Sex Differences in Determinants of Performance

by Dr Emma Ross, 2024.

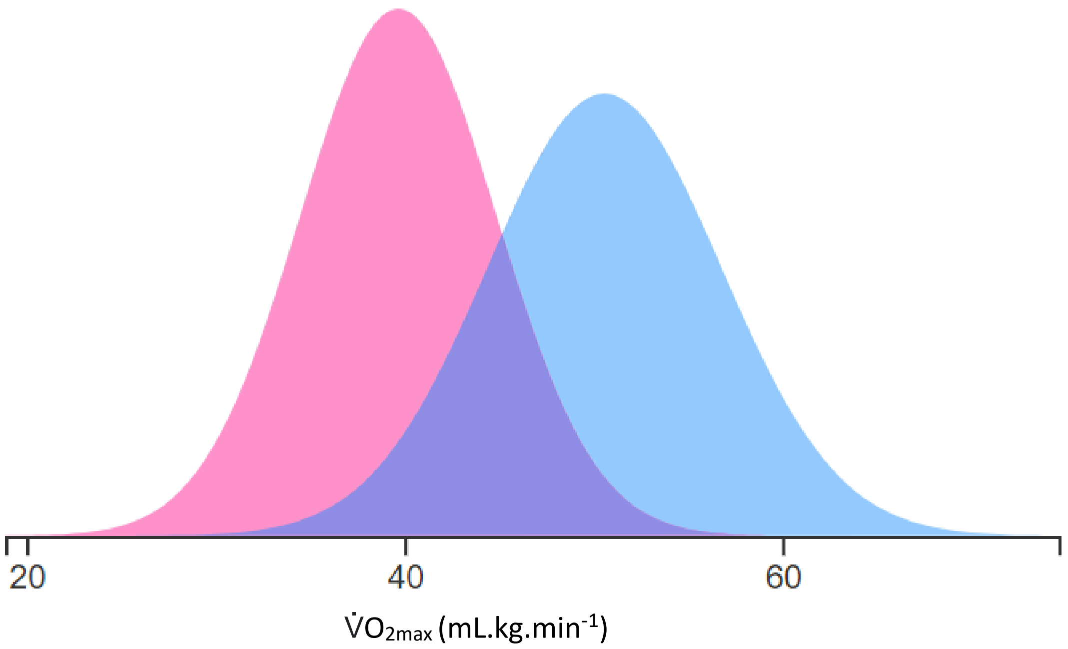
Bernd Heinrich, author of 'Why We Run' describes how our evolution as a species is the foundation of our physical and psychological attributes which make us fantastic endurance runners. He talkes of 'man the hunter' and how our ability to endure gave us superior hunting skills and we outran our prey, not in speed but in our enduring ability to keep moving. I revisited the book recently to see what Bernd had to say about sex differences in our performance capabilities – after all, if why and how we run is based on 'man the hunter', why and how are women so good at endurance exercise? He writes on the topic, not just about humans, but about how many other species have incredible sex differences – which is called sexual dimorphism – take the male tree frogs, who have to perform at 60% of their VO_{2max} for hours and hours to sustain a mating call. Although both female and male frogs are the same length and have the same leg size, the trunk of the males is 15% bigger, so well developed from his chest muscles and vocal cords having to create the mating calls, and comprised of muscle fibres much better suited to aerobic metabolism than his silent, female counterpart.

Humans are not classified as being highly dimorphic

Unlike tree frogs, humans are, overall, quite similar when we compare males and females. But even though the differences are not extensive, they are still important to consider, because they underpin the biomechanics and physiology that supports sporting and physical performance.

As well as differences in height, weight (about 7% and 14% respectively) and anatomical bone structure, like women having a wider pelvis and shorter foot length, when it comes to other factors which are relevant to performance, on average, women have smaller heart and heart volume, and therefore a lower cardiac output than men by about 30%. Women have a smaller lung capacity by about 25%, a lower blood volume, and less Hb in that blood (which is the bit that carries the oxygen) – so less overall oxygen carrying capacity. All this means that women have, on average, a lower $\dot{V}O_{2max}$ than men by about 20%.

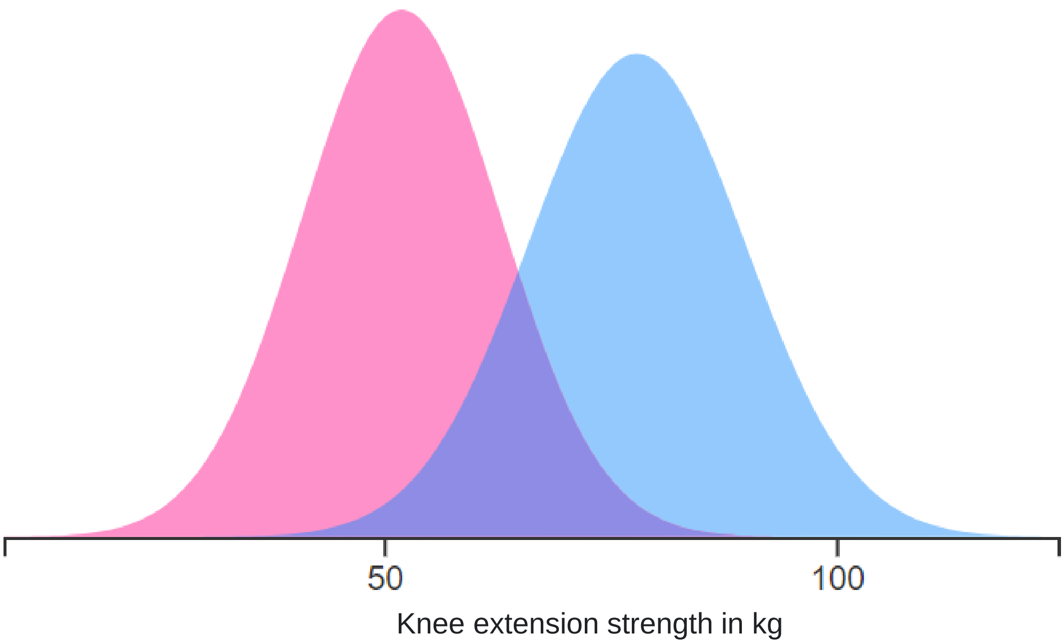
However, within that maximal aerobic capacity, elite women can run marathons at about 75-85% of $\dot{V}O_{2max}$, essentially the same as for elite men. So theoretically speaking (and it is only theory because we know performance is determined by much more than one physiological variable), if a woman raced a marathon alongside a male with the same $\dot{V}O_{2max}$ as her, they'd have equal chance of recording the same time. The chances of a woman having the same $\dot{V}O_{2max}$ as a man are quite high – the graph below shows the overlap in natural variability of $\dot{V}O_{2max}$ for active men and women. So if your $\dot{V}O_{2max}$ was 45ml.kg.min^{-1} as a woman, there are lots of men who would share the same physiological aerobic capacity with you (there is about a 35% overlap in male and female data here).



Created using www.sexdifferences.org (pink curve is data from females, blue curve is data from males) using data from (Sharp, et al., 2002)

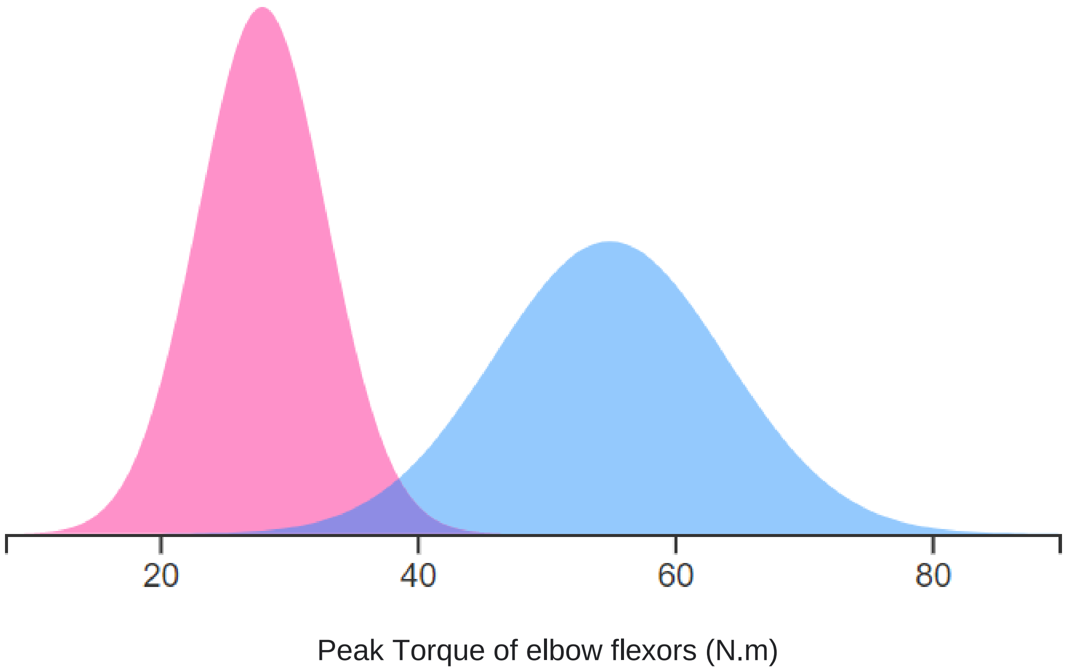
When we look at strength, the picture is a little different from aerobic capacity. Largely because of the presence of testosterone all through development from in utero to adulthood, bones and muscles grow bigger and stronger in men. Men are 50% stronger in the upper body and 40% stronger in their lower body than women. It's a common misconception that women have more type I fibres than men, which is why they aren't as strong explosively – women and men have about the same proportion of type I and II fibres, but in men, the type II fibres, which we use for power and strength are bigger, in reality they take up more space in the overall muscle, than type II fibres do in women. That still means men are stronger.

If we look at a sex difference graph again, but this time for quadriceps strength during a leg extension 1-repetition max exercise, we can see that there is still overlap – some women will be as strong as some men in the lower body, but the likelihood of this happening is less compared to $\dot{V}O_{2max}$.



Created using www.sexdifference.org (pink curve is data from females, blue curve is data from males) using data from (Pincivero, et al., 2004)

Men are about 40% stronger in terms of upper body strength when compared to women. In the lower body this difference is more like 30%. The sex difference graph below, represents peak elbow flexion torque, performed on an isokinetic dynamometer. It shows much less overlap in strength of this upper body muscle group between men and women, even after a strength training programme.



Created using www.sexdifferences.org (pink curve is data from females, blue curve is data from males) using data from (Gentil, et al., 2016)

Training adaptation

Interestingly, women and men adapt to strength training slightly differently, and although men have stronger muscles per see than women, women are just as good at adapting to training. If you prescribe training at a set % of someone's maximum strength (that's called relative strength, let's say your maximum leg press was 60kg, then we might prescribe 3 sets of 12-15 reps at 75% of that, i.e. 45kg), men and women make similar gains with strength training. But if you look at how they are producing that new strength, the women have undergone more non-muscle mass adaptations than the men. We know that in everybody, strength gains are achieved by a combination of an increase in muscle mass (your muscles get bigger) and improved neuromuscular factors (your brain and nervous system get better at sending signals to your muscles to switch them on during a contraction). About 40% of your increase in strength in response to training is because of increases in muscle size, and 60% is due to other factors more related to how well your nervous system fires your muscles, and how coordinated the movement becomes – better coordination means more force is produced in a given movement. In women, it's been found that changes in strength, depend less on the muscle growth side of things and more on how well we can activate the muscle(s) in question. In fact, if you express the power produced by a muscle relative to it's size – lets call that muscle power quality – after a strength training block women improve by 9% but men see no change. That means the increase in men's strength is mainly down to the increase in muscle size at the end of the day. In women, not so much, and their muscles produce more power for their size.

Muscle Fatiguability

There is an interesting element of female physiology that lends itself to enduring better than in males, and that is fatiguability. If women and men are working at the same relative percentage of their maximum muscle strength, let's say 60% of their maximum strength, then the women would out last the men doing repeated contractions. And the difference isn't trivial: in research studies, women keep performing, rep after rep, for 60% longer than men doing the same resistance exercise. Better still, in the second half of the menstrual cycle, when progesterone is high, this effect is amplified.

So even though men tend to be stronger than women, there is still a 36% overlap of leg strength between men and women, so if a female went and found one of those men with the same maximum leg strength as them, lets say 100kg 1RM, and they both started doing leg extensions with a weight of 60kg, the woman could outperform the man, and go for longer before they had to stop. And its' not that women can wreck our muscles more than men, the level of fatigue at the end point is the same in men and women's muscles, its just that the women could keep going for much longer in order to get there. It's important to note that this difference dissipates when the intensity of contraction reaches about 80% MVC. The same body of research also suggests that recovery from neuromuscular fatigue is quicker in women, such that it takes less time for women to be able to recover and produce maximal strength or power again after a set to fatigue.

Whilst initial studies in muscle fatiguability were performed in single leg contractions, similar findings have been demonstrated when neuromuscular fatigue has been assessed following endurance running.

Hormones and sex differences

One of the big differences between males and females is our sex hormones. Although both males and females have testosterone, oestrogen and progesterone, the levels in which it is produced is vastly different across the sexes. Men's primary sex hormone is testosterone, which had a 24 hour cycle of fluctuation, peaking early in the morning and slowly declining throughout the rest of the day. Women's main sex hormones oestrogen and progesterone also undergo rhythmic fluctuations, but over an (approximately) 28 day cycle.

Some of the important functions of testosterone is that it stimulates muscle growth and development, and is also increases the concentration of red blood cells and haemoglobin – critical components for oxygen transportation. This is reflected in men being stronger, with a larger blood volume.

Oestrogen plays a role in fat accumulation – women usually have about 5-10% more body fat than men, and it is distributed differently. Females deposit fat around the hips, bottom and upper arms, and males around the trunk and abdomen. Oestrogen is also shown to increase oxygen utilisation in muscle tissue, which could afford women an advantage in lower intensity, endurance exercise.

So, will women ever out-perform men?

A number of research papers which use data modelling of performance in long-distance events, have suggested that women will outperform men in the near future. However, it is more likely that women will remain slower than their male counterparts with a strangely consistent 10% difference in speed across distance and modality (run, swim, cycle, triathlon) for sprint and endurance race distances.

Interestingly, in earlier modelling studies the ultra-endurance races appear to present larger gender differences in the region of 20% to 30% across distance and modality. One study in 2013 reported a 23.7% difference between men and women over the double Iron ultra-triathlon, a figure supported from other papers in this series over different distances and modalities. Whilst these gender differences appear to remain for multi-day events including the 'Marathon des Sables', they may be narrower (back down to ~10%) in some events—particularly those that require less load bearing (e.g. swimming and cycling). Performances in ultra-distance swimming show a general female dominance. Indeed, while in 10-km open-water swimming the annual fastest males are ~6% quicker than the fastest females, the top 20 females in extreme-endurance competition (46 km) are ~12 – 14% faster than their male counterparts. This observation does not appear anomalous. A recent review assessing male and female performances in several extreme-endurance, open-water swimming events, showed that females were on average 0.06 km·h-1 faster than males.

The notion that with increasing distance (in foot races, in particular) the performance gap between men and women actually increases, is challenged in a very recent study which took a large data set of results to look again at the gap in endurance performance between men and women as distances increase. This time, rather than analyse the performance of just elite runners or all participants, the researchers pair-matched women and men during short-distance events and examined the difference between their times over longer distances. Data 1,881,070 unique runners, allowed 7251 pairs of men and women with the same relative level of performance to be obtained, and short races (25–45km-effort) were compared to longer races (45–260km-effort).

The study concluded, for the first time, that the gap between men and women shrinks when trail running distance increases, and suggested that this demonstrates endurance is greater in women. Although women narrow the performance gap with men as race distance increases, top male performers still outperform the top women.

Several physiological factors that could give women an advantage over men during ultra-endurance races:

Fatiguability

Women display less fatigue in leg muscles after trail and ultra-trail running exercises. Although sex differences in fatigability may partly be related to a different psychological approach of the race between men and women (e.g. pacing), it is this the lower level of fatigability which could partly explain the better performance in women in extreme duration running races. This lower level of fatigability could be related to the fact that women have a greater proportional area of type I fibres in several key muscles for locomotion. Additionally, women oxidise more lipids and less carbohydrates and protein than men during prolonged exercise. The ability of women to save glycogen stores and minimise protein catabolism, is theoretically an advantage during ultra-endurance exercises.

Energy availability

An important consideration for the female athlete is the effect of energy availability on sex hormone concentrations, and the consequences of this. The foremost nutritional challenge facing female athletes is the ability to meet their daily caloric demands. Low energy availability can result from high training volumes and/or unintentional or deliberate restriction of dietary energy intake. The consequences of low energy availability are widespread, and likely affect females more profoundly and rapidly, owing to its impact on with menstrual function (i.e., loss of menstrual cycle hormones, cessation of periods) that, in turn, reduces bone health. Given that oestrogen associates positively with bone mineral density, females with diminished oestrogen levels are at an increased risk of stress fracture, and this may have implications for the injury risk and availability. Even females with regular periods appear to be more susceptible than males to adverse changes in bone health following short-term low energy availability. Relative energy deficiency in sport (RED-S) is not limited to impacting menstrual health and bone density. Females who are in frequent, regular, or chronic states of low energy availability are at significant increased risk of gastrointestinal issues, reduced adaptation to training, decreased aerobic endurance capacity, immune function disruption, cognitive dysfunction, depression and low mood.

The idea that women could start to outrun men at ultra endurance events, is actually linked to the fact that to do so, they would be required to sacrifice their reproductive capabilities. That is, if they could become light and lean enough, there is a possibility they might be competitive with their male counterparts. But in order to be light, lean and fit enough, they would likely live in a state of low energy availability. Not only would this lead to a state of infertility, but it is not sustainable, since the knock-on effects of RED-S has widespread impact, both physically and emotionally, which would preclude any participation, let alone success in sport.

Gastrointestinal Distress

On average, the female stomach is ~10% smaller than the male stomach and may, therefore, females are more likely to exhibit greater fullness following a standardized meal. Whole gut and colonic transit times are longer in females when compared to males and females exhibit attenuated rates of gastric emptying for both solid foods and fluids. The GI system behaves differently in women also because of sex-related features in the brain. The nerve cells that control the movement of food through the intestines are more sluggish in response to brain inputs in women than in men. These findings may have important implications for fuelling during prolonged exercise.

In population-based research, females report a higher frequency of GI symptoms most commonly nausea, bloating, abdominal pain, and constipation. in a 1984 survey of >700 marathon runners (85% male – so a participation bias will exist within this data set), females more commonly reported symptoms of lower-GI distress (e.g., abdominal cramping, urge to defecate, diarrhoea, bloody defecation). However, there was little difference in the frequency and/or severity of most GI symptoms between males and females during a 161-km ultra-marathon, with the exception of stomach bloating which was more common in females. More research is warranted to establish if the greater female propensity for GI distress extends to ultra-endurance competition.

GI distress has also been linked to the menstrual cycle, with bloating, abdominal pain and cramping, and diarrhoea all commonly reported pre-menstrual and menstrual symptoms. In addition, There is evidence that in the second half of the cycle, as progesterone levels increase, we become slightly more insulin resistant, which means insulin – which is responsible for keeping our blood-sugar level stable – becomes less effective. When our blood sugar is slightly less stable, this can cause food cravings or periods of low energy which could have a knock on effect to performance, particularly during longer races where glucose availability is key to the onset of, and rate of fatigue. Some research also suggests colonic transit time is prolonged during the luteal phase of the menstrual cycle, when progesterone levels are highest. For athletes, it is important to consider if such differences might impact nutrition guidelines and practices such as the timing and total volume of food consumed, before, during, and after training and competition.

Biomechanics

Women tend to have a more economical gait and a lower rate of perceived exertion compared to men during endurance activities. Although, female biomechanics do put women at a significantly (up to 8 times) greater risk of knee joint injury. A wider pelvis, increases the Q angle between hip and knee, placing more angular stress on the knee joint. Over reliance on recruitment of the quadriceps muscles during running causes strength imbalance between the glutes and hamstrings at the back of the leg, and the quads at the front. Females also tend to have poorer movement mastery and functional movement techniques, which mean their limb and body position during running, lunging, squatting, landing, turning, accelerating and decelerating, often put lower body joints, particularly the knee, under greater strain, and at increased risk of injury.

Breast movement is a female-specific factor which can alter the biomechanics and energetics during running, and affords women with smaller breast sizes an advantage over those with larger breasts, if this latter group fails to find optimal breast support. Breast movement can shorten stride length, worsen running economy, increase muscle activation in the torso and increase perception of effort at a given running speed. The cumulative effect of biomechanical and physiological changes as a result of breast movement has been estimated to cost a mile over a marathon .

Pacing

When it comes to pacing during endurance events, a number of studies have shown that females adopt a more even pacing strategy, and slow down less across marathon distance events. One study found that females were 1.46-times more likely to maintain their running pace (defined as a decrease in velocity of 30%) compared to males [5]; the mean change in pace was 15.6% and 11.7% for male and females, respectively. Only one study has assessed sex-differences in pacing during ultra-endurance sport. In a 100-km ultra-marathon, the difference between male and female velocities at 10-km splits were examined, finding that females exhibited a slower relative starting speed, but a higher finishing speed than males. These findings suggest that females may pace better than their male counterparts during both marathon and ultra-marathon running, certainly in the non-elite category. The mechanisms underpinning the differences in pacing may extend beyond differences in fatigue resistance and also include disparities in decision making, such as overconfidence, risk perception, or willingness to tolerate discomfort. Compared to females, males consistently overestimate their abilities in endurance sport, congruent with a greater degree of slowing in the latter stages of racing. Individuals with a greater proclivity for risk appear to slow more considerably in distance running, even in regression models which account for other psychological constructs, training, and experience. Testosterone concentrations have been associated with risk-taking behaviour, and researchers speculate that this might contribute to the pacing explanation. If this is the case, it would also be interesting to consider if pacing is altered across the menstrual cycle, since oestrogen has been associated with greater risk taking, and in the days before ovulation, where oestrogen peaks, it would be interesting to see if pacing is influenced.

Psycho-social factors

The main barrier to many endurance runners is training time. One study, which surveyed participants of 38 and 53 mile races in Scotland found that negotiation-efficacy was important for factoring in training around work and family commitments. An inherent reduced sense of entitlement to leisure is thought to exist in females with caring responsibilities due to traditional family roles, thereby leading to constraints in training time. This may be an insight into why fewer females take part in ultra-running, particularly at the greater distances as these events take even greater amounts of time to train. Roles and responsibilities of males and females in the family have seen considerable changes in the last several decades, with men and women increasingly contributing equally to caring for children as more women are in employment. When domestic duties are shared between partners, overall physical activity participation is increased and enhanced, particularly for women; yet women still struggle to negotiate leisure and sport access in an environment where discourses of 'good motherhood' continue to denote women as the primary caregivers. In the Scottish ultra-race study, where even though both males and females expressed negotiation efficacy to find time to train, some females still reported having delayed training due to caring responsibilities for young children. Social expectations are often internalized and females can be less confident to negotiate time that is required for training. This lack of confidence presents as a complex mix of internal interpersonal, intrapersonal and structural constraints, and this warrants further investigation.

Participation Bias?

The influence of a runners performance level, on the gap between men and women, also partly explains why considering all runners gives an incorrect representation of the reality, as does considering elite runners only. The women who participate in ultra-endurance events (participation is usually between 10 and 20%) are likely to have specific (possibly even unique) characteristics, in terms of genetics, training history, training conditions and injury resilience. Therefore, considering the average performance of both men and women disadvantages the former, as it can be hypothesised that the pool of women racers demonstrate a specific, more homogenous, high performance orientated set of characteristics than the men participating in the event.

In fact, in our ACSM symposium in 2021, Sandra Hunter raised this very question, that she had been studying for the previous decade. Are sex differences in finishing times, or running velocity in marathon and endurance events, explained, even in part by the participation levels of men and women. Over a 31 year period, for the New York Marathon, approximately 34% of the sex difference in velocity among the first-place finishers was associated with the ratio of men-to-women finishers. The authors concluded that the greater sex difference in running speed that occurs with age and with increased finisher placing, was primarily explained by the lower number of women finishers than men. This group then studied ultra-marathon distance races, using top-10 ultramarathon running times, age at performance date, and the number of men and women finishers from 20 races (45–160 km) in the US Track and Field Ultra Running Grand Prix. Men were 18% faster than women for all events but the sex difference in speed was the least for 100 km (15) and greatest for 45km (19%). The sex difference in speed increased with finishing place (1st place 16% vs 10th 21%). The sex difference in speed was largest when there were fewer women than men finishers in a race. These data provide evidence that lower participation rates and less depth among women competitors can amplify the sex difference in running velocity above that due to physiological sex differences alone.

Final thoughts…

Do we need to understand sex differences at all? Why, in sport, do we need to understand so thoroughly the *difference* between males and females, when in fact, sport is always competed in a sex disaggregated manner (with few exceptions, such as equestrian events). Even in mass participation races, women compete in womens categories. Their performance isn't determined by their ability to run faster or do better than men, because sport, in order to be safe and fair, is governed to allow women to compete against women, and men to compete against men. However, because so little research is conducted in to womens bodies in sport, perhaps the reason it's so important to understand sex differences, is so that we can be very aware of when what we currently know about performance can't be assumed to hold true for women (because the original research was likely performed on males). Maybe knowing where sex differences exist will allow a more focused approach to understanding the female body in sport in the future. Where are the most prominent differences, and what questions does that ask of existing evidence based approaches, or assumed knowledge? Or maybe it's just interesting to consider, when we look to push the limits of human performance, or human endurance, where the opportunities are to allow women to truly fulfil their potential.