COMPARISON OF BIOMECHANICAL ASPECTS OF PERFORMANCE IN MALE AND FEMALE ATHLETES

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INTRODUCTION

It is generally believed that the technique of skilled male and female athletes is identical; that elite females will perform a skill almost exactly the same as elite males. If skilled athletes have uniform technique in a particular sports skill, over time top athletes will develop similar technique, regardless of their sex. The question regarding whether skilled male and female athletes have similar technique has not yet been answered conclusively.

There are undoubtedly some major physiologic differences between men and women which will could produce differences in technique. Such physiologic differences include upper and lower extremity strength, muscle endurance, muscle recruitment order, muscle reaction time and joint laxity (Huston & Wojtys, 1996). There are also differences in the type and frequency of injuries to male and female performers in similar sports, which may be related to structural or biomechanical factors of these athletes. Finally, there are some skills in which female performances are approaching those of their male counterparts,and reasons for this closing gap are of some interest. The purpose of this report is to examine the extent of the biomechanical differences in technique, injury mechanics and performance between genders.

Structural Characteristics of Female Athletes

Structural differences among women and men often have led to generalized incorrect statements. Females may have some unique structural factors such as: wider pelvis, shorter legs, more oblique femurs, larger ratio of leg weight to body weight, greater fat deposition on the thigh, and greater carrying angle of the arm (Wells, 1991) which may affect technique. If there are differences in technique based on sex-related structural factors, then these technique differences need to be emphasized by coaches and teachers of sport skills.

During childhood and adolescence, the rate of growth of the hips increases by about the same amount in both males and females, whereas the shoulders and throacic cage grow more rapidly in males. Therefore, although hip width ends up about the same in both sexes, men tend to have wider shoulders in relation to their hips, and women have wider hips compared to their shoulders (Atwater, 1990). Absolute pelvic width is very similar in both sexes; Atwater (1990) reported mean values for bicristal breadth of 28 cm for both sexes, with a slight decrease to 27 cm for elite track and field athletes. When pelvic width is expressed relative to height (BC/Ht), the ratio is somewhat larger in females because the females are not as tall. The ratio of pelvic width to shoulder width (BC/BA) is higher in mature females than it is in males because the male's shoulders are broader (Atwater, 1990). The misconception that absolute pelvic width is greater in females than in males is prevalent in the literature dealing with comparisons between athletes of both sexes; Atwater (1990) reported over 20 references which described the "wider female pelvis".

Pelvic size and width vary greatly between each sex and between the sexes, with the exception of the wider dimensions of the true pelvis in women for childbirth. The wider female pelvis relative to leg length produces varus at the hips (femoral angle usually <125 deg) and frequently is associated with increased anteversion of the femoral head and increased valgus of the knee accompanied by increased Q angle (Arendt, 1994).

The greater valgus angle of the thigh of the average female is known as genu valgum, and is seen in females who have a wider than average pelvis and shorter than average legs. Although some females may have greater valgus angles of the thigh, this is uncommon among female athletes. Generalizations that females as a group are inferior to males in running events due to their wider pelvis and greater femoral obliquity have often been stated with no scientific proof (Atwater, 1990).

Females have also been described as having an increased carrying angle of the forearm, as a consequence of having wider hips. However, an anthropometric study found no significant differences in the carrying angle of the forearm between the sexes in any age group (Beals, 1976). The effects of carrying angle on throwing mechanics are unclear; the increased valgus position of the elbow may increase the range from elbow flexion to elbow extension, and increase elbow extension range of motion.

Women were found to have shorter limbs relative to their body length, and narrower shoulders (Arendt, 1994). In the upper limb, women have shorter upper arms compared to their forearms, opposite to that of men. This may alter the mechanical advantage of both the upper and lower arm segments for women as compared to men. Shorter limb segments would decrease the potential velocity at the end of a series of segments; but would decrease the torque necessary to produce any given angular velocity of the segments due to the decreased moment of inertia. Since mechanical advantage is the ratio of the resistance arm to the force arm of the limb segment, it is also affected by the insertion points of the muscles from the joint axes.

It is often noted that the mean height of the center of gravity of a woman is lower than that of a man, giving females an advantage in balance sports (Francis, 1988). However, this difference has been reported to be about 2% of standing height, or about 1.3 inches for someone 5 feet 9 inches tall which would not be a significant difference in terms of performance in most activities (Atwater, 1988). Activities such as the high jump and long jump in which a higher center of gravity at take off will enhance performance may slightly favour male athletes. However, females who participate in these events normally have a specific body type with a higher average center of gravity. Center of gravity differences are more determined by an individual's height and body type than by gender (Atwater, 1988).

Muscular Strength

On average, the female has about two-thirds the strength of the male; absolute upper body strength is 30-50% that of a male, while that of the lower extremity is 70% that of a male of the same size (Thein & Thein, 1996). Greater muscle mass and chest and shoulder girth in the male accounted for differences in upper body strength, while the shorter relative leg length of the females allowed them to more closely match that of the male in lower extremity strength (Thein & Thein, 1996).

The muscular strength of girls and boys diverges markedly with the onset of puberty; at age 11-12 girls have 90 per cent of boys' strength; by age 15-16 this has decreased to 75% of strength. Muscle fiber and total muscle cross sectional area of women average 60%-85% of these areas in men.

A comparison of peak torques between male and female judoists suggested that knee flexor strength was 30% higher in men than in women; while knee extensor strength was 40% higher in men when compared to women. The flexor-extensor torque ratios and the angles of maximum torque were similar between genders (Wit, Traskoma, Eliasz, Gajewski & Janiak, 1993). A comparison of measured peak torques of elite male and female sprinters (Alexander, 1989). reported that male sprinters had 50% greater hip extension torques and 42% greater hip flexor torques than females. Both knee flexor and knee extensor strength was 50% higher in the male sprinters; while plantafflexor and dorsiflexor strength was 30 greater in the males. The relationships between peak torques and sprinting speed were found to be different for the male and female groups (Alexander, 1989).

Females are also significantly weaker in upper body muscle groups, and in ability to lift a load from the floor. Examination of scores from the Incremental Lifting Machine, and Kin Com elbow flexion and extension torque values, revealed that women were able to lift only 48% of the load lifted by men (Stevenson, Greenhorn, Andrew, Thomson & Bryant, 1988). The Kin Com back strength comparisons indicated that strength values for females were 60% of those attained by males. Analysis of the data suggested there were sex differences in lifting technique which accounted for the differences in performance, beyond those differences found in elbow strength (Stevenson et al., 1988).

There is often an imbalance between the hamstrings and quadriceps in females; and men tend to have relatively stronger quadriceps muscles. Stability of the knee has been stated to be more muscle dominant in men, and more ligament dominant in women (Moeller & Lamb, 1997). For female athletes, the quadriceps is the dominant muscle group contributing to knee joint stability, while the hamstring dominates in male athletes (Huston & Wojtys, 1996).

Flexibility

It is generally agreed that females are more flexible than males in most joints (Entyre & Lee, 1988; Grana & Moretz, 1978; Gray, Taunton & McKenzie, 1985). In a recent study comparing male and female volleyball players, it was found that the female players had greater hip and shoulder flexibility than their male counterparts (Lee, Entyre, Poindexter, Sokol & Toon, 1989). As well, greater vertical jump was correlated with increased hip range of motion for the men, but not for the women. For the women, there was a negative correlation between hip range of motion and height jumped; suggesting that the players with the greatest vertical jump had the least hip flexibility. No explanation was given for this finding, but it was suggested that flexibility differences may be related to anatomical differences of the hip joint between the sexes and that increased flexibility of the hip joint was more beneficial for the men (Lee et al., 1989).

Physiological Variables

Differences in skeletal muscle characteristics, metabolic profiles and functional performance between males and females were investigated using young (15-24 years) male and female twins as subjects (Komi & Karlsson, 1978). It was concluded the performance of females was from 61% to 84 % of that of males. Females had a greater distribution of slow twitch fibres (49 vs 55 %); less activity in glycolytic enzymes; and greater activity in fat oxidizing enzymes. A notable difference between the two groups was an almost 100% longer rise time of isometric force in females. When compared to females, the males demonstrated higher aerobic and strength performance capacity, more efficient neuromotor output during contraction, more slow twitch muscle fibres and more active glycolytic enzymes (Komi & Karlsson, 1978).

An examination of electromechanical response times and muscle elasticity in men and women concluded that there are sex linked differences in musculotendinous elasticity which may account for observed performance differences (Winter & Brookes, 1991). Electromechanical delay was found to be significantly longer in female subjects (39 vs 45 msec), which was attributed to increased muscle elasticity in women. This elasticity could reside in series and parallel components in muscle or tendon, or in cross bridge attachments. This finding partially explains some performance differences between males and females in some activities (Winter & Brookes, 1991).

Highly trained male and female athletes often have similar physiological profiles. A study of performance-matched male and female marathon runners had approximately the same **V02** max (about 60 ml.kg.min-1) (Helgerud, Ingjer & Stromme, 1990). For both sexes the anaerobic threshold was reached at an exercise intensity of about 83% of **V02** max, or 88%-90% of maximal heart rate. The females' running economy was poorer, ie. their oxygen uptake during running at a standard submaximal speed was higher ($p<.05$). The heart rate, respiratory exchange ratio and blood lactate concentration also confirmed that a given running speed resulted in a higher physiological strain for the females (Helgerud et al., 1990).

Injury Rates

Women's sports, once dominated by a slow defensive style, are now played with speed, precision and power. But with these changes have come increased injuries, and female athletes have higher injury rates than men in many sports, particularly alpine skiing, volleyball and apparatus gymnastics (Moeller & Lamb, 1997).

An early survey of collegiate female athletes reported that injuries sustained by female athletes were essentially no different than those of men, and that well trained women athletes are not more prone to injuries than men (Haycock & Gillette, 1976). More recent studies have reported that females sustain a higher incidence of injuries in most sports played by members of both sexes. In a comparison of injuries on professional male and female basketball teams, the women's injury frequency was 1.6 times that of men (Zelisko, Noble & Porter, 1982). Women sustained significantly more knee and thigh injuries, as well as sprains, strains and contusions; but no increased patellofemoral injuries. Although females have greater flexibility, they suffered significantly more strains than the males, and well as a higher proportion of contusions, possibly due to greater capillary fragility (Zelisko et al., 1982). Women soccer players were found to have a higher incidence of ankle sprains than male players, due to hormonal differences affecting ligaments, premenstrual discomfort giving poor coordination, or lack of injury preventative information (Brynhildsen, Ekstrand, Jeppsson & Tropp, 1990). In a study of the 1987 National Volleyball tournament, females had an injury rate of 2.31100 hours of play, while males had an injury rate of 1.71100 hours of play (Schafle, Requa, Patton & Garrick, 1990).

In most team sports, the knee is the most common site of injury in all athletes (Gray et al., 1985; Henry, Lareau & Neigut, 1982). Jumper's knee, or acute tendinitis of the patellar tendon which occurs in athletes in jumping sports, is common in volleyball players of both sexes with no significant difference between the sexes (Ferretti, 1986). Serious knee ligament injuries in volleyball are more common in female volleyball players than in males (80 versus 20% respectively) (Ferretti, Papandrea & Conteduca, 1990). Knee injuries in basketball were found to occur more frequently in women than in men, constituting 16% of all injuries compared with 12% of the men's (Molnar & Fox, 1993).

There has been found to be a higher ACL injury rate for females than for males (Arendt, 1994; Moeller & Lamb, 1997), the exact causes of which are presently unclear. An article on this topic in Sports Illustrated magazine (McCallum, 1995) has suggested "The game of basketball has, in some respects, surpassed the physical ability of women to withstand it. —the increase in ACL tears can be attributed to the increased speed and aggressiveness of play by the women having gone beyond the ability of ligaments to withstand the stress."

The National Collegiate Athletic Association (NCAA) in the United States has been compiling injury data since 1982 and reported the rates of female ACL injuries (Arendt & Dick, 1995). The NCAA data show that female basketball and soccer players have higher rates of knee injuries, especially ACL injuries, than males. The injury rate for female soccer players was over two times higher than for the men (0.31 vs 0.13 occurrences per 1000 athlete exposures). The incidence of ACL injuries was even higher in basketball, where women were four times as likely to sustain injury as were men (0.29 vs. 0.07) (Arendt & Dick, 1995). During the 1989 to 1990 intercollegiate basketball season, the NCAA reported that female athletes injured their ACLs at a rate 7.8 times more than their male counterparts (Huston & Wojtys, 1996). Female volleyball players also experience a high number (26) of ACL injuries in NCAA competition especially in game situations in the latter part of the season. In a series of 52 serious knee injuries in volleyball, 80% of the injuries were sustained by females (Ferretti, Papandrea, Conteduca & Mariani, 1992). Most injuries (64%) occurred when jumping or landing from a jump, and all were non contact injuries (Ferretti et al., 1992; Moeller & Lamb, 1997).

Factors in ACL Injuries

Female athletes may have a higher incidence of ACL injuries due to a lower level of conditioning than males (Hutchinson & Ireland, 1995). However, ACL injuries also occur in subjects with a high degree of fitness and skill, so the possibility of a lack of fitness or experience may not be an important factor (Gray et al., 1985).

This higher injury rate may be due to intrinsic factors, such as ligament size, inherent ligament laxity, notch dimensions, muscular strength and coordination, and limb alignment, as well as extrinsic factors such as level of skill, level of experience, shoes, floor and shoe floor interface (Arendt, 1994). Q-angle has been suggested as a factor in ACL injuries, but there is no apparent relationship between Q-angle and ACL injury (Gray et al., 1985). Compared with the male, the female knee and ACL tends to be smaller, implying there is less tissue to restrain anterior and displacement forces (Hutchinson & Ireland, 1995). Joint laxity has also been implicated in the difference in the rate of ACL tears and other knee injuries, again with conflicting results regarding whether lax ligaments or tight ligaments are the greater risk factor for injuries. There is some question regarding the effect of increased flexibility on injury rates, some studies have reported higher incidence of injuries with increased ligament laxity. Professional football players with loose knee ligaments were found to sustain knee injuries more often than those with tight ligaments (Nicholas, 1970).

The majority of ACL injuries occur during non contact situations, including planting and cutting, straight knee landing, and one-step stop landing with the knee hyperextended (Arendt & Dick, 1995). The higher risk of ACL injuries in women is likely multifactorial with no single structural, anatomical or biomechanical feature solely responsible for this increased rate.

Gender and Landing Forces

Landing from a jump has been reported to be one of the most common mechanisms of injury to female basketball players, as Gray (1985) reported that fourteen of twenty four ACL ruptures (58%) occurred when landing. Over 60% of volleyball knee joint injuries were reported to have occurred during the landing phase, and the mechanism of jumping, landing, and twisting upon impact with the ground or floor was associated with 61% of all knee injuries and 92% of ankle injuries in volleyball (Gerberich, Luhmann, Finke, Priest & Beard, 1987).

A recent study (James, 1997) examined the effects of gender on lower extremity landing forces in a group of male and female subjects. The subjects performed 10 landings from three heights: 50, 100 and 200% of maximum vertical jump (MVJ) height. Force platform and high speed video data were collected and were used to compute ankle and knee joint moments, tibial compressive forces, and knee joint shear forces. Gender differences were found for the ankle joint moment and knee joint shear forces, with the greatest differences occurring at 200% of MVJ height. The females exhibited greater knee joint shear forces than the males in the sample; and lesser ankle joint moments than the males. The results suggest that females may experience different joint force magnitudes than their male counterparts, possibly indicating a mechanism by which females may be more susceptible to certain types of knee injuries, especially ACL injuries (James, 1997). Higher joint forces coupled with increased joint laxity and weaker quadriceps musculature (Gray et al., 1985) may be critical factors in knee ligament injuries.

Gender and Skill Performance

Throwing

It is well known that boys can throw further and more skillfully than girls at all ages; due to both environmental and biological factors (Thomas, Michael & Gallagher, 1994). The majority of females do not attain a mature throwing pattern; their immature pattern is characterized by lack of body rotation, shoulder medial rotation and wrist flexion (Armour & Elliott, 1989). These movements are involved in decreasing the rotational inertia of the body and associated limb segments, to increase ball velocity. It has been reported that throwing performance in seventh grade girls was developmentally similar to first grade boys (Halverson, Roberton & Langendorfer, 1982). The distance thrown by girls may be from 60 to 70% of the distance thrown by boys; some of this difference may result from lack of practice because the developmental level of girls' throwing seems to change very little with time (Nelson, Thomas & Nelson, 1991). In a longitudinal descriptive study, Nelson et al. (1991) found that girls continued with block trunk rotation after 3 years (with no specific training), while nearly all boys showed differentiated rotation after the 3 year interval. The timing of the throwing pattern takes longer to develop than throwing form, as Ives et al. (1993) suggested that some gender differences in performance are based on neuromuscular coordination mechanisms.

Throwing distance and throwing velocity were found to differ the most among a group of skills measured between males and females. Differences were 1.5 SD units at 3 years of age and increased dramatically over childhood and adolescence to over 3.5 SD units. Stated another way, at 17 years of age the average male throws further than 99% of the 17 year old females (Thomas & Thomas, 1988).

Differences in throwing technique were also reported in a group of elite male and female water polo players (Armour &Elliott, 1989). The females had a restricted range of trunk rotation in the backswing, restricted range of shoulder lateral rotation in the backswing, and lack of hip and shoulder rotation during the throw. The wrist movement of the female throwers was characterized by wrist flexion throughout the forward swing, while the male subjects were able to initially flex, then extends, and finally flex the wrist again prior to release. The difference in wrist movement may have resulted from inability to grip the ball due to the females' smaller hand span. The trunk of the male players was more tilted with respect to the vertical than the females, which is characteristic of more skilled players. The ball velocities attained by these subjects were 19.9 m/s for the males and 14.7 m/s for the females (Armour & Elliott, 1989).

An interesting question has been raised regarding the development of a mature throwing pattern by males and females (Thomas & Marzke, 1992): are females developing through the same patterns for overhead throwing? Is the mature pattern exhibited by the expert male and female the same? As girls mature, their unskilled throwing pattern is retained, but they throw further due to increased size; Boys seem to throw further because they become larger, and they also improve the mechanics of the throwing motion (Thomas & Marzke, 1992).

The throwing patterns of males and females require more study to determine if gender differences really exist. Some unanswered questions include (Thomas & Marzke, 1992):

- whether expert males and females use the same throwing pattern supported by the same muscle groups
- the developmental patterns of boys and girls as they progress to the

mature pattern whether intense training programs can alter the pattern of female throwing.

Swimming Mechanics

The prepubertal female best approximates her male counterpart in strength, aerobic power, oxygen pulse, heart rate and size. Swimming is an excellent example to use when examining specific physiologic considerations for women in sports. Prepubescent boys and girls have similar winning times for all strokes (Sanborn & Jankowski, 1994), in fact times for girls 8 years old and younger may be even faster than the boys'.

Females swimmers with their shorter arm length and shorter bodies must take more strokes and hence increase the number of shoulder movements to cover the same distance (Arendt, 1994). Most strokes in swimming primarily depend on upper body strength as the main motor through the water, so women may be working their comparatively weaker upper body muscles harder to cover the same distance.

Several investigators have examined swimming mechanics of male and female subjects (Arellano, Brown, Cappaert & Nelson, 1994; Pelayo, Sidney, kherif, Chollet & Tourny, 1996). Elite male swimmers typically swim 10% faster than their female counterparts, and males have longer stroke lengths but stroke rates are similar (Arellano et al., 1994). It has been suggested that the longer stroke length produced by men is likely the result of greater propulsive force; while males and females have similar stroke frequencies. Stroke frequency was reported to be significantly higher for females in the 800m freestyle than for males in the 1500m freestyle (Pelayo et al., 1996).

A study (Arellano et al., 1994) of the swimming events at the 1992 Barcelona Olympics revealed that stroke rates were not significantly different (approximately 1-2%) between sexes at any race distance. The differences in final race time between men and women were 9% for the 50m freestyle, 9.1% for the 100m and 9.3% for the 200m freestyle races. The average race velocity differences were also similar, with differences of 9.1%, 9.1% and 9.3% respectively. Gender comparisons of average starting time, average finishing time, average turning times and average stroke length were also approximately 9%, suggesting that the 9% final time difference can be accounted for in each of the race components examined (Arellano et al., 1994).

Skill techniques

The vast majority of published research describing skilled athletic performance has been based only on the techniques of male athletes. Very few studies have described only the techniques of skilled female throwers (Terauds, 1984) but several studies described skilled male and female throwers, including shot, discus and javelin throwers (Bartlett, 1992; Bartlett & Best, 1988; McCoy, Gregor, Whiting, Rich & Ward, 1984; McCoy, Gregor, Whiting, Rich & Ward, 1985; Rich, Whiting, McCoy, Gregor & Ward, 1985). Those studies which have examined female throwers sometimes suggest that temporal and anthropometric variables related to performance in females are different from those related to male performances (Ballreich, 1983; Schulter, 1983). The extent and implications of these possible differences in performance have not yet been fully examined, nor even acknowledged by most researchers in sport biomechanics. An extensive search of the sport biomechanics literature revealed no specific discussion of male-female differences in biomechanical variables of sports techniques.

Running Performances

In 1972, women were finally allowed to participate in the marathon (42.2 km), and shortly after the ultramarathon (Bam, Noakes, Juritz & Dennis, 1997). Since that time, there have been rapid improvements in women's distance running world records, and it has been suggested that the world class running performances of women may equal those of men by the end of this decade (Whipp & Ward, 1992). For men, the slopes of the velocity-date curves are remarkably similar; while for women, the slopes are also similar but are higher for most running events (Whipp & Ward, 1992). The marathon slope, however, was appreciably greater for the women. Interpolation of these curves into the future suggests that the average velocities for these events will be no different by the first half of the next century — the intersection for the marathon is 1998. A recent study of female ultramarathon runners (Bam et al., 1997) reported that females can maintain a faster race pace at distances over 42 km than males at these distances.

Speechly et al. (1996) have suggested that when comparisons on performances are made between the genders, top female runners are consistently 9-11% slower than their male counterparts over all distances raced. After examination of the average running speeds for a group of male and female runners over distances from 10 to 90 km, the female group ran significantly faster (171 m.min-1 vs 155.2 m/min-1) than the males (Speechly, Taylor & Rogers, 1996). They found that the female athletes were able to exercise at a significantly greater fraction of V02 max than males, possibly due to greater utlilization of FFA as fuel. This was not in agreement with Costill et al. (1987) who suggested that males should have an enhanced level of fatty acid oxidation due to their larger number of mitrochondria to oxidize lipids (Costill, Fink, Flynn & Kirwan, 1987). Other investigators have suggested that females are able to utilize fat to a greater extent (and thus utilize less carbohydrate) than equally trained and nourished males during moderate intensity long duration exercise. They speculated that as a result of a slower rate of muscle glycogen depletion, females should be able to perform better than males in long distance exercise (Tarnopulsky, MacDougall, Atkinson, Tarnopulsky & Sutton, 1990).

When male and female athletes were matched on their performance on a standard marathon (42.2 km) level, males showed a tendency for larger performance decrements with increasing distance, and the females outperformed the males at the 90 km distance (Speechly et al., 1996). The females exercised at higher levels of their V 0 2 max, and these data suggest that females are able to maintain a higher work rate for longer during ultra endurance exercise.

Female distance athletes may have the edge over their male counterparts for some of the following reasons (Tate, 1997):

- Females have greater fat stores, both by having an average of 10% more body fat, but also producing greater utilization of fatty acids as fuel and greater FFA oxidation
- The presence of estrogen, which is lypolytic, acts as an antioxidant, and produces greater resistance to fatigue. The muscles of females are less damaged during running due to the effects of antioxidants and estrogen.
- Estrogen has a powerful effect on red cell metabolism-hexokinase.
- Estrogen facilitates oxygen delivery to the working muscle- females have increased oxygen delivery to the muscle due to estrogen
- the coachability of female athletes compared to males, due to the newness of the sport for females and to their psychology; suggesting they are more coachable.
- Less damage has been reported in female muscles with eccentric exercise due to the presence of estrogen; when male rats were injected with estrogen, less muscle damage was reported following eccentric exercise
- Estrogen effects may be related to life cycle: females give life so must be protected from excessive damage due to exercise

Rowing Technique

A study was conducted which examined the gender differences in work output during maximal rowing (Smith & Spinks, 1990). Force-angle data collected during a 6 min maximal rowing ergometer test was used to examine differences between experienced male and female rowers in biomechanical variables. Variables measured were propulsive power output per kg (PPO), stroke consistency and propulsive effectiveness; males were found to more effective than females on each of these variables. The results indicated that female rowers match male rowers in effectively applying force to the line of travel and in coordinating ankle, knee and hip movements. Improvement in the accuracy with which force-angle values are reproduced stroke after stroke by female athletes is required. The difference between male and female performances (times) in most swimming races is 9%; ranging from 8.9% to 9.2%; female rowers may reduce the influence of biological limitations (Smith & Spinks, 1990).

Javelin Throwing Technique

A three dimensional analysis was performed on male and female javelin throwers during the finals of the 1992 Olympic Games in Barcelona (Mero, Komi, Korjus, Navarro & Gregor, 1994). Greater release speeds, longer last step and pull distance, and higher grip position at release were measured in males when compared to females ($p<.05$). Attitude angle was greater in females (40 +5°) than in males (31 + 6"). The correlation coefficient between between resultant release speed and distance thrown was .77 in males and .74 in females. Both males and females had the same run up speed at the beginning of final foot contact (5.6 m/s). The peak linear velocities of the shoulder, wrist, elbow and hand were significantly higher for the males. No significant differences were observed between males and females in any timing parameter or in angular velocities (Mero et al., 1994). An orderly progression in peak speeds from proximal to distal segments was clear in both genders, suggesting that kinetic energy may be transferred from larger segments to the javelin (Mero et al., 1994).

High Jump Technique

The high jump event for males and females was analyzed in detail from film records of the 1987 World Championships (Dapena, 1988). The data for both the top male and female competitors was included, allowing comparisons of some of the key parameters of the event. The best average height cleared for the males was 2.36 m, while that for the females was 2.00 m; a difference of 15% between male and female jumpers. Two important aspects of performance in this event are a fast run up speed, and a low position of the center of gravity at touchdown. Dapena (1988) reported that in this sample of high jumpers, the male high jumpers used faster and lower run ups than the females. This is because the male high jumpers are usually stronger, which permits them to use faster and lower run ups with less risk of buckling the takeoff leg. The arm actions of male high jumpers, measured from the vertical velocity of the arms, were stronger than those of the females, likely due to the greater strength of the male high jumpers. The female high jumpers had more somersaulting angular momentum than the males. Since female high jumpers do not jump as high as males, they have less time in the air to rotate through the same angle, requiring more angular momentum (Dapena, 1988).

Shot Put Technique

In an extensive review of available literature, only a few studies (McCoy et al., 1984; Terauds, 1984) were located which described the techniques of elite female shot putters, or attempted to compare these techniques to those of male throwers. In the shot event, the shot thrown by male athletes is 16 lb (7.26 kg), while that thrown by females is 8 lb 9 oz (3.88 kg). Since there are differences in the dimensions and weight of the equipment used, it may not be possible to make comparisons of performance in the throwing disciplines between males and females (Kenntner, 1983).

In shot putting, women now achieve similar distances to men, with implements which are only 53% as heavy. In a study of elite male and female shot putters McCoy et al., (1984) reported that the males had significantly greater distance thrown, height of release and velocity of release, but these differences were not related to the differences in stature between male and female throwers. They noted that release height is determined by the vertical position of the body in space, and the angle of the arm at release.

A recent study using the shot put attempted to determine the relative importance of certain measured anthropometric, strength, and technique variables to throwing performance in elite male and female track athletes (Alexander, Lindner & Whalen, 1996). Previous research (Alexander, 1989) has suggested that there may be differences in the types of variables that affect performance of female athletes, as compared to those of males in skilled sprinting. For example, the relationship between the strength values at a joint, as measured by joint torques, and the resultant angular velocities produced at that joint during a skilled performance, are different for male and female athletes. As well, while many elite male throwers are very tall with long limb segments, elite female throwers are often relatively short with correspondingly shorter limb segments (Komi & Mero, 1985). However, female throwers may be able to generate superior angular velocities of some body segments, as reported for the knee and elbow joints of several javelin throwers (Komi & Mero, 1985).

A brief article describing how the rotation style of shot putting is particularly suited to the female physiology, noted the following (Durant, 1977):

- females have a lower center of gravity than males- both at rest and in motion- because of heavier hips, shorter legs, smaller upper bodies, lighter musculature and 20 to 30% more body fat
- females are less capable of rapid, forceful muscular activity than males because of lighter musculature and a lower basal metabolic rate
- the female cannot set her body into motion as fast as males can- a fact only exacerbated by adding a 4 kilo shot to her body weight

In a recent study to compare performance between sexes, the shot put performance of skilled male and female collegiate throwers was examined to determine the similarities and differences in technique between the sexes (Alexander et al., 1996). Sixty-one athletes (males = 30, females = 31) were filmed from a sagittal view while competing in a shot competition, and seventy two variables were measured or calculated from film data. Although some of the variables were related to distance thrown, such as length of the glide, other variables such as angle of release and height of release were not found to be significant predictors of distance. The findings may be related to the skill level of this group of subjects, who were elite university throwers, but not international or world class athletes. However, the study does suggest that there are different aspects of technique which should be emphasized for female throwers, including knee extension during the glide, elbow velocity during the delivery, and a greater angle of shoulder flexion at release. For the male throwers, the CG velocity during the glide, the vertical acceleration of the CG during the delivery, and the trunk angle at the start of the glide are all important for producing longer throws (Alexander et al., 1996).

Summary

There is evidence to suggest that there are some differences between the techniques of elite male and female athletes, suggesting that coaches may need to emphasize different aspects of technique for each gender. More research examining these techniques is required. The question regarding whether these differences are due to strength and structure differences, or due to differences in neural patterns remains unanswered.

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