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Kinesiology Analysis of Athletics at the Ancient Olympics and of Performance Differences Between Male and Female Olympic Champions at the Modern Games in Running, Swimming and Rowing

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Kinesiology and physics were employed to better understand the performance of male and female athletes in the Ancient and in the Modern Olympic Games. In what we now call the Ancient Olympics (actually the Pan-Hellenic Games at Olympia), then open only to men, athletes competing in the long jump (part of the pentathlon) carried 1.5-3 kg weights called halteres. By training today's athletes, we have learned that by coordinating the backward and forward thrusting of those weights, about 5% in distance can be gained. In the javelin (also part of the pentathlon) a cord wound around the javelin unwrapped as the javelin was thrown, providing spin stabilization. Performance enhancing drugs were legal at the Ancient Olympics. When women competed in the Heraea Games at Olympia, they ran 5/6 (83%) as far as men, which was the female/male performance ratio of 1928 Olympic champions when women resumed athletics competition. Regarding the Modern Olympics, for running, swimming and rowing, using physics and kinesiology, equations for the velocity ratios of female/male elite athletes were derived and then populated with parameters from studies of over 2000 athletes. Assuming equal training and efficiency, the female/male ratio for running velocity simplifies to the relative female/male lean-to-weight ratio; while for swimming and rowing, the velocity ratio becomes the 8/9th power of the relative lean-to-weight ratio, a remarkable similarity. For the average of Olympic champions in two time frames from 1980 until the present, the actual velocity ratios of about 90% are within tenths of a percent of the expected values, except for running where women have a 1% inefficiency due to longer-than men stride length (relative to height) induced by hip-height geometry. That extra 1% of wear strongly suggests that female athletes should strengthen knee joints to reduce the tendency of females to have six times the likelihood of ACL ligament tears as men.

Keywords: *Long Jump, Javelin, Ancient Olympics, Gender Differences, Lean-to-Weight Ratio*

Introduction

The methods of the present (such as kinesiology, physics and proper technique) can explain the athletic exploits of the distant past and illuminate the differential ability of today's male and female athletes. For nearly 2,800 years, the Olympic Games have been amajor focus of athletic competition. Although the term "Olympic Games" will be used throughout this paper, that term of today is somewhat misleading regarding competition in the ancient world. The competition at Olympia is clearly the oldest and best known venue in ancient Greece, Miller (2004), but was only one of four venues. The contemporary name for the Olympic Games was the Pan-Hellenic Games at Olympia, first contested in 776 BC and lasting more than 1000 years until abolished in 393 AD. The Games at Olympia would be contested on year one

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of a cycle, the Nemean and Isthmian Games on year 2, the Pythian Games on year 3 and then the Nemean and Isthmian Games would repeat on year 4, Panhellenic Games (2017), which can be found at https://en.wikipedia.org/wiki/Panhellenic_Games.

These games were also called the Stephanitic Games since each winner received a wreath called a Στεφανι in Greek (Stephani or Stefani in Latin letters). At Olympia, the Games were dedicated to Zeus, a male god, and thus were only open to men, due to the religious customs of that time.

Thanks to the Foundation of the Hellenic World (2015), a list of 875 events with dates and winners at Olympia (from 776 BC to 277 AD) has been gleaned from ancient records. We inserted those 875 dates, events and winners into an Excel spread sheet. Of those, 43 results were ambiguous, creating a reliable list of 833 events. These were sorted alphabetically by event, to obtain the frequency of each event and thus of each sport. The list of 833 events was also sorted alphabetically by winner, to identify multiple winners. Of the 833 contested events, 49% were in athletics, 32% in combat events, 11% in chariot racing, 4% in equestrian racing and 4% in artistic performance. See the Perseus Project 1 (2015) and the Olympic Legacy (2015) for further information about those events. Clearly, the main interest was in athletics and combat competition, covering 81% of all contested events. Table 1 lists the 406 athletics events from the 833-event data base.

Table 1. *Athletics Events at the Ancient Olympic Games*

Event	**Comments/Distance**	**First Year**	**Last Year**	**Times Held**
Stadion	X1, 192 m	776 BC	269 AD	250
Stadion-Boys	X1, 192 m	632 BC	133 AD	30
Diaulos	X2, 384 m	724 BC	153 AD	37
Diaulos in Armour	X2, 384 m	520 BC	185 AD	29
Dolichos	X7-24, 1344-4608 m	720 BC	221 AD	29
Pentathlon	Discus, Javelin, Long Jump, Stadion, Wrestling	708 BC	241 AD	31

Source: Author's Calculations from Foundation of the Hellenic World (2015).

The 22 starting blocks for the running events are still at either end of the stadium at Olympia. A plethron was defined as 100 feet, although the length of a foot varied among the four stadia, Romano (1993). The runners shuttled from one end to the other, covering multiples (indicated by X1, X2, etc.) of six plethron (600 Greek feet, 192 metres), each called a stadion, providing the modern word "stadium", Romano (1993) and the Perseus Project 2 (2015). The shortest (and original) event was the one-length stadion for men. A stadion for boys was later added. Two versions of the two-length diaulos were contested, onewith armour and one without armour.

The dolichos was contested over a distance that varied from seven to 24 lengths, roughly comparable with the 1500 metres up to 5000 metres runs of today. For races, over one length, the runner went down one lane, looped around a post and returned along the adjoining lane. Leonides of Rhodes was the most decorated runnerof the Ancient Olympics with 12 wreaths. He won all three of the highly competitive shorter running events (the stadion, diaulos and diaulos with armour) over four consecutive Games, Foundations of the Hellenic World (2015).

The pentathlon was a five-eventcontest, including four elimination events, the discus, javelin, long jump and stadion. The remaining athletes wrested for the championship. The long jump and javelin are of special interest here, because artefacts of those events have survived and because we have a reliable long jump distance to replicate.

In Section 2,Ancient Olympic training methods for men are explained, including the use of performance enhancing drugs (PEDs). Kinesiology is used to reverse-engineer the techniques most likely used in the long jump, in which weights were carried in each hand. A mechanical device is described that was used for the javelin.

We now turn to the role of women in sport at Olympia, a described in Were Women Allowed at the Olympics (2015), http://www.perseus.tufts.edu/Olympics/faq5.html and Miller (2014), pages 150-159. The religious practices of the day defined the women's role in ancient Greek sports, based on the gender of the god to whom a competition was dedicated. As mentioned above, what we now call the Olympic Games was dedicated to Zeus, a male god; hence, only men were allowed to compete. Unmarried women could and did attend. For example, the High Priestess of Demeter was an honoured dignitary. Married women were not supposed to attend; however, Kyrniska of Sparta was a double Olympic champion in 396 and 392 BC, having owned and trained the winning chariot horses in the tethrippon. She accepted her laurel wreathes outside the stadium. Kallipateira of Rhodes trained her son inside the stadium but was discovered. She was pardoned since her father, three brothers, a nephew and her son were champions. Thereafter, trainers had to be naked.

Women competed at Olympia at different times from the men, in the Heraea Games, dedicated to Zeus' mythological wife, Hera. It is noteworthy that the torch for today's Olympics is lit at Hera's shrine, located next to the ancient Olympic stadium, giving women a meaningful symbol of equality and respect.

In the last portion of Section 2, the nature of those Heraea Games is discussed which forms a segue into Section 3, which covers the Modern Games and the relative performances of men and women. The sports of athletics and swimming comprise nearly 30% of the Modern Olympic events. These are highly publicised and televised. Running events drawn from athletics are covered herein as these are timed, thus allowing velocity to be computed for women compared their male counterparts. Walking events and the marathon are excluded, as the terrain varies from one Games to the next. All swimming strokes are included for that sport. Rowing is also included because velocity is easily calculable and the kinesiology of the sport has been developed.

In 1896, women did not compete in the first Modern Games, due to the reticence of the Games founder, Baron de Coubertin. By 1900, women were competing in a variety of Olympic sports. Swimming began for women in 1912, athletics in 1928, 1000 metres rowing in 1976 and 2000 metres rowing in 1988. Thus, in Section 3, this paper will explore gender differential behaviour in running, swimming and rowing using starting dates of 1912, 1928, and 1988 respectively.

Thispaper will employ a performance measure that is both intuitive and informative: the velocity ratio of female/male Olympic champions. The laws of kinesiology and physics will be used to derive the velocity ratio for women/men for the three sports, in terms of physiology, training and efficiency. The actual velocity ratio of female/male Olympic champions will be compared with values calculated under the assumption of equal training and efficiency for both genders, based on kinesiology data for over 2000 athletes.

Ancient Olympics: Training, Long Jump, Javelin and Participation of Women

To improve athletic performance in today's world, an athlete works at increasing power output by focusing on training and nutrition. That power output must then be applied efficiently to the demands of a sport, enhanced by coaching, technique and equipment. Psychology can then be employed to convince the athlete that power and performance can be successfully applied to the sport. This paper will explore elements of training and nutrition, psychology and technique at the Ancient Games.

Athletes employed rudimentary concepts of nutrition by eating copious amounts of meat while training, Sports and Drugs (2015). Today, it is well known that ample protein is needed to maintain muscle mass while undergoing intensive training. In the Ancient Olympics, they probably thought that eating meat would somehow allow them to emulate the strength and stamina of the animal being consumed. They also ate heart, knowing that the heart pumped and needed oxygen. They would not have understood that just eating heart would not convey increased oxygen clearance. They also ate animal testicles. There may have been rudimentaryunderstanding of the source of animal vitality; but mainly the idea was to acquirevitality by ingesting that organ. Today, steroids and growth hormones, not the originating organ, are (illegal) performance-enhancing drugs (PEDs) of choice.

PEDs were legal at the Ancient Games. Athletes took hallucinogens, opium juice and strychnine, Sports and Drugs (2015). These provided a psychological lift and also provided some physiological benefit. Efforts to catch cheats who use PEDS in the Olympics and to take away their championships only spans about the last 50 years of the nearly 2,800 years of Olympic history. Strychnine was used as late as 1908 when Thomas Hicks won the marathon, yet nearly died from the effects of that drug (Wallechinsky and Loucky, 2012). Later-to-be-US-General George Patton took an injection of opium prior to the running portion of the 1912 Olympic modern pentathlon in which he had his best placement (Wallechinsky and Loucky, 2012).

As to technique, the long jump contestants in the pentathlon had to jump with halteres, smoothed weights, in each hand, weighing 1.5 to 2 kg. Using kinesiology, might there have been some benefit in the running long jump, by carrying weights? An athlete converts kinetic energy into potential energy while jumping vertically or horizontally, Stefani **(**2008**)**. Suppose an athlete with body mass m_1 runs at a horizontal velocity v_1. The kinetic energy is .5 $m_1 v_1^2$. The athlete then jumps at an angle θ_1 converting the kinetic energy into potential energy attaining a height h_1. The potential energy is$m_1gh_1f(\theta_1)$where the function *f* includes the effect of the jumping angle and *g* is the acceleration of gravity. That height allows the athlete to cover a horizontal long jump distance d_1, depending on a function *F*, where the potential energy is $m_1g\ d_1F(\theta_1)$.

Now, assume the same athlete carries a weight increasing the body mass to m_2. All the of the above equationsare then replaced with subscripts of *2*. Assuming the achieved kinetic energy and thus the potential energy remain the same and the jumping angle remains the same: it follows that $d_2/d_1 = m_1/m_2$. Since the body mass m_2 is larger than m_1, then the distance d_2 must be smaller than d_1. It is not logical to assume that they would carry weights that would shorten the long jump distance.

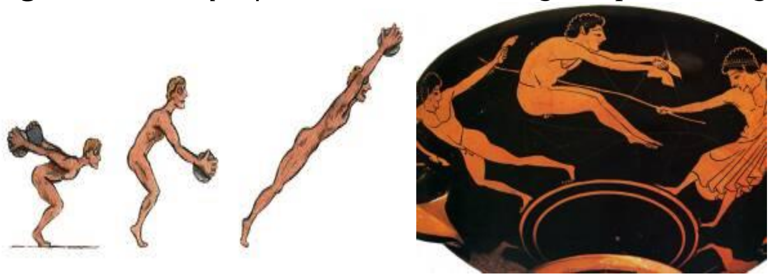
Instead, researchers have investigated the effect on a standing two-footed long jump of the coordinated swinging of the weights in the forward direction, thus moving the centre of gravity farther forward than would ensue without the weights. Minetti and Ardigo (2002) found that trained athletes could gain 5.7% carrying a 2 kg weight with the optimum weight being 5-6 kg. Huang et al. (2005) established a gain of 4.5% using 2 kg weighs with an optimum weight being equal to 8% of body mass. The conclusion is that a 5% gain is possible with proper technique. The best weight is 8% of body mass for both researchers.

An epigram indicated that Phayllos of Kroton once jumped 55 Greek feet (16.3 metres). He competed in the Pythian Games in 482 and 478 BC. Researchers from KU Leuven, in The Ancient Long Jump and Phayllos (2012), indicated that after eight weeks of training, athletes jumped 15 metres using five two-footed jumps, five for the number of events in the pentathlon. The left part of Figure 1 shows the resulting technique through the forward thrust. The right photo from KU Leuven shows the landing, as shown on a contemporary urn.

Another bit of ancient technology was twisting a cord around the javelin, ending in a loop for the thrower's finger. That loop provided leverage and, as the cord unwrapped, the javelin was spin-stabilized (Miller, 2004 p. 69-70).

As mentioned above, women competed in the Heraia Games, contested in a different year from the Olympic Games; but in the same Olympic stadium. Unmarred women competed. Married women served as officials and trainers. We do not know if men were allowed to attend. The Greek government empowered the so-called Sixteen Women, all married, to coordinate female sports in all of Greece. There was therefore a coordinated effort to promote athletic competition for women. Women competed in three age groups, over a shortened distance, reduced from 600 Greek feet to 500. This implies that women were assumed to be about 5/6 or 83% as proficient as men. Coincidentally, when women resumed Olympic athletics competition in 1928, the female champions performed 83% as well as their male counterparts.

Figure 1.*Technique for a Two-Footed Long Jump with Weights*



Source: KU Leuven, The Ancient Long Jump and Phayllos (2012)

Modern Olympics: Explaining Gender Differences in Running, Rowing and Swimming

In this section, the laws of physics and kinesiology will be applied to running, rowing and swimming to derive the theoretical velocity ratio of female/male athletes. Parameters needed to evaluate those equations will be taken from elite-athlete data in Table 2 for running, from Tables 2,4 and 5 for rowing and from Tables 2,3 and 5 for swimming, based on 10 studies involving 2286 athletes. The ratios of the body masses of men/women in Table 5, based on three studies and 1434 athletes, are so consistent over time and sport, that only the mean of all values is used: m_w/m_m equal to 1/1.256 = 0.796. Table 6 summarizes useful results from the derived equations that aid in evaluating an athlete's progress in training.

Table 7 compares the theoretical ratios (assuming equal training and efficiency) with those of Olympic champions in the three sports, so that a hypothesis of equal training and efficiency can be tested. The history of the Modern Summer Olympicsis divided into five periods. First, the WW1 period (1896-1924) includes the first Games of 1896 and the years surrounding WW1 up to a rebound of performance at the second post-war Games in 1924. Second, the WW2 period (1928-1952) similarly spans the era surrounding WW2. Third, the Cold War period (1956-1976), includes Games with Eastern Block and Western Block prides at stake. Fourth, the Boycott period (1980-1988) includes the two boycotted Games, ending with a rebound in 1988, amid controversy over rampant use of PEDs. Fifth and finally, the Anti-Drug period covers 1992-2016, an era dominated by efforts to combat PED use.

Running

The power generated by arunnercan be measured on a treadmill or cycling ergometer. Studies show that such ergometer power, *P*, depends on the athlete's lean body mass, *LBM*, and training (*Tr*), as given by (1).

$$P = LBM\ Tr \quad (1)$$

That is, *P/LBM* is a constant for equally trained athletes of both genders, Baker et al. (2001), Maud and Schutz (1986), Sveinsson et al. (2009) and Taguchi et al. (2011). A fraction of the generated power, *P e*, is then applied to the centre of gravity of a runner with body mass *m*, where *e* is the efficiency less than or equal to one, depending on a combination of coaching, technique and equipment. That applied power results in the runner achieving a velocity, *v*, as given by (2), using Newtonian mechanics,Lerner (1996) and Stefani (2008**).** The angles in (2) measure the direction of the forward movement of the centre of gravity.

$$P\ e = m\ v\ f(angles)\ constants \quad (2)$$

If both sides of (2) are divided by *m*, then *P/m*, the power-to-weight ratio, depends directly on *v* for fixed *e*. That is, each 1% increase in *P/m* while training implies a 1% increase in velocityif efficiency is maintained. That relationship is shown in Table 6.

Table 2. *Relative Lean-to-Weight Ratio LTW (LTW = LBM/m = 100 - %Fat)*

Source	**Event**	**Men**		**Women**		**LTW_W/LTW_M (sd)**
		N	**%Fat (sd)**	**N**	**% Fat (sd)**	**%**
Fleck (1983) US Olympians	Running	24	6.4(1.2)	21	13.7 (3.6)	92.1 (2.5)
Vucetic et al. (2008) Elite Athletes	Running	41	5.8 (2.4)			
Malina (2007) US College Athletes	Running			70	14.2 (1.3)	91.0 (1.8)
Yoshiga and Higuchi (2003) Elite Athletes	Rowing	120	11.9 (6.2)	71	20.9 (5.2)	89.8 (5.7)
Fleck (1983) US Olympians	Swimming	39	12.4 (3.7)	41	19.5 (2.8)	91.9 (3.5)
Van Erp-Baart et al. (1989) Elite Athletes	Swimming	20	10.7 (3.3)	50	21.4 (5.6)	88.0 (4.4)

Table 3. *Drag Coefficient Ratio*

Source	**Men**		**Women**		**Cd_W/Cd_M**
	N	**Cd(sd)**	**N**	**Cd(sd)**	
Toussaint (1988)	32	.55(.09)	9	.47 (.07)	0.854
Zamparo (2009)	84	.353	66	.318	0.900
Mean	116		75		0.890

Table 4. *Cranking Ratio Cr for Elite Rowers (Yoshiga and Higuchi, 2003)*

Study	**Men**				**Women**				**Cr_W/Cr_M**
	N	m	LBM	Time	N	m	LBM	Time	
Equal m	57	63		436	37	62		477	0.850
Equal LBM	20		52	446	10		51	466	0.930
	77				47				0.890

Table 5. *Body Mass Ratio for Men/women*

		Men		**Women**		
Source	**Event**	**N**	**m (sd)**	**N**	**m (sd)**	**m_M/m_W**
Mc Ardle (1981) 1964 & 1968 Olympians	Running and Jumping	354	71.8	181	57.5	1.249
Mc Ardle (1981) 1964 & 1968 Olympians	Swimming	516	73.1	300	58.3	1.254
Pyne (2000) 1988 & 1994 Australian Olympians	Swimming	43	81.8 (7.0)	42	64.8(6.1)	1.262 (.115)
US Olympians 2000	Rowing	19	92.5 (8.1)	19	73.3(6.7)	1.261 (.114)
		932		542		1.256 (.11)

The goal here is to analyse the velocity ratio of women/men, which follows from (1,2), where *LTW* denotes the lean-to-weight ratio, given by *LBM/m*. It is assumed that angles are the same for both genders. Those angles and any constants therefore cancel.

$$v_W/v_M = (LTW_W/LTW_M)\ (Tr_W/Tr_M)\ (e_W/e_M) \qquad (3)$$

If men and women are equally trained and efficient, (3) depends only on relative lean-to-weight, LTW_W/LTW_M (as noted in Table 6). That is, for each 1% by which the relative lean-to-weight is increased while maintaining training and efficiency, the runner will increase velocity by 1%.

Table 6. *Parameters for Assessing Progress in Training*

Sport	**Ratio of v_W/v_M For Equally Trained and Efficient Athletes**	**Changes in v Due to Training for Equally Efficient Athletes**
Running	LTW_W/LTW_M	P/m
Swimming	$(LTW_W/LTW_M)^{8/9}$	$[Pm^{1/3}]^{1/3}$
Rowing	$(LTW_W/LTW_M)^{8/9}$	$[P/m^{2/3}]^{1/3}$

Source: Authors Derivations

The relative lean-to-weight values from Table 2 for running are used to provide estimates for the most recent two time periods in Table 7. Considering Games before estimates are available, after 1928, women gained relative to men creating an average velocity ratio of 88% for the entire second period. The ratio increased to 89% for period three. We have examined side-by-side photos of Olympic champions 80 years apart, including women's 100 metres champion Elizabeth Robinson (1928) compared to Shelly Ann Fraser-Price (2008); men's 400 metres champion Eric Liddell (1924) compared to Jeremy Wariner (2004), and men's 10000 metres champion VlhoRitola (1924) compared to Kenenisa Bekele (2004). There are no visible physiological differencescompared to the present-day athletes, so that the increase in the average velocity ratio from 88% to 89% is probably not due to changes in the relative lean-to-weight ratio; but rather due to a time frame when greater numbers of women became active in sport and thus women had better training (through better nutrition and access to trainers) and improved efficiency (through better coaching, technique and equipment).

Table 7. *Estimated and Actual Velocity Ratios for Female/Male Olympic Champions*

	Running		**Rowing**		**Swimming**	
Period	Estimate N=156	Running Velocity Ratio N=103	Estimate N=1789	Rowing Velocity Ratio N=49	Estimate N=1815	Swim N=181
1896-1924 (WW1 and Recovery)						83
1928-1952 (WW2 and Recovery)		88				87
1956-1976(Cold War)		89				90
1980-1988 (Boycotts and Recovery)	92	91		90	91	91
1992-2016(Anti-Drug)	91	90	90	90	90	90

Source: Authors Calculations Based on Sources in Table 2-5 and on Walechinsky's Books.

For the fourth period, the estimated velocity ratio, assuming equal training and efficiency, was 92% while the observed ratio for male and female Olympic champions was actually 91%. For the fifth period, the expected ratio was 91% compared to the actual ratio of 90%. It is likely that training was reasonably equal, meaning that women were 1% less efficient than men. Why? Female runners are six times as likely to have an ACL tear as men because their pelvis and hips are wider than for men, relative to height, causing relative overstriding and some knee rotation, Williams and Cavanagh (1987), Gilland (2009) and Hewitt (2010). The data in Table 7 provides a scaling for that overstriding. Because a female runner has her leg a bit straighter and knee a bit rotated compared to men at stride's end, women apparently put 1% of the force, intended to move the athlete forward, into the knee and ankle joints, causing the female champion to run 1% slower than suggested by relative *LTW*. The take-away message is that female athletes should strengthen the knees to protect against potential injury.

Rowing

The law of hydrodynamicsis to rowers and swimmers what Newtonian mechanics is to runners (Lerner, 1996; Stefani, 2008). The kinesiology of a rowing ergometer differs from that of a cycling or treadmill ergometer. That is, *P/LBM* is not equal for equally trained women and men. An additional influence, herein called the cranking effect, *Cr*, is present, as studied by Lutoslawska et al (1996) and Yoshiga and Higuchi (2003) in rowing. The term cranking is used here in a rowing context because a similar phenomenon was studied where arm cranking is employed in other types of exercise physiology (Hubner-Wozniak et al, 2004; Washburnand Seale,1984; Weber et al., 2006). The power generated on a rowing ergometer is given by (4).

$$\text{Power generated} = P = LBM\ Tr\ Cr \qquad (4)$$

As in (2), a fraction of that power is efficiently applied to a racing shell causing it to move forward with velocity *v*, Stefani (2008) and Stefani and Stefani (2000). The area in contact with the water, approximately the 2/3 power of body mass due to buoyancy, induces drag. The equation of motion is given by (5), where *Cd* is the drag coefficient, relating actual measured drag to a theoretical equation using the entire surface area, whereas only part of that surface area in contact with the water flow (Tuck and Lazauskas, 1996).

$$P\ e = v^3\ m^{2/3}\ Cd\ \text{constants} \qquad (5)$$

If both sides of (5) are divided by $m^{2/3}$, then $[P/m^{2/3}]^{1/3}$becomes the rower's power-to-weight parameter, as in Table 6, giving changes in$v$ if efficiency $e$in constant (boat drag would not change). Rowers can be ranked for placement on a racing shell, based on performance on a rowing ergometer for$P/m^{2/3}$. That same power-to-weight expression can then be used to estimate velocity over

2000 metres (Cosgrove et al., 1999; Ingram et al., 2002; Lutoslawska, 1996). That is, every 1% improvement in $P/m^{2/3}$implies a 1/3% increase in velocity, for constant *e*. The velocity ratio (6) follows from (4,5), where constants cancel.

$$v_W/v_M = [(Tr_W/Tr_M)(e_W/e_M)]^{1/3} [(LTW_W/LTW_M)(Cr_W/Cr_M)]^{1/3} (m_W/m_M)^{1/9} \quad (6)$$

If women are as equally trained and efficient as men, in rowing, then the velocity ratio would be given by the rest of (6). Table 2 (*LTW*), Table 4(*Cr*) and Table 5 (*body mass*) provide the values needed to estimate the velocity ratio under the assumed conditions of equal training and efficiency as shown in Table 7.

Women began rowing at 2000 metres, the same distance as for men, in 1988. For period four, female Olympic champions rowed 90% as fast as men. For period five, elite female rowers were estimated to row 90% as fast as men under conditions of equal training and efficiency, which is the actual value achieved by female Olympic champions. The conclusion is thatfemale rowing champions have been as equally trained and efficient as their male counterparts since 1988.

The rightmost two bracketed terms in (6) can be simplified for use as a physiological training aid. Data from Tables 2,4 and 5 provide approximations that are accurate to within 1%. The cranking ratio (Cr_W/Cr_M) is approximately the same as relative *LTW*, (LTW_W/LTW_M), likely due to the fact thatin contrast to the treadmill and cycling ergometers, where lower body strength and cardiovascular efficiency seem to depend only on lean body mass; instead, the rowing ergometer requires those influences plus full body action, logically depending on *LTW*. Also, the mass ratio (m_W/m_M) is approximately the square of relative LTW, probably due to hormonal differences; however more study is ended to fully understand that relationship.

Adding powers of relative *LTW*, for equal training and efficiency, the approximate velocity ratio become $(LTW_W/LTW_M)^{8/9}$, as shown in Table 6. That is, for each 1% by which the relative lean-to-weight is increased while maintaining training and efficiency, the rower increases velocity by about (8/9)%.

Swimming

For swimming, as for running, a treadmill or cycling ergometer can be used to measure power, as given by (1). For swimming, the fraction of power applied is more complicated than just *P e*. A swimmer applying force while immersed in water does so with a propelling efficiency much like that of the propeller on a boat, Toussaintet al. (1983), depending on the size of the swimmer, which depends on body mass, *m*. Thus a swimmer’s efficiency becomes $e = m\ e_S$ where e_S depends on coaching, technique and equipment. The applied power equation and the response of a swimmer is given by (7), as modified from (5). Here, the drag coefficient is that of the swimmer which varies from swimmer to swimmer, Toussaint et al. (1988).Consistent with power depending on training, it has been shown that power for swimmers can be improved by effective training, Machado et al. (2011).

$$P\ m\ e_S = v^3\ m^{2/3}\ Cd\ constants \quad (7)$$

If the body mass terms are collected on the left side of (7), then a swimmer's velocity depends on the power-to weight relationship $[P\ m^{1/3}]^{1/3}$, see Table 6. Every 1% improvement in $P\ m^{1/3}$implies a 1/3% increase in velocity, for constant e_S and *Cd*. The velocity ratio follows from (1,7).

$$v_W/v_M = [(Tr_W/Tr_M)(e_W/e_M)]^{1/3}\ [(LTW_W/LTW_M)/(Cd_W/Cd_M)]^{1/3}(m_W/m_M)^{4/9} \quad (8)$$

If women are as equally trained and efficient as men in swimming, then the velocity ratio would be given by the rest of (8). Table 2 (*LTW*), Table 3(*Cd*) and Table 5 (*body mass*) provide the values needed to estimate the velocity ratio under the assumed conditions of equal training and efficiency as shown in Table 7. Women first competed in swimming in 1912.

In Table 7, female Olympic champions gained from being 83% as fast as their male counterparts in period one, to 87% in period two and then to 90% in period three. We have examined side-by-side photos of Olympics champions over at least 80 years, including women's 100 metres champion Ethel Lackie (1924) compared to Jodie Henry (2004) and men's multiple event champion Johnny Weismuller (1924) compared to Michael Phelps (2008). There are no visible physiological differences, so that the increase in the average velocity ratio from periods one to three are probably due to better training and efficiency, in a time frame when greater numbers of women became active in sport, as was noted for running.

For periods four and five, the estimated velocity ratios under conditions of equal training and efficiency were 91% and 90%, respectively, each equal to the actual velocity ratio. The conclusion is that women have been as equally trained and efficient since 1980 (and probably since 1956, because the velocity ratio for period three was about the same as for periods four and five).

The rightmost two bracketed terms in (8), as was true with (6), can be simplified into a physiological training aid, using data from Tables 2, 3 and 5, which provide approximations that are good to within 1%. The drag coefficientratio (Cd_W/Cd_M) is approximately the same as relative *LTW*, (LTW_W/LTW_M), probably because both are due to body density; hence the middle-bracketed term in (8) is approximately one. As with rowing, the mass ratio (m_W/m_M) is approximately the square of relative *LTW*. The approximate velocity ratio become $(LTW_W/LTW_M)^{8/9}$, as shown in Table 6, surprisingly the same as for the other hydrodynamic sport, rowing. As with rowing, for each 1% by which the relative lean-to-weight is increased while maintaining training and efficiency, the swimmer increases velocity by about (8/9)%.

Conclusions

The methods of the present explain the athletic exploits of the distant past and illuminate the differential ability of today's male and female athletes. At the Ancient Olympics, the athletes ingested copious amount of meat, heart and animal testicles, apparently believing that the attributes of the animal would be imparted to the athlete. We now understand the underlying biochemical nutritional processes, some of which are illegal and obviously tempting. Unlike now, performance-enhancing drugs were legal at the Ancient Olympics. Modern researchers have reverse-engineered the carrying of weights in the long jump. A two-footed standing long jump can be enhanced 5% bythe coordinated thrusting of weights forward. The legendary accomplishment of Phayllos jumping 55 Greek feet, probably with five two-footed jumps, has been recreated. The javelin throw was enhanced via a wrapped strap with a ring that provided leverage and spin stabilizing. Women competed in the Heraea Games at Olympia, running 5/6 (83%) of the length of the men's events, coincidentally the performance ratio of female/male Olympic champions when women re-entered Olympic athletics competition in 1928, over 2000 years later.

For the Modern Olympics, the laws of physics and kinesiology were employed to derive the velocity ratio of elite female/male athletes in running, rowing and swimming, involving training, efficiency and physiological parameters. Olympic history was divided into five periods covering WW1, WW2, the Cold War, Boycotts and the Anti-drug period, which extends until today. The WW1, WW2 and Boycotts periods each ended with a rebound of performance. Since 1928 when women first competed in athletics, the female/male velocity ratio for Olympic champions increased from 88% to values of 91% and 90% respectively for the most recent two periods, values that are one percent less that what would be expected for equal training and efficiency, a difference consistent with body-geometry-induced over striding that gives women six-times the likelihood of ACL tears compared to men. The lesson is that female athletes should be vigilant at strengthening their knees. For rowing, female Olympic champions women haveachieved 90% of men's velocity since 1988, a value consistent with equal training and efficiency. For swimming since 1912, women improved from 83% in the first period to ratios of 91% and 90% in the two most recent periods, consistent with equal training and efficiency.

Put simply, women now have about 90% of the lean-to-weight ratio that men have and therefore their Olympic champions run, row and swim about 90% as fast, having achieved parity in training and efficiency.

A result for today's athletes-in-training is that each percent by which the lean-to-weight ratio is increased, running velocity increases about 1% while rowing and swimming velocity increases about (8/9)%, other factors held equal. In training, power output for runners and swimmers can be measured on a treadmill or cycling ergometer while for rowing a rowing ergometer is used. Foreach percent that sport-specific power-to-weight ratios are increased for running (*P/m*), for rowing ($P/m^{2/3}$) and for swimming ($Pm^{1/3}$), velocity increases about 1%, (1/3)% and (1/3)% respectively, with other factors held constant.

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