The Perfect Pushup^{TM} manufacturers claim that their method enhances "muscular recruitment when compared with the conventional hand-on-floor push-up exercise" (Youdas et. al., 2010, pg. 3356). Using surface electrodes, Youdas et. al. compared muscle activation of the triceps brachii, pectoralis major, serratus anterior, and posterior deltoid for both the conventional pushup and the Perfect Pushup^{TM} through three different hand widths: shoulder width, wide base, and short base (Youdas et. al., 2010).

The results of the study showed no significant difference between muscle activation for the conventional pushups compared to the Perfect Pushup^{TM} (Youdas et. al., 2010). However, electromyographic data did show a greater activation of the triceps brachii and posterior deltoid muscles during a narrow base pushup (Youdas et. al., 2010). Similar studies have analyzed other exercise variations, such as the front squat and back squat, to get a better understanding of muscular activity. Research and electromyographic data show that the front squat elicits a greater response from the vastus medialis during the ascending phase, while the semitendinosus activity is greater in the back squat (Yavuz et. al., 2015). This information supports the conclusion that front squats are more beneficial for knee extensor development (Yavuz et. al., 2015). Electromyography can be used to compare essentially any exercise variation as well as different exercises to compare muscle activation. For trainers and coaches, examining previous studies or even conducting electromyography research independently makes it possible to optimize training to target the desired muscle or muscle groups.

Along with detecting muscle activation during training, electromyography also is used to analyze muscular dysfunction for sports rehabilitation. In instances of acute injury or chronic problems in athletes, it is important to discover which muscles are having trouble firing compared to a healthy individual. In the case of low back pain, chronic problems could come as the result of weakness in any of the many muscles in back, abdomen, or hip (Shenoy, 2010). Electromyography gives therapists and trainers the ability to examine each muscle group individually throughout various ranges of motion and discover deficiencies that might otherwise go unnoticed. Discovering inappropriate muscle activation patterns makes it possible for spot-specific therapy to be implemented in order to help athletes recover from all sorts of problems (Shenoy, 2010).

Dynamometry

Another area of biomechanical technology that has similar points of impact on sports is dynamometry. Dynamometers come in many different forms and with different functions, but the main purpose of dynamometry is to assess force, torque, pressure, and power (Mafi et. al., 2012, pg. 95). Similar to electromyography, the main uses of dynamometry in sports are in research and rehabilitation. However, dynamometry encompasses a wider range of tools than electromyography possesses.

One of the very first dynamometers was developed by George Graham and John Desaguliers in 1763 as a means to measure muscular force on humans (Pearn, 1978). Before the introduction of dynamometry, the primary way to test muscular strength was through the lifting or moving of standardized weights (Pearn, 1978). The main problem with using this method as a means to test muscular strength is that it is nearly impossible to isolate the force produced by just one muscle when multiple muscles will fire during lifting efforts. During lifts, the prime mover is supported by synergists that assist in moving the load, making it hard to claim. that the prime mover is responsible for all of the weight. The Graham-Desaguliers dynamometer was able to examine maximum static force of the upper arm and separate out the force produced by the biceps and the force produces by the brachialis (Pearn, 1978). Graham and Desaguliers laid the groundwork for the development of technology that can more accurately test muscular strength and power than standardized weights.

One of the most common dynamometers used today is the handgrip dynamometer. The first handgrip dynamometer as developed by Edme Regnier in the late 18th century (Pearn, 1978). The basic design of the handgrip dynamometer was a “sprung-steel bar” which, when distorted would cause a pointer to move to the correct force value (pg. 133). The Regnier dynamometer was able to utilize various attachments that allowed for the testing of hand grip strength a thigh strength (Pearn, 1978). In one of his more well-known experiments, Edme Regnier used his dynamometer to assess the effects of electricity on the grip strength of paralyzed women.

Today, the handgrip dynamometer is useful for sports in both rehabilitation and research settings. Some still operate through the use of springs, similar to Regniers design, but most are either digitized or function with hydraulics. They are easy to use and can be relatively cheap depending on the desired level of accuracy. Just like with electromyography, handgrip dynamometers are useful in analyzing injuries and developing rehabilitation for athletes. Within rehabilitation, objective data is useful in diagnosing and treatment. For athletes with hand and arm muscular injuries or neurological impairments, it is not beneficial to simply know that he or she is weaker in one hand than the other. The handgrip dynamometer can give a specific value to the force of the grip, decreasing the chances of misdiagnosis and giving a distinct goal for treatment (Mafi et. al., 2012). Clinicians can contrast grip strength between an injured arm and non-injured arm or compare results to normal values in order to establish what the goal of treatment should be.

Handgrip dynamometers are also used in prediction of sport performance, with grip strength tests being used commonly across multiple sports (Cronin et. al., 2017). One of the sports where grip strength is a primary contributor to performance is in climbing. During climbing, the hands and fingers are required to support a large percentage of the athlete's weight at various times. Research has been conducted on conventional maximal handgrip strength using a handgrip dynamometer and handgrip strength endurance, with results showing a very large correlation between the two in elite climbers (Cronin et. al., 2017). Another sport where grip strength is highly important is in gymnastic events such as the high bar, parallel bars, and still rings. Through the use of handgrip dynamometers, gymnasts can be analyzed for grip strength weakness or competency for events such as these.

Other sports where hand grip strength has shown to be a predictor of performance are court sports, such as tennis, handball, and volleyball. In all of these sports, serving and throwing velocity is an important aspect of the game. Research into court sports reveals as moderate to very large correlation between hand grip strength and velocity of serves or throws (Cronin et. al., 2017). Player ability and ranking in court sports also appears to be strongly associated with factors such as jumping ability, motor coordination, sprint acceleration, and hand grip strength (Cronin et. al., 2017). While handgrip dynamometers are some of the most common, dynamometers can be used to assess force of contraction in almost any muscle, allowing for similar benefits in sports performance and rehabilitation as seen with the handgrip dynamometer.

Another major form of dynamometry is the force plate. Rather than analyze muscular forces, force plates examine the interaction between the ground and an athlete, or the ground reaction force (Beckham et. al., 2014). Force plates are most commonly used in lab settings due to their cost and fixed positioning, but they are useful because most force plates are able to measure the ground reaction force in the vertical, medial-lateral, and anterior-posterior planes (Beckham et. al., 2014). Previous research has shown the relationship between ground reaction force and athletic functions such as, agility, sprint performance, and maximum back squats (Beckham et. al., 2014).

Understanding how the athletes interact with the ground through ground reaction force provides insight that other testing methods cannot. For example, force plates can be used to measure vertical jump height just like a standard vertical jump stand. However, total height does not display all of the data that is important for coaches and athletes. Unlike standard vertical jump stands, force plates can also measure the peak force of a jump, as well as impulse and rate of force development (Beckham et. al., 2014). All of these factors can change across multiple jumps even if the total height remains the same (Beckham et. al., 2014). For coaches and trainers, peak force and rate of force development are arguably more important to know, because an athlete could be missing their vertical jump potential due to other factors such as poor technique. Similarly, force plates give information on sprinting that is missed when coaches use sprint times as method of testing. While one athlete has a faster time, another athlete might have a higher potential displayed by a greater peak force and rate of force development. Force plates are a highly beneficial area of dynamometry in evaluating sports performance and the needs for technique improvement.

Inertial Tracking Systems

The seventh major category of biomechanical technology is inertial tracking systems. The main purpose of inertial is the determination of positioning and velocity of the body within space (Lebel et. al., 2013). Just like a force plate can track ground reaction force in three planes of motion, inertial tracking can determine orientation and velocity across three planes and within a global coordinate system (Lebel et. al., 2013). This is done through the use of several tools: mainly the gyroscope, which tracks position, and the accelerometer, which tracks velocity. The combined technology is relatively small, and inertial tracking modules can be attached to the body similarly to electrogoniometers. The modules transmit data from the gyroscope and accelerometer to a collection point, giving quantifiable data for the movement and position of the attachment site (Lebel et. al., 2013). This data can then be converted into 3-D imaging, giving a simulated appearance of that data on a computer. For instance, an athlete could place a module on the upper arm and the forearm and receive data on the kinematics of the elbow joint.

Before the introduction of inertial tracking, positioning and motion of the body in space were analyzed through video capture as discussed above. However, there are situations in sports that make the use of inertial tracking preferred over 2-D or 3-D video analysis. First off, 2-D video analysis cannot obtain the same data on velocity and global position as the other two methods can. Without additional tools such as video analysis software, 2-D video capture is beneficial for mostly qualitative information. In comparing 3-D video analysis to inertial tracking, inertial tracking has the major benefit of having less operational constraints such as camera setup and locational fixity (Lebel et. al., 2013). For the most accurate measurements, 3-D visual analysis requires sensors on the body that can be picked up by multiple cameras at various angles. The setup for this is normally in a room with fixed cameras all around the desired area to ensure that the sensor can be picked up at all times through all ranges of motion in dynamic movement. With set cameras, it is difficult to analyze exercises that require movement outside of the fixed setup. 3-D visual analysis requires the functioning pieces of technology, i.e. the cameras, to be unattached to the athlete. In contrast, the major functioning technology of inertial tracking systems, the gyroscope and the accelerometer, are attached directly to the athlete, allowing more freedom in location.

Inertial tracking is mostly utilized in sports research and analysis of athletes. With its ability to measure kinematics of the body, the technology can be utilized to analyze any type of movement, from ski jumps, to gait patterns, and even sports equipment with implanted modules. In 2015, van der Slikke et. al. used inertial tracking modules to examine the kinematics of wheelchairs in wheelchair basketball match settings (van der Slikke et. al., 2015). Within the sport, linear and rotational accelerations play a large role in the overall performance of the athlete (van der Slikke et. al., 2015). Through the use of an inertial tracking system, van der Slikke et. al. were able to analyze both accelerations across numerous different movement patterns to better understand the kinematics in match settings (2015).

In sports where equipment such as balls or rackets are used, inertial tracking modules are beneficial in studying the acceleration of that equipment. In 2020, Worsey et. al. used a special soccer ball with implanted inertial tracking technology to study the impact of the ball on the head (Worsey et. al., 2020). Also using electromyography, Worsey et. al. were able to study the acceleration of the ball into the head as well as the muscular responses of the body to the impact (2020). The study revealed differences in abilities of novice players compared to elite players in reacting to accepting the force of the ball to the head, contributing to a higher chance of novice players sustaining head injuries as a result of ball to head contact (Worsey et. al., 2020). The range of information that inertial tracking can provide is extensive and applicable to essentially every movement within sports.

Modeling and Simulation

The final area of study for technology in biomechanics is modeling and simulation. In essence, modeling deals with the construction, whether virtually or physically, of something that is an imitation of something else. Models can be made for anything, with common models being made of the human body, various limbs or joints, equipment, and vehicles. Simulation deals with the exposure of models to various scenarios or stressors to understand how they function or react. Modeling and simulation are used across numerous industries, including sports equipment development and sports research.

One common use of modeling and simulation within the sporting world is the utilization of crash test dummies to determine the safety of vehicles for vehicular sports such as NASCAR and Formula 1. Crash test dummies are models of the human body that employ sensors that can record the forces acting on certain parts of the body. The first crash test dummy was developed and used in 1949 for simulation for the air force (Xu et. al., 2018). As technology has advanced, crash test dummies have grown in reliability and usefulness. Dummies are generally categorized into three different purposes: testing frontal impact, side impact, or rear impact (Xu et. al., 2018). The difference in functions makes it possible to study the safety of a vehicle during a collision from impact in any direction. For motorsports, where high speeds and impact are common, crash test dummies help provide the necessary research into optimizing vehicle design to prevent extreme forces during collisions.

With improved technology, virtual modeling and simulation can also be used in research to enhance safety. In 2020, Decker et. al. used virtual simulation to examine injury risk and mechanical loading values of an average male with NASCAR safety features such as a “helmet, 7-point safter belt system, head and neck restraint, poured-foam seat, steering wheel, and leg enclosure" (Decker et. al., 2020). In the study, forty-five different impacts were applied to the model, and the probability of injury to each region of the body was calculated (Decker et. al., 2020). Through the simulation, Decker et. al. were able to defend the uses of the numerous safety features of a NASCAR vehicle because of their ability to keep injury risk relatively low (Decker et. al., 2020). Outside of motorsports, modeling and simulation can be used in the production protective equipment such as helmets and pads to understand ability to withstand forces and mechanical loads. Furthermore, modeling and simulation can be used in the production of sports equipment such as bats and rackets to optimize performance and weight.

Besides enhancing sports equipment production and testing, modeling and simulation assists in research into how the body moves and how to optimize that movement. In 2007, at team of researchers developed a simulation of a human body to determine the optimal coordination to maximize vertical and horizontal jump distance (Nagano, Komura, and Fukashiro, 2007). The simulation was made up of nine body segments along with thirty-two attached lower limb muscles (Nagano, Komura, and Fukashiro, 2007). The results of the simulation showed a greater importance of the center of mass location during the vertical jump (directly above the feet) compared to the horizontal jump (Nagano, Komura, and Fukashiro, 2007). Furthermore, results displayed a higher need to utilize the hip joint throughout a horizontal jump (Nagano, Komura, and Fukashiro, 2007).

Modeling and simulation are also useful in running analysis. The British Journal of Sports Medicine recently published a study examining running-related injury development over time through the use of simulation (Hulme et. al., 2019). In order to investigate the injury development, Hulme et. al. used a model that underwent weekly running distance increases based off the accepted acute: chronic workload ratio (2019). Results showed that, despite adhering to the recommended increases in weekly distance, the human body will eventually hit an individual’s physical workload limit, resulting in a running-related injury (Hulme et. al., 2019). Through modeling simulation, it is possible to examine many other conditions or movements to optimize performance and injury prevention.

Conclusions

Biomechanics is a broad topic that encompasses many different technological applications. Its affect on sports can be seen in almost every element of athletics, including injury prevention, technique improvement, rule enforcement, performance optimization, overall health and condition analysis, sports timing, and product development and testing. Through the use of artificial optical device technology such as 2-D visual analysis, athletes and coaches can help improve technique, and prevent injuries. Artificial optical devices also assist in rule enforcement for sports. Technology in anthropometry is beneficial in determining overall health in individuals as well as body comparison to ideal athletes of each sport. Timing device technology continues to improve, increasing the ability to more accurately measure sporting event times.

Electrogoniometry has an impact on technique improvement as well as assisting in the rehabilitation process of athletes. Electromyography has numerous applications for sports, ranging from general research, to fatigue analysis, to sports rehabilitation, to performance optimization. Dynamometry presents a wide variety of technology that has different application in sports. The hand grip dynamometer helps with predicting performance and minimizing error within rehabilitation. The force plate provides value through technique improvement and understanding how the body interacts with the ground. Inertial tracking systems make it easier for athletes and coaches to understand the kinematics of the body or sports equipment, as well as understanding mechanisms of injury. Lastly, modeling and simulation make sports equipment development and testing much simpler and safer. Furthermore, modeling and simulation help coaches and athletes how the body functions over long periods of time without the need for that much time to actually pass.

Biomechanical technology will continue to improve just as general technology does, making all of these areas more efficient and possibly even opening up new areas of technological advancement. In the meantime, coaches and athletes alike can benefit from the utilization of current technology in ways they had not previously realized. The purpose of technology is to make life easier, faster, and more efficient, and the same is true for sports through the implementation of biomechanics.

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