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Section: Invited Commentary

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INVITED COMMENTARY

NATURE VS. NURTURE: HAVE PERFORMANCE GAPS BETWEEN MEN AND WOMEN REACHED AN ASYMPTOTE?

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Running Head: Have Performance Gaps Reached an Asymptote?

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ABSTRACT

Men outperform women in sports requiring muscular strength and/or endurance, but the relative influence of “nurture” versus “nature” remains difficult to quantify. Performance gaps between elite men and women are well-documented using world records in second, centimeter or kilogram sports. However, this approach is biased by global disparity in reward structures and opportunities for women. Despite policies enhancing female participation (Title IX legislation), USA women only closed performance gaps by 2 and 5% in Olympic Trial swimming and running, respectively, from 1972 to 1980 (with no change thereafter through 2016). Performance gaps of 13% in elite mid-distance running and 8% in swimming (~4 min duration) remain, the 5% differential between sports indicative of load carriage disadvantages of higher female body fatness in running. Conversely, sprint swimming exhibits a greater sex difference than sprint running suggesting anthropometric/power advantages unique to swim block starts. The ~40 y plateau in the performance gap suggests a persistent dominance of biological influences (e.g., longer limb levers, greater muscle mass, aerobic capacity, lower fat mass) on performance. Current evidence suggests women will not swim or run as fast as men in Olympic events, which speaks *against* eliminating sex segregation in these individual sports. Whether hormone reassignment sufficiently levels the playing field in Olympic sports for transgender females (born and socialized male) remains an issue to be tackled by sport governing bodies.

Key Words: athletics; track; swimming; gender; sex difference

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Introduction

Sport is one of few institutions where men and women typically (but not always) are placed in distinct categories to compete, a practice established during the Modern Era of the Olympic Games. The battle of the sexes in sport continues to be a topic of interest in both scientific literature and the media (e.g., under isolated competitions when women outperform male competitors). The sex difference in performance is highly cited over several decades, predominantly in sports measured objectively by time (e.g., running, swimming), centimeters and kilograms. However, elite athletes by their nature are "outliers" so any valid comparison of men and women must be equally representative of the population distribution (e.g. top 0.5-1%) to assess differences.

Elite men outperform women in sports requiring muscular strength/endurance and/or aerobic capacity. [1,2,3] Much of this performance gap is explained by biological sex differences, but environmental influences arguably play an important role although difficult to quantify. [4] It was predicted [5] women would eventually equal or exceed men in running (200 m through the marathon) based upon greater rates of female performance improvement extrapolated over time. This sparked an ongoing debate; [6,7] specifically, will women athletes surpass men, particularly as distance increases in sports where greater inherent body fatness poses less of a disadvantage?

The performance gap (i.e., % sex difference) currently appears relatively stable for international distance running [3,8] and swimming, [9] but may be increasing [10] in sprint events, particularly when observed within shorter specific time frames. Current theories also suggest if the distance becomes sufficiently long (e.g., ultra-marathon running, swimming), [6,11-12] women will close the gap. However, contributing factors are not solely biological, but also socio-cultural (e.g., norms of acceptance, access to coaching, motivation, participation opportunities). [13] Both female percentage of events (47.5%) and competitors (45.5%) continued to increase in the 2016 Olympic Games.

Objective of this Commentary

Current approaches to examine the sex difference in performance rely upon world records or international race databases limited by selection bias due to unequal cultural acceptance and sport opportunities for women globally.[4] Thus, an alternate approach (i.e., examining sport performances following a major societal shift within a nation) attenuates this bias and facilitates partitioning the effects of nature vs. nurture. Our goal was to focus upon the effects on the performance gap following "equal opportunity" legislation in the USA.

Methodological Approach

Following 1972 federal legislation (Title IX), sport opportunities for USA women increased beyond high school (e.g., due to college scholarships), although the deadline for institutions to comply was much later. Moreover, recent financial incentives from USA National Team/Olympic medal compensation and professionalism are similar for men and women in swimming and running. [4] Therefore, examination of American elite performances since 1972 (Title IX) could reflect relative contributions of socio-cultural factors (nurture) versus assumed constants of biological differences (nature) on the performance gap. Swimming is distinct from other competitive sports in the USA, because boys and girls traditionally train together from early ages (7-8 y) up through college, having similar access to coaching and competition.[4] Moreover, unlike distance running, women's Olympic swimming has been held for over a century (similar to men), and long considered a socially acceptable, "gender neutral" sport for girls. [14] Comparison to another Olympic weight-bearing sport (i.e., running) with events of similar duration/ intensity could account for other biologically-relevant differences in performance. Furthermore, any historical change would estimate the magnitude of the effect that socio-cultural factors played in male-female differences, while any plateau thereafter theoretically representing the extent to which biological factors persist.

The Olympic Trials represents the most highly competitive event in the USA with all top athletes competing in a single competition. Thus, this yields a representative sample distribution of elite performances (as opposed to a random individual swim or track meet) under similar environmental conditions (unlike world records). Performance times for top eight finishers were extracted from official archived results on the websites of USA Swimming[15] and USA Track and Field News.[16] Only 100 to 1500 m events in athletics were extracted due to incomplete historical data (several female events not added until 1984), and distance only up to 400 m swimming where both men and women compete in the Olympics (with change to occur in 2020). The % sex difference was calculated for each pairwise comparison (1^{st} place male vs. 1^{st} place female through 8^{th} place) similar to other studies [7,10,17] using the following equation (where n = nth placing for a given event): Sex Difference (%) = $[(\text{Female}_n \text{ (s)} - \text{Male}_n \text{ (s)}) / \text{Male}_n \text{ (s)}] * 100$.

Historical progression of the performance gap

Data are illustrated each year by distance with a locally weighted polynomial regression for swim and run events (Figure 1 A and B), with an early plateau clearly observed in both sports. Following Title IX, overall mean swim performance gap was higher in 1972 (13.2 ± 2.0%) and 1976 (12.4 ± 1.7%) versus all subsequent years (1980-2016), remaining stable thereafter at 11.2 ± 1.7% (across all swim strokes/distances a net change of 2%). Surprisingly, the swimming performance gap was actually lower in 1968 compared to 1972, possibly due to the Olympic Trials held in different pools and dates (influencing performance due to timing of taper/rest cycles). For running (Panel B), the performance gap was also higher in 1972 (17.3 ± 3.0%) and 1976 (14.2 ± 2.4%) compared to all subsequent years (1980-2016), remaining stable at 12.6 ± 2.0% (net change of 4.7%). Greater sex differences occurred in swim sprints (50/100m) but, conversely, lower in run sprints (100/200m).

Compared to men in the 1972 Olympic Trials, women swimmers in 2016 would have placed among the top 8 men in 1972 in all events (winning 100 m Breaststroke, 400 m Freestyle*)* *except* for 100 m Freestyle (Table 1). In contrast, for every running event *except* the marathon, 2016 female winners would have placed *last* in the 1972 field of male competitors (Table 2). Narrowing of the run performance gap ranged from 3% (200 m) to 7% (800 m). However, the 5 km (added later to the Olympics) showed no closure in the gap and in 10 km, the gap actually widened significantly by 3%. This apparent paradox compared to swimming is likely due to technological enhancements (e.g. pool construction, lane lines and swim suit/equipment designs) and rule changes/stroke techniques that dramatically improved overall swim performances since 1972 as compared to a relative flattening in track performances.

Mandating similar athletic opportunities for girls (Title IX) clearly narrowed the performance gap. We estimate increased opportunities for women in the U.S. closed the performance gap up to 5%, but at a magnitude of less than half (2%) in a sport (swimming) with a longer history of elite competition and social acceptance for women. Moreover, this narrowing in the gap occurred relatively soon (within 8 y), remaining stable at ~13 and 11% for run/swim sprints to mid-distance events, similar to world best times using regression models finding a stable gap (since 1983) averaging 10-11% for running (all distances through the marathon) and 9% for swimming. [9] As suggested previously[10], the question is whether current environmental influences (opportunity, reward structures) are minimally contributing to this gap, suggesting differences are now attributed predominantly to nature? At the elite level, significant sex differences persist, which speaks *against* eliminating sex segregation in these Olympic sports. [18]

Influence of event duration

Performance gaps in events of similar duration are compared in Figure 2 (averaged across 1980-2016) for < 30 s (50 m freestyle vs. 200 m run), ~60 s (100 m freestyle vs. 400 m run), ~120 s (200 m freestyle vs. 800 m run) and ~240 s (400 m freestyle vs. 1500 m run). Performance gaps differed by sport across all event durations but were lower in running 200 m compared to swimming 50 m freestyle by 2% and higher for running in events $\geq$ 60 s, widening to 5% at ~4 min. As distance increased, performance gaps in swimming became progressively smaller; however, this inverse relationship was absent in running, a consistent finding across world record run performances from 1500 m through the marathon. [3,8,19]

The smallest performance gaps (100 m run, 400 m freestyle) occurred on opposite ends of the sprint-endurance spectrum. Based on the 5% higher gap in running versus swimming in a 4 min Olympic event, fat mass carriage likely contributes ~5% of the running performance gap, representing ~37% of the total performance gap in the 1500 m. Interestingly, this corresponds to an experimental model where adding excess mass to men (normalizing to their female counterparts' body fatness) reduced the sex difference in run performance by 30% [20], a stronger predictor than run economy or cardiorespiratory capacity.[21]

After "removing" the impact of fat/load carriage, the residual male advantage in swimming 400 m remains at ~8% (Figure 2). Numerous factors may account for this. Lower absolute cardiorespiratory capacity due to: reduced hemoglobin mass, blood volume, heart/lung size relative to stature, and muscle mass likely explain female disadvantages [1,8] as well as shorter levers applying force (distance per stroke). Leg power off start/turns appear to contribute ~1% of the male advantage [22] in 400 m pool swimming, based upon slightly lower differences (~7%) in elite 10 km open water swimming. [17] Reduced sex differences as swim distance increases is consistent with others, [7,23] but contrasts with ultra-distance running where the magnitude of performance gaps may widen (up to ~17% faster for men). [24,25] A lower disadvantage for women in open water distance swimming[26,27] is attributed to enhanced center of buoyancy, [28] swimming economy,[19] greater mechanical efficiency [29] and lower underwater torque (tendency for feet to sink). [30] However, data from select ultra-distance events (i.e., non-representative samples)[26,27] led to speculation that if competitive events are long enough, women may eventually close the performance gap in distance running[11] and swimming.[12] Unlike predictions of eventual closure, [12] current evidence using representative elite populations[17] suggests a sex difference will persist.

One might assume performance gaps would be greatest in events requiring explosive muscular power/sprinting ability, but we found this only in swimming, not running. The greater gap in sprint swimming (13%) vs. running (10-11%) suggests anthropometric advantages associated with the start and/or upper body power in swimming contribute an additional ~2% beyond advantages for men assumed during sprint running. The gap was predicted to eventually close in sprints, [31] an interesting position given our lowest performance gap in the 100 m run. A small rise in performance gap of sprint events during the 1980s was attributed to improved drug testing, presumably reducing anabolic steroid abuse in women. [10] Physical characteristics advantages under the influence of testosterone (muscular hypertrophy/strength) are well known. [32] However, if power/strength advantages are the primary determinants of sprint performance, then in both swimming and running the shortest Olympic distances (50 m and 100 m, respectively) we might expect a greater male advantage, which was observed only in swimming and not running. Our data was consistent with the proposal that less inertia to be overcome by women to accelerate a smaller body mass on land might explain lower sex differences associated with the shortest running events on the track. [33]

A significant portion of the residual sex difference observed in elite sprint running (~10%) is likely due to greater male muscle mass to generate peak horizontal power, although few studies on anaerobic power differences are available.[34] Testosterone levels do not predict performance in sprint/power events in elite athletics. [35] Furthermore, sex is not binary with examples of genetic intersex conditions, which may be more prevalent in elite female Olympians. [18] The validity of sex testing for sport classification (based on testosterone levels) remains a controversial issue beyond the scope of this commentary. However, looming as a future issue is whether testosterone hormone reassignment (after some minimal time following "completion of anatomic changes") sufficiently levels the playing field in Olympic sports for transgender females (born and socialized male).[36,37] Longitudinal studies following post-pubertal hormone reassignment might quantify the impact of testosterone per se on performance. Although few IOC cases are under consideration, post-pubertal anthropometric advantages (stature, lever length) would presumably persist along with any potential socio-cultural "advantage" during growth and development.[36]

Nurture factors remaining to be quantified

In terms of other "nurture" factors, increasing age of elite athletes reflects motivation to train and remain competitive in sport. Men and women may peak at similar ages (late 20s), but top placing marathoners were older for women. [38] Older swimmers are returning due to professional sponsorships available (e.g., 41 y old female 2008 Olympic silver medalist). Recent reports [39] suggest 20 y is the peak age for international swimming with "little sex difference" consistent with Olympic medalists in swimming. [40] Although some key factors (increased professional opportunity, later competitive age) appear "equivalent" between the sexes, other possible "nurture" influences may remain, although difficult to quantify. Some sports may favor greater male professional sponsorships and create more limitations for women to return following extended lay-offs or other time challenges for training during childbearing years. Given the historical context (2% narrowing in swimming over 44 y), a reasonable assumption might be that no more than 2% of the current performance gap could still potentially be attributed to socio-cultural influences (e.g., in running or other sports).

Conclusion

Performance gaps between USA men and women stabilized within less than a decade after federal legislation provided equal opportunities for female participation but only modestly closed the overall gap in Olympic swimming by 2% (5% in running). Although performance gaps narrow as swimming distance increases, the opposite effect (lowest gap at shortest distance) occurs in running. The magnitude of each biological "advantage" for men is, therefore, not necessarily constant along sprint/endurance domains, further compounding the difficulty in quantifying socio-cultural influences on the performance gap. The sex difference in 400 m swimming (8%) compared to 1500 m running (13%) suggests a 5% mode differential is due to sex-specific fat during weight bearing. Other advantages include lever lengths and stature, particularly more evident in sprint swimming than running (added on top of the ability to generate greater peak velocity). Stable historical trends in a society accepting of female Olympic athletes suggest women will not swim or run as fast, primarily due to underlying biological differences. Future trends may prove otherwise if sex classification lines continue to blur.[18]

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Disclosure statement

No potential conflict of interest was reported by the authors.

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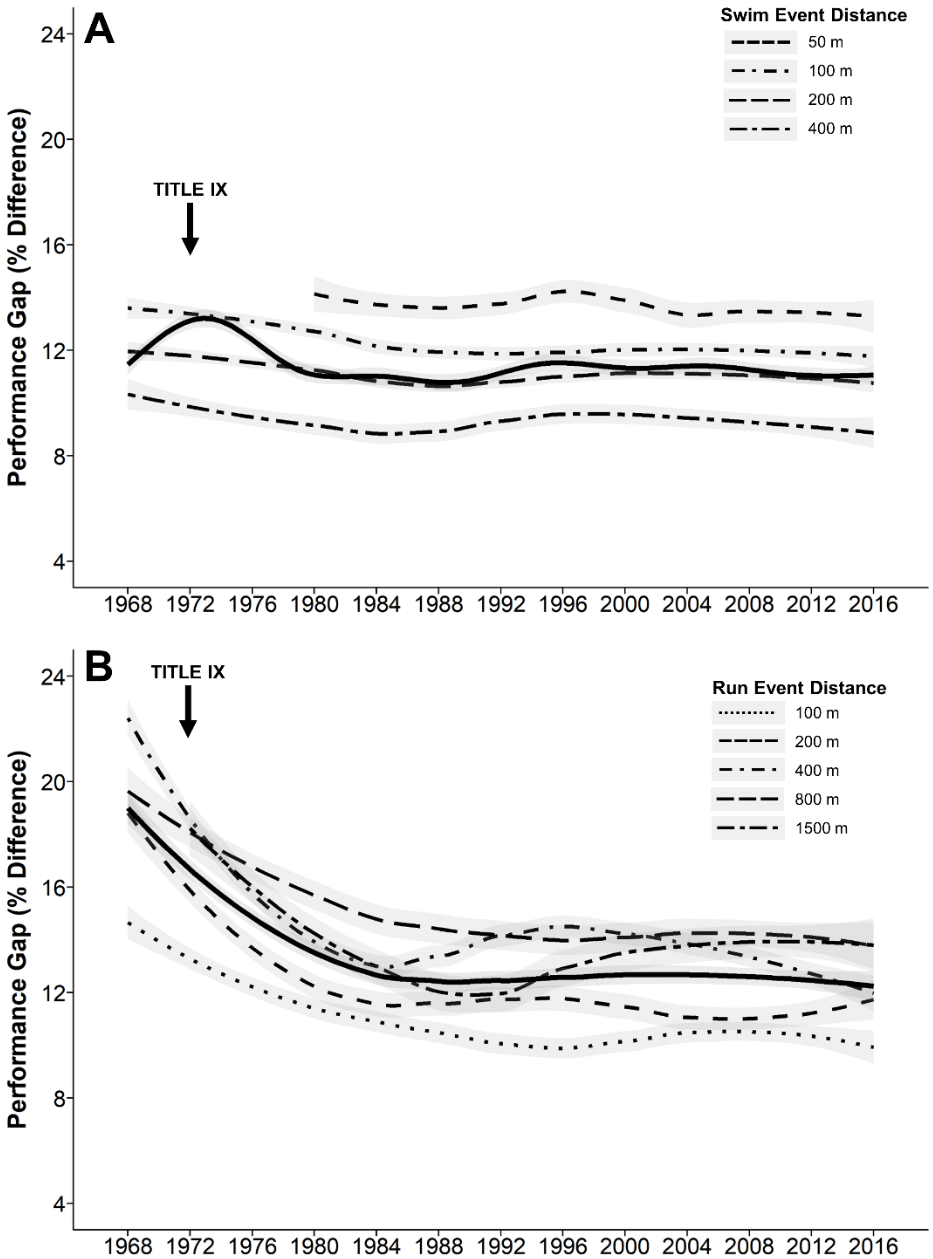

Figure 1. Performance gap in USA Olympic Trials (1968-2016) for top eight finalists over time with data smoothing function plotted by distance (Panel A: All swimming strokes combined and Panel B: Running events up to 1500 m). Solid lines denote the overall mean and shaded areas represented 95% Confidence Intervals. Stabilization occurred after 1980.

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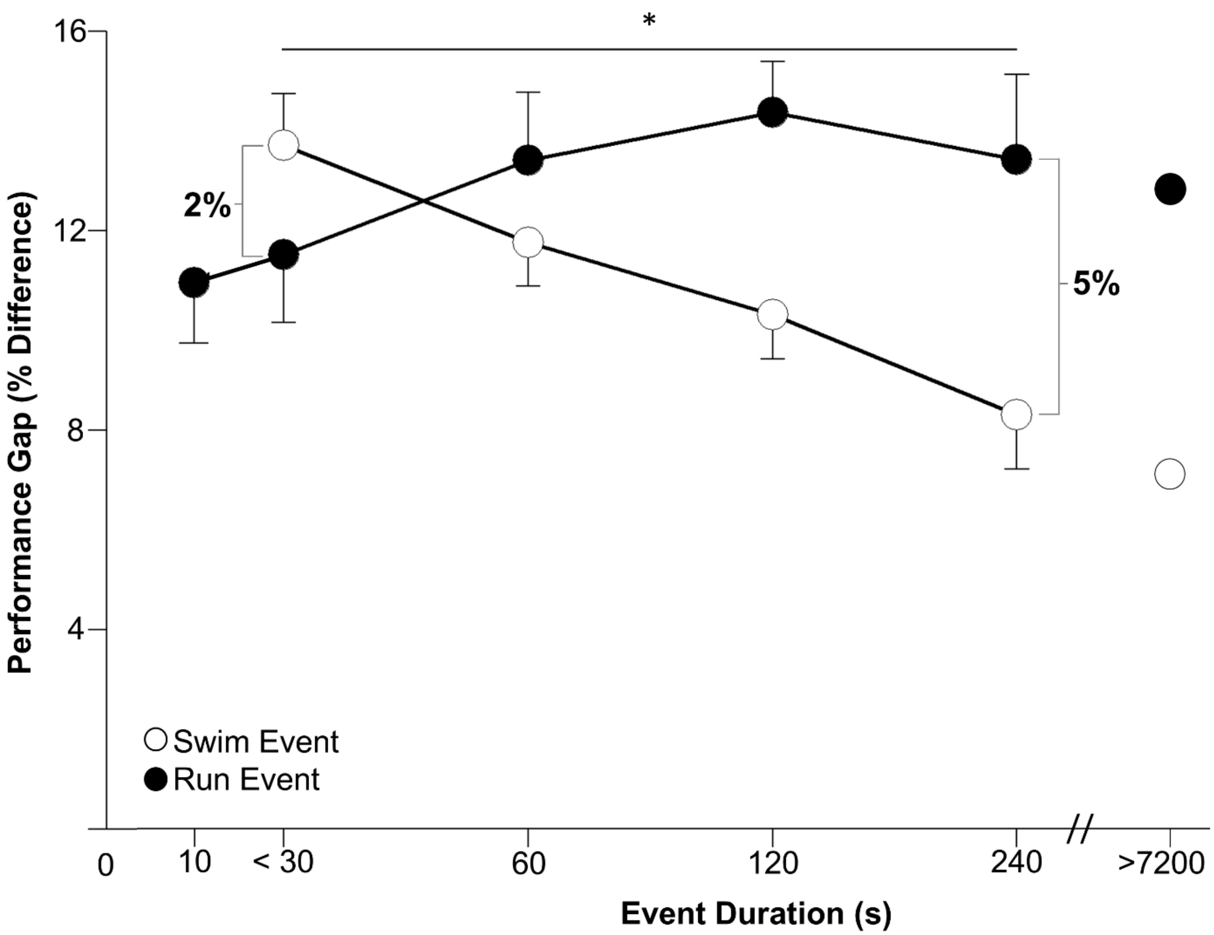

Figure 2. Mode-specific sex differences after historical stabilization (collapsed across USA Olympic Trial data years 1980-2016). Events compared by relative duration: < 30 s= 50 m Freestyle vs. 200 m Run; 60 s = 100 m Freestyle vs. 400 m Run; 120 s = 200 m Freestyle vs. 800 m Run; 240 s = 400 m Freestyle vs. 1500 m Run.

* indicates difference between freestyle swimming and running at each duration. Open and closed circles at 7200 s are published values.[3,17]

Table 1. %Sex Difference by Swimming Event Over 44 Years (1972 vs. 2016)

SWIMMING	**Mean (±SD) Sex Difference by Event (1972 vs. 2016)**		**1st Place Time (s)**		**2016 Top Woman's Place in Men's 1972 Race**
Event	**1972**	**2016**	**1972 Men**	**2016 Women**	
50 m Free	14.3 ± 0.5%[A]	13.1 ± 0.5%*	23.07	24.28	70th
100 m Free	13.2 ± 0.4%	10.9 ± 0.6%*	51.91	53.28	9th
200 m Free	11.2 ± 0.6%	9.3 ± 0.6%*	113.58	114.88	5th
400 m Free	9.5 ± 0.8%	8.5 ± 1.5%	240.70	238.98	1st
100 m Back	14.6 ± 0.9%	11.8 ± 1.3%*	58.61	59.02	2nd
200 m Back	14.4 ± 1.3%	10.9 ± 0.5%*	126.57	126.90	3rd
100 m Breast	16.2 ± 1.0%	12.0 ± 0.9%*	65.99	65.20	1st
200 m Breast	13.5 ± 0.7%	12.3 ± 1.1%*	143.27	144.08	2nd
100 m Fly	14.9 ± 1.1%	12.7 ± 1.4%*	54.56	56.48	2nd
200 m Fly	12.7 ± 1.1%	11.4 ± 0.9%*	121.53	126.80	12th
200 m IM	13.0 ± 1.2%	10.7 ± 1.0%*	129.30	129.54	Tie 2nd
400 m IM	12.0 ± 1.1%	9.0 ± 0.8%*	270.81	273.73	3rd
Overall	**13.2 ± 2.0%**	**11.1 ± 1.5%**	-	-	-

[A] For 50 m Free, 1980 is the earliest year available for women so compared both groups from 1980

* Performance gap narrowed ($p < 0.05$) for all events except 400 m Free

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Table 2. %Sex Difference by Running Event Over 44 Years (1972 vs. 2016)

RUNNING	**Mean (±SD) Sex Difference by Event (1972 vs. 2016)**		**1st Place Time (s)**		**2016 Top Woman's Place in Men's 1972 Race**
Event	**1972**	**2016**	**1972 Men**	**2016 Women**	
100 m	13.4 ± 0.6%	9.1 ± 0.9%*	9.90	10.74	> 38th [X]
200 m	15.5 ± 0.8%	12.6 ± 1.0%*	20.40	22.25	>28th [X]
400 m	19.1 ± 1.3%	11.9 ± 0.7%*	44.01	49.68	>20th [X]
800 m	20.4 ± 0.6%	13.2 ± 0.6%*	104.30	119.10	>26th [X]
1500 m	18.3 ± 3.4%	13.9 ± 0.5%*	221.50	244.74	>24th [X]
5 km	11.8 ± 0.7%[B]	11.9 ± 0.7%	802.80	905.01	>18th [X]
10 km	9.8 ± 0.4%[C]	12.7 ± 0.5%†	1715.60	1901.62	>15th [X]
Marathon	15.5 ± 0.5%[D]	12.8 ± 0.7%*	8157.80	8900.00	20th
Overall	**17.3 ± 2.8%**	**12.1 ± 1.9%**	-	-	-

* Performance gap narrowed ($p < 0.05$).

† Performance gap widened ($p < 0.05$) from 1988 (earliest common available data for both men and women).

[B] For 5 km, 1996 is the earliest year available for women.

[C] For 10 km, 1988 is the earliest year available for women.

[D] For marathon, 1984 is the earliest year available for women.

[X] Place corresponds to the total number of male Olympic Trial competitors listed (or last place finish in 1972 for the 2016 top woman).