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Women Upward—Sex Differences in Uphill Performance in Speed Climbing, Ski Mountaineering, Trail Running, Cross-Country Skiing, and Cycling

Grégoire P. Millet,[1] Antoine Raberin,[1] Raphael Faiss,[1] Nicola Giovanelli,[2] Thierry Galindo,[3] Nicolas Place,[1] and Øyvind Sandbakk[4]

Q1 [1]Institute of Sport Sciences, University of Lausanne, Lausanne, Switzerland; [2]Department of Medicine, University of Udine, Udine, Italy; [3]Fédération Française de la Montagne et de l'Escalade, Paris, France; [4]School of Sport Science, UiT The Arctic University of Norway, Tromsø, Norway

Introduction: Women have generally lower values in body size and lean to fat mass ratio, maximal anaerobic power due to a lower muscle mass, and fewer fast-twitch fibers, although they can show higher resistance to fatigue or greater metabolic flexibility than men. These factors are well known and explain the sex differences in endurance sports such as distance running (10%–12%). Several of the above-cited factors—particularly the differences in body composition and in skeletal muscle characteristics—may directly impact the vertical displacement and uphill performance. However, there is a lack of sex difference reports in sports with uphill locomotion. ***Methods:*** The sex differences in world-level endurance performance over 10 years (2013–2022) in 6 different sports with uphill displacement (speed climbing, vertical race in ski mountaineering, vertical kilometer in mountain running, cycling, cross-country skiing, and ultratrail running) were calculated. ***Results:*** The sex differences are generally larger (18%–22%) than in endurance sports performed primarily on flat terrains. This may be due to the lower lean to fat mass ratio commonly reported in women. On shorter uphill events (eg, sport climbing, vertical kilometer, and short climb in cycling), the sex differences appear even more pronounced (28%–35%), potentially being explained by additional factors (eg, anaerobic capacity, muscle composition, and upper body contribution). ***Conclusion:*** This novel analysis over 10 years of elite endurance performance in different sports with uphill displacement shows that the sex differences are Q2 generally larger (18%–22%) than in endurance sports performed primarily on flat terrains.

Keywords: women, men, elite athletes, body composition

Women remain underrepresented in sport science research, making up only 39% of total participants in studies published in 3 leading journals in this field. Less than 13% of these studies focused exclusively on women,[1,2] despite that medical outcomes conducted on men are not always fully applicable to women given the anatomical, physiological, and hormonal differences between sexes. One way to better understand these sex differences is by comparing male and female performances in different sports.

Differences in sport performance are a topic of increasing interest, with a large body of literature in many endurance (eg, distance running, swimming, cycling, etc), explosive power (eg, track sprinting), and team sports. A general consensus is that sex differences in endurance performance are relatively homogeneous at 8% to 12% across many sports (eg, speed skating, track or road running, swimming rowing, kayaking, track cycling, etc).[3–5] The physiological and anthropometrical factors explaining this difference are well known. First, it arises from a lower maximal oxygen uptake in women that is known for decades,[6,7] with the highest published values of 92 to 96.7 mL/kg/min in males[8,9] and 78 to 80 mL/kg/min in females,[10,11] mainly due to convective factors (eg, total hemoglobin mass and cardiac output), whereas diffusive muscle factors may be slightly more effective in women.[12] Women also have generally lower values in body size and lean to fat mass ratio, as well as lower maximal anaerobic power due to a lower muscle mass and less fast-twitch fibers,[13–15] although they can show higher resistance to neuromuscular fatigue[16,17] and greater metabolic flexibility (ie, rate of lipid oxidation).[18,19]

These sex differences in sport performance have been shown to remain relatively stable over the last 4 decades,[20,21] confirming that sexual dimorphisms are the primary cause of it, although additional factors directly impacting female participation in sport (eg, economical, sociological, and psychological) cannot be ruled out.

Several of the above-cited factors—particularly the differences in body composition and in skeletal muscle characteristics—may directly impact the vertical displacement and uphill performance. However, to our knowledge and surprisingly, there is a lack of sex difference reports in the sports with uphill locomotion.

Beyond the interest of such analysis to better describe sexual dimorphism, it may also have direct implication for comparing sport events (eg, trail vs road or track running). For example, we[22] recently reported that the sex differences (2011–2022: 17.1% [6.4%], 16.9% [5.5%], and 16.3% [6.7%], respectively; mean [SD]) in 3 races of various distances of the world's most important mountain ultramarathon event (ie, Ultra-Trail du Mont Blanc, 170 km, 10,000 D+ positive elevation; Courmayeur-Champex-Chamonix, 100 km, 6100 D+; and Orsières-Champex-Chamonix, 100 km, 6100 D+) were larger than the commonly assumed 8% to 12%. This was particularly surprising as it is generally advocated that women exhibit several metabolic characteristics that would confer an advantage in ultraendurance competition.[23] Finally, a

Raberin https://orcid.org/0000-0001-5032-8301
Faiss https://orcid.org/0000-0001-6029-9516
Millet (gregoire.millet@unil.ch) is corresponding author, https://orcid.org/0000-0001-8081-4423 Q3

better understanding of how incline influence sex differences in elite sport performance may contribute to practical applications in these sports as sex-adapted pacing, training, or recovery methods.

The aim of the present article was therefore to analyze sex differences in elite performance across sports performed in uphill terrain.

Methods

In our descriptive study design, the top-10 performances of women and men, respectively, in World-level (ie, world cup, world championship, and professional competitions) events were extracted in the following 6 sports over a 10-year period (2013–2022):

1. Speed climbing: All world cup and world championships results over a 10-year period were collected from https://ifsc.results.info. As speed climbing is a head-to-head sport, the best time from the top 10 men in the final rounds was compared with the best time from the top 10 women in the final rounds. The average times for the top 10 men and the top 10 women in the final rounds were calculated. Any values that were more than 20% above the best time were not included, as they were considered to be due to a technical error and/or a stop in effort (eg, fall of the direct opponent, technical fault, false start, etc). Because of the COVID-19 pandemic, no event took place in 2020.
2. “Vertical race” in ski mountaineering: All world cup and world championships results over a 10-year period were collected from https://www.ismf-ski.org. Control of the race conditions (eg, same course and similar snow and weather conditions) between male and female competitors was performed by an expert (T.G.) to ensure an accurate sex difference calculation.
3. “Vertical kilometer” in mountain running: The most important national and international vertical kilometer races were analyzed. Some of them were included in Vertical Kilometer World Circuit (under the International Skyrunning Federation) and others were under World Athletics (for the difference between mountain running, trail running, skyrunning, see Scheer et al[24]). Only the races at which athletes from national teams took part were selected. This allowed us to be sure that the performance caliber in both women and men field was of the world-class level. Because in 10 years the rules and the calendars changed a lot, it was not possible to have the same number of results for all races (see Table 1). The rankings of each race were downloaded from the race websites and then compiled into an Excel spreadsheet for statistical analysis. Of note, in the Chiavenna–Lagunc vertical race, the use of poles was not allowed, and in the other races, it was allowed, but we do not know if the athletes used poles or did not. Also, we could not consider the world championships or world cup in mountain running races because the race courses between men and women were usually different.
4. Cross-country skiing: Tour de Ski performances in flat and uphill terrains for the last 9 km race stage in the years 2012 to 2019 were collected from www.fis-ski.com by an expert (O.S.). These were seasons with pursuit races and relatively comparable conditions (except 2014, in which women tended to have faster race conditions than men). The initial 5.8 km is performed in flat/varied terrain and was defined as level terrain, whereas the last 2 km has a 405-m elevation and was defined as uphill.
5. Road and track cycling: Climbing times for road cycling were retrieved from publicly available GPS data recorded on https://www.strava.com and cross-checked with final race result (with the finish of the race at the top of the selected climb) from https://www.procyclingstats.com. Climb time for the winner and average time for the first 10 riders were used for comparisons. Track cycling data were extracted for the world championships races from publicly available detailed race results from the race timing company https://www.tissottiming.com/2024?sport=ctr. Average speed over the racing distance was calculated for the winner and top-10 riders for comparisons.
6. Mountain ultrarunning: Uphill and downhill split times for the 3 main of the 3 highest passes (col Bonhomme, col de la Seigne, and Grand col Ferret of the Ultra-Trail du Mont Blanc) were retrieved from publicly available split times on https://utmbmontblanc.com.

Q4 Q5

Male and female winners’ performances as well as the mean of the top-10 results were used to calculate sex differences. Yearly average was then calculated in each sport, and the average of the 100 male and female results (10 y × top-10) was calculated for a comparison across sports (Tables 1–6).

Results

Sex differences between the male and female winners for each sport are reported in Tables 1 to 6 together with the comparison of the top-10 male and female performers. As top-10 was regarded more robust by minimizing the impact of individual atypical performances (ie, super-performer in 1 sex category), the results and discussion will focus on top-10 sex differences, unless mentioned otherwise.

The sex difference in speed climbing (Table 2) ranged between 29.1% and 37.3% (10-y average: 34.1%) and is larger than the one reported in the “Vertical race” in ski mountaineering (10-y average: 22.8%) (Table 3). The sex difference reported in running “vertical km” (28.2%) was also larger than the known value in distance running (eg, 10%–12%) (Table 1).

In cross-country skiing (Table 4), the sex difference was almost 2-fold uphill when compared with the flat section (18.4% vs 9.4%).

In professional road cycling, the only data available at the professional level for uphill performances over the 10-year period were on a short climb of ~3 min. The sex differences were larger uphill than for flat performance (individual track pursuit; 31.5% vs 9.2%).

Finally, in mountain ultrarunning, the sex differences of the uphill and following downhill sections of the 3 highest passes of the Ultra-Trail du Mont Blanc were calculated. Uphill and downhill sex differences were very similar (19.7% vs 22.0%).

To emphasize the differences between sports, the uphill sex differences in the 6 sports are displayed in Figure 1.

Discussion

To our knowledge, the present analysis provides novel data of the sex differences in uphill elite sport performances. The main findings of the present study are as follows:

1. Uphill sex differences are relatively homogeneous (18%–22%) across endurance sports with relatively long competition times (ski mountaineering, cross-country skiing, and ultratrail)

Table 1 Performances 2013–2022 in Male and Female Elite Athletes in "Vertical Kilometer" Running

Location, country (distance, km; D+, m)	Record men: Time (year) Athlete	Record women: Time (year) Athlete difference, %	Sex difference between male and female winners, % *Sex difference between means of top-10 male and female athletes, %* 2013	2014	2015	2016	2017	1018	2019	2020	2021	2022	Mean (SD) 2013–2022
Canazei, ITA	31:34 (2016)	37:39 (2017)	25.4	16.4	17.5	22.0	15.1	19.0	19.1	14.8	19.2	19.1	18.8 (3.2)
(2.6; 1000)	P. Gotsch	A. Mollaret 19.3	*26.9*	*21.4*	*19.8*	*24.2*	*20.4*	*22.6*	*26.7*	*39.6*	*35.3*	*24.3*	*26.1 (6.5)*
Chamonix, FRA	34:07 (2015)	39:50 (2019)	20.2	20.9	20.7	21.8	17.5	23.4	13.5		19.5	17.9	19.5 (2.9)
(3.8; 1000)	F. Gonon	C. Dewaelle 16.8	*26.5*	*22.6*	*23.5*	*20.7*	*21.0*	*37.5*	*26.3*		*27.3*	*21.7*	*24.1 (2.8)*
Chiavenna, ITA	30.30 (2013)	35:40 (2018)	23.7	25.6	22.2	20.7	9.7	10.7	35.2	20.1	12.7	13.6	19.4 (7.9)
(3.1; 1027)	B. Dematteis	A. Mayr 16.9	*21.3*	*25.3*	*26.2*	*30.8*	*21.6*	*24.1*	*39.9*	*22.4*	*22.3*	*21.6*	*25.6 (5.8)*
Col di Lana, ITA	33:19 (2018)	39:49 (2018)		26.7	24.0	23.3	24.8	19.5		19.6	20.9	16.2	21.9 (3.4)
(2.0; 1000)	V. Kovacic	V. Kreuzer 19.5		*37.0*	*35.0*	*36.9*	*35.1*	*40.4*		34.2	*36.3*	*30.7*	*35 (2.8)*
Fully, CH	**28:53** (2017)	34:14 (2022)	20.6	16.9	31.7	18.7	21.8	15.7				10.4	19.4 (6.6)
(1.92; 1000)	P. Gotsch	C. Dewaelle 18.5	*30.1*	*24.9*	*27.3*	*30.4*	*24.0*	*20.7*				*26.0*	*26.2 (3.4)*
Grand Serre, FRA	30:13 (2018)	**34:01** (2019)	15.3	17.4	18.0	14.4	13.1	14.5	5.5		12.9	11.2	13.6 (3.7)
(2.07; 1000)	R. Bonnet	A. Mollaret 12.6	32.9	*31.0*	*28.6*	*22.5*	*24.2*	*22.4*	*22.6*		*24.3*	*17.4*	*25.1 (4.9)*
Limone, ITA	36:02 (2018)	42:43 (2021)	24.2	33.3	15.8	15.4		21.5	28.3		11.1	25.2	21.9 (7.4)
(3.7; 1080)	R. Bonnet	A. Mayr 18.5	*27.1*	*31.3*	*24.6*	*25.3*		*27.1*	*48.9*		*26.6*	*46.1*	*32.1 (9.7)*
Rosetta, ITA	47:57 (2021)	59:26 (2021)						33.3	26.7	22.9	23.9	22.1	25.8 (4.5)
(6.9; 1979)	T. Moia	V. Kreuzer 23.9						*28.3*	*28.3*	*26.6*	*36.0*	*28.5*	*30.6 (4.0)*
Mean (SD)			21.6 (3.7)	22.5 (6.3)	21.4 (5.4)	19.5 (3.5)	17.0 (5.6)	19.7 (6.8)	21.4 (10.8)	19.4 (3.4)	17.2 (4.9)	17.0 (5.2)	**20.0 (3.5)**
			27.5 (3.9)	*27.6 (5.6)*	*26.4 (4.7)*	*27.2 (5.7)*	*24.4 (5.5)*	*27.3 (6.6)*	*32.1 (10.1)*	*30.7 (7.7)*	*29.7 (6.0)*	*27.0 (8.8)*	***28.2 (4.1)***

Note: Last column displays the 10-year mean and SD of the reported sex differences.

Table 2 Sex Difference (%) in World Cup and World Championship Performances 2013–2022 in Male and Female Elite Athletes in Speed Climbing

Sex difference between male and female winners, %
Sex difference between means of top-10 male and female athletes, %
World Records—Male: Kiromal Katibin (INA) 5:00 (2022). Female: Aleksandra Miroslaw (POL) 06:53 (2022)—30.6

2013	2014	2015	2016	2017	2018	2019	2021	2022	
Chongqing, CHN	Chongqing	Saanich, CAN	Chongqing	Chongqing	Moscow, RUS	Moscow	SL City, USA	Seoul, KOR	
(22.03.13)	(27.04.14)	(17.05.15)	(30.04.16)	(22.04017)	(21.04.18)	(12.04.19)	(28.05.21)	(05.05.22)	
35.5	31.3	29.2	41.6	34.2	30.7	28.8	41.9	20.4	
41.2	*33.3*	*27.5*	*39.5*	*34.3*	*26.9*	*33.1*	*37.8*	*28.0*	
Baku, AZE	Baku	Chongqing	Nanjing, CHN	Nanjing	Chongqing	Chongqing	Villars	S.Lake	
(22.06.13)	(03.05.14)	(20.06.15)	(08.05.16)	(30.04.17)	(05.05.18)	(26.04.19)	(01.07.21)	(22.05.22)	
28.6	40.4	36.3	33.7	33.2	31.1	29.5	35.6	24.0	
33.0	*34.6*	*34.7*	*37.8*	*36.8*	*34.6*	*28.1*	*35.2*	*26.6*	
	Haiyang	Haiyang	Chamonix	Villars	Tai An, CHN	Wujiang	Moscow	SL City	
	(20.06.14)	(26.06.15)	(12.07.16)	(07.07.17)	(13.05.18)	(05.05.19)	(16.09.21)	(27.05.22)	
	38.5	33.1	38.8	45.1	34.1	30.8	22.2	19.1	
	38.7	*33.8*	*37.5*	*41.3*	*38.6*	*30.7*	*25.5*	*28.0*	
Perm, RUS	Chamonix, FRA	Chamonix	Villars, CH	Arco	Villars	Villars		Villars	
(20.09.13)	(10.07.14)	(10.07.15)	(15.07.16)	(25.08.17)	(07.07.18)	(04.07.19)		(30.06.22)	
26.6	28.1	34.8	36.1	35.7	33.0	36.8		33.1	
23.9	*31.8*	*31.2*	*39.5*	*42.6*	*28.9*	*36.9*		*38.5*	
Mokbo, KOR	Arco, ITA	Wujiang	Arco,	Edimburgh, GBR	Chamonix	Chamonix		Chamonix	
(27.09.13)	(30.08.14)	(17.10.15)	(26.08.16)	(23.09.17)	(13.07.18)	(11.07.19)		(08.07.22)	
43.5	38.3	30.3	39.8	24.1	32.4	33.0		28.2	
46.2	*35.6*	*27.9*	*43.4*	*31.6*	*34.7*	*35.6*		*26.2*	
Haiyang, CHN	Gijon, ESP		Paris, FRA	Wujiang	Arco	Hachioji, JPN		Edimburgh	
(16.10.13)	(08.09.14)		(14.09.16)	(07.10.17)	(27.07.18)	(11.08.19)		(09.11.22)	
33.3	49.6		29.0	25.0	32.8	26.9		23.2	
37.1	*44.2*		*33.1*	*30.5*	*333.7*	*32.9*		*24.1*	
Wujiang, CHN	Mokbo		Wujiang	Xiamen	Innsbruck, AUT	Xiamen		Jakarta, IDN	
(20.10.13)	(11.10.14)		(18.10.16)	(14.10.17)	(06.09.18)	(18.10.19)		(24.09.22)	
26.6	31.6		29.0	40.7	34.3	24.2		29.3	
30.2	*28.7*		*32.0*	*40.9*	*32.7*	*30.9*		*32.6*	
	Wujiang		Xiamen		Wujiang				
	(18.10.14)		(22.10.16)		(20.10.18)				
	34.0		32.3		31.7				
	33.7		*35.3*		*35.1*				
					Xiamen				
					(27.10.18)				
					34.5				
					37.8				
34.0 (7.4)	36.5 (6.8)	32.7 (3.0)	35.0 (4.8)	34.0 (7.6)	32.7 (1.4)	30.0 (4.1)	33.2 (10.1)	25.3 (5.1)	**32.7 (6.2)**
36.2 (7.7)	*35.1 (4.7)*	*31.0 (3.3)*	*37.3 (3.7)*	*36.9 (4.9)*	*33.7 (3.8)*	*32.6 (3.0)*	*32.8 (6.5)*	*29.1 (4.9)*	***34.1 (5.2)***

Note: Last column displays the 10-year mean and SD of the reported sex differences.

Table 3 Sex Difference (%) in World Cup and World Championship Performances 2013–2022 in Male and Female Elite Athletes in "Vertical Race" Ski Mountaineering

Sex difference between male and female winners, %
Sex difference between means of top-10 male and female athletes, %

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	
Ahrntal, ITA	Verbier, CH	Puy St Vincent, FRA	Arinsal, AND	Arinsal, AND	Wanlong, CHI	Arinsal, AND	Arinsal, AND	Ponte di Legno, ITA	Ponte di Legno, ITA	
(12.01.2013)	(19.01.2014)	(12.01.2015)	(17.01.2016)	(22.01.2017)	(15.12.2017)	(27.01.2019)	(26.01.2020)	(20.12.2020)	(17.12.2021)	
22.3	16.0	19.3	19.9	19.3	24.0	24.4	20.1	18.1	17.4	
26.8	*23.0*	*23.6*	*23.3*	*21.6*	*26.3*	*25.3*	*23.0*	*22.4*	*20.9*	
Pelvoux, FRA	Courchevel, FRA	Arinsal, AND	Les Marecottes, CH	Tambre, ITA	Arinsal, AND	Villars, CH	Berchtesgaden, GER	Verbier, CH	Arinsal, AND	
(14.02.2013)	(26.01.2014)	(25.01.2015)	(06.02.2016)	(01.03.2017)	(28.01.2018)	(13.03.2019)	(07.02.2020)	(29.01.2021)	(16.01.2022)	
19.2	14.3	21.4	21.4	19.3	16.5	19.9	22.1	20.1	18.3	
22.6	*22.8*	*24.2*	*24.2*	*21.4*	*18.4*	*21.2*	*23.05*	*22.2*	*21.1*	
Arinsal, AND	Les Diablerets, CH	Verbier, CH		Val Aran, FRA	Puy St Vincent, FRA	Disentis, CH		Arinsal, AND	Boi Taüll, ESP	
(09.03.2013)	(02.03.2014)	(7.02.2015)		(09.04.2017)	(09.02.2018)	(24.03.2019)		(04.03.2021)	(10.02.2022)	
21.9	13.3	16.1		21.2	18.8	19.8		18.2	13.3	
26.7	*22.4*	*19.9*		*24.4*	*23.2*	*23.3*		*22.8*	*18.6*	
						Madonna, ITA		Madonna, ITA	Flaine, FRA	
						(06.04.2019)		(26.03.2021)	(07.04.2022)	
						18.0		18.2	18.1	
						23.5		*19.3*	*20.9*	
21.1 (1.7)	14.6 (1.8)	19.0 (2.7)	20.6 (1.1)	19.9 (1.1)	19.8 (3.8)	20.5 (2.7)	21.1 (1.5)	18.7 (1.0)	17.9 (0.4)	19.2 (2.5)
25.4 (2.4)	*22.7 (0.3)*	*22.6 (2.4)*	*23.7 (0.7)*	*22.3 (1.8)*	*23.0 (3.5)*	*23.3 (1.7)*	*23.2 (0.4)*	*21.7 (1.6)*	*21.0 (0.1)*	*22.8 (1.9)*

Note: Last column displays the 10-year mean and SD of the reported sex differences.

Table 4 Sex Difference (%) in Tour de Ski Performances for the Last Stage 2012–2019 in Flat and Uphill Terrains

Terrain	2012	2013	2014#	2015	2016	2017	2018	2019	Average
Flat section	5.7	6.9	1.1	6.4	3.6	8.5	12.3	9.6	6.7 (3.5)
	10.3	*9.3*	*3.2*	*9.8*	*7.6*	*10.5*	*11.6*	*10.1*	*9.1 (2.6)*
Uphill section	17.6	19.2	12.9	13.8	11.6	18.3	12.5	20.7	15.8 (3.5)*
	17.3	*21.2*	*14.3*	*16.4*	*14.4*	*19.9*	*16.0*	*21.9*	*17.7 (3.0)**
Overall time	12.1	13.8	7.5	10.4	8.0	13.9	12.4	15.6	11.7 (2.9)
	14.2	*16.3*	*9.2*	*13.3*	*11.3*	*15.7*	*14.3*	*16.5*	*13.8 (2.5)*

Sex difference between male and female winners, %; *Sex difference between means of top-10 male and female athletes, %*

Note: These were seasons with pursuit races and relatively comparable conditions (except 2014#, in which women tended to have faster race conditions than men) over the 9-km race that is quite flat/varied terrain over the first 5.8 km with the last 2 km having a 405-m elevation. Last column displays the 10-year mean and SD of the reported sex differences.
*Significantly larger sex difference in the uphill compared with the flat section and overall time.

Q9 **Table 5 Performances 2013–2022 in Male and Female Elite Athletes in Professional Cycling**

	Sex difference between male and female winners, % *Sex difference between means of top-10 male and female athletes, %*										
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean (SD) 2013–2022
Uphill—Mur de Huy—Flèche Wallonne Records—Male: A. Valverde—02:58 (2014). Female: A. Van der Breggen—03:30 (2017) 18.0											
Mur de Huy	29.7	33.7	10.6	15.5	8.2	25.8	24.4	23.9	34.8	25.5	23.2 (9.1)
(1.24 km ; D+ 121 m ; slope 10%)	*34.3*	*36.4*	*27.6*	*30.1*	*29.5*	*28.9*	*27.8*	*27.4*	*39.5*	*33.9*	*31.5 (4.2)*
Flat (track cycling) Records—Male: F. Ganna—60.09 km/h (2022). Female: C. Dygert—54.74 km/h (2020) 8.9											
Individual pursuit	7.8	6.7	7.2	9.1	6.8	5.4	9.8	8.0	7.7	9.2	7.8 (1.3)
(Male 4 km; female: 3 km)	*9.3*	*8.8*	*8.1*	*10.5*	*9.0*	*9.3*	*9.7*	*8.3*	*9.9*	*8.8*	*9.2 (0.7)*

Note: Last column displays the 10-year mean and SD of the reported sex differences.

2. On shorter uphill events (eg, sport climbing, vertical km, and short climb in cycling), the sex differences appear even more pronounced (28%–35%).
3. When compared with horizontal/level displacement, in the 2 sports analyzed (eg, cross-country skiing and cycling) where comparison was possible, uphill sex differences are systematically around 2-fold larger.
4. Sex differences are not larger in uphill versus downhill in ultratrail running.

One of the key findings of the present study is that uphill performance differences between males and females is larger than the 8% to 12% commonly reported in the literature for many endurance sports.

The present discussion will focus on the potential explanatory mechanisms underlying the widening of the sex differences in sport performance when comparing uphill and level locomotion. Among the sex dimorphisms previously introduced, 2 may particularly penalize women uphill: (1) the lower lean to fat mass ratio and (2) the lower muscle mass and amount of fast-twitch fiber proportion.

Uphill locomotion requires moving the body mass upward, and any additional mass will alter vertical velocity. Men are on average heavier than women by ~17%,[25] but this is mostly because of a higher skeletal muscle mass[26] due to increased cross-sectional area muscle fibers (mostly type II).[13,27] For instance, it was found that female elite athletes have a lean body mass 15% lower than male elite athletes.[28] Moreover, physically fit women have a 8% to 10%-point higher fat mass than similarly fit men (eg, 24% vs 16%).[29,30] Thus, the reductions in muscle mass and in the lean/fat mass ratio contribute to impairing performance in uphill locomotion to a larger extent than in level running, despite the center of mass also being continuously displaced in vertical movement (ie, spring mass model).

There are also important differences in the morphological composition of these muscles: women have a greater proportional area of type I muscle fibers with a higher density of capillaries per unit of skeletal muscle.[14,17] This has considerable metabolic consequences: a higher fat and lower carbohydrate oxidation at a given exercise intensity[31] with a higher ATP resynthesis from oxidative phosphorylation during exercise. Women also present greater vasodilatory responses,[32] promoting greater muscle perfusion during exercise.[14] Overall, the metabolic flexibility and lower fatigability are the most important underlying mechanisms supporting the statement that sex differences are narrowing with increasing

Table 6 Performances 2017–2022 in Male and Female Elite Athletes in Ultratrail

Location, country (distance; D+)	Sex difference between male and female winners, % *Sex difference between means of top-10 male and female athletes, %* UTMB records—Male: K. Jornet—19:49:30 (2022). Female: C. Dauwalter—22:30:55 (2021) 13.6									
	2013	2014	2015	2016	2017	2018	2019	2021	2022	Mean (SD) 2013–2022
UTMB, Chamonix, FRA	9.9	15.8	19.4	14.8	35.5	25.7	20.9	8.4	17.3	18.6 (8.2)
(171 km ; 9963 m)	*25.1*	*23.2*	*25.9*	*24.1*	*36.7*	*19.4*	*20.2*	*18.2*	*23.8*	*24.1 (5.4)*
Uphill										
Uphill section 1	8.3	13.3	15.0	–21.2	21.8	23.9	16.5	11.4	9.0	10.9 (13.2)
D+ 742 m	*23.8*	*20.4*	*19.3*	*7.9*	*33.8*	*18.3*	*11.7*	*12.4*	*22.5*	*18.9 (7.7)*
Uphill section 2	8.6	15.9	15.9	11.5	24.0	22.5	12.5	12.3	18.7	15.8 (5.1)
D+ 965 m	*24.0*	*20.9*	*22.1*	*8.9*	*33.4*	*18.8*	*9.7*	*12.7*	*24.1*	*19.4 (7.9)*
Uphill section 3	13.0	12.5	16.7	25.9	35.3	8.8	4.9	11.5	14.9	16.0 (9.3)
D+ 734 m	*22.5*	*20.4*	*27.1*	*25.6*	*25.3*	*12.8*	*17.8*	*14.4*	*20.0*	20.7 *(5.0)*
Mean (SD)	10.0 (2.6)	13.9 (1.7)	15.8 (0.8)	5.4 (24.2)	27.0 (7.3)	18.4 (8.3)	11.3 (5.9)	11.7 (0.5)	14.2 (4.9)	16.5 (6.5)
	23.4 (0.8)	*20.6 (0.3)*	*22.8 (4.0)*	*14.1 (10.0)*	*30.9 (4.8)*	*16.6 (3.3)*	*13.0 (4.2)*	*13.2 (1.1)*	*22.2 (2.1)*	*19.7 (5.9)*
Downhill										
Downhill section 1	17.9	11.1	10.3	–8.8	8.3	33.9	35.3	23.0	3.5	14.9 (14.2)
D– 905 m	*22.3*	*18.9*	*19.0*	*14.5*	*35.0*	*23.5*	*11.1*	*15.6*	*21.0*	*20.1 (6.8)*
Downhill section 2	13.6	4.3	34.0	12.2	22.7	34.8	16.5	18.4	19.5	19.6 (9.9)
D– 537 m	*28.9*	*15.8*	*20.0*	*30.1*	*36.3*	*21.8*	*26.8*	*20.7*	*26.4*	*25.2 (6.2)*
Downhill section 3	21.8	10.5	23.1	22.6	16.9	25.1	7.0	3.2	0.1	14.5 (9.5)
D– 928 m	*18.3*	*25.0*	*21.1*	*25.5*	*29.0*	*17.9*	*17.3*	*13.6*	*17.6*	*20.6 (4.9)*
Mean (SD)	17.8 (4.1)	8.7 (3.7)	22.5 (11.8)	8.7 (16.0)	16.0 (7.2)	31.3 (5.3)	19.6 (14.4)	14.8 (10.4)	7.7 (10.4)	16.3 (7.6)
	23.2 *(5.4)*	*19.9 (4.7)*	*20.0 (1.1)*	23.3 *(8.0)*	33.4 *(3.9)*	*21.1 (2.9)*	*18.4 (7.9)*	*16.7 (3.7)*	*21.7 (4.4)*	*22.0 (4.8)*

Abbreviation: UTMB, Ultra-Trail du Mont Blanc. Note: Example of UTMB. Last column displays the 10-year mean and standard-deviation of the reported sex differences. The 3 uphill sections correspond to the 3 main passes of UTMB: (1) La Balme 1714 m—Croix du Bonhomme 2456 m, (2) Les Chapieux 1551 m—Col de la Seigne 2516 m, (3) Arnouvaz 1795 m—Grand Col Ferret 2529 m. Total D+ : 2441 m. Downhill sections: (1) Croix du Bonhomme 2456 m—Les Chapieux 1551 m, (2) Col de la Seigne 2516 m—Lac Combal 1979 m, (3) Grand Col Ferret 2529 m—La Fouly 1601 m. Total D–: 2370 m. Each downhill section was the next section immediately following its respective uphill section to ensure that the comparison was at the same portion of the race and not too largely impacted by different fatigue levels. We did not include the first and last climbs or the downhill section of the race as the performance is too largely impacted by pacing strategy.

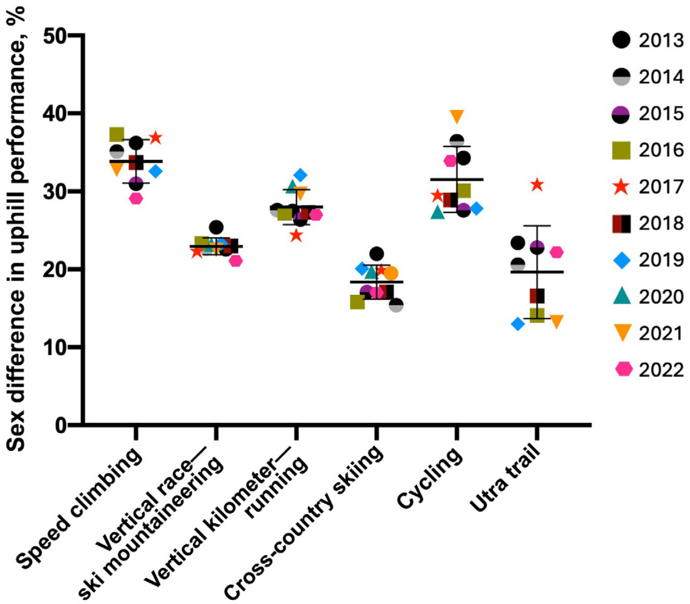

Figure 1 — Ten-year mean and SD of sex differences (%) in uphill performances calculated in 6 sports from the mean of top-10 performances in male and female elite athletes, respectively, over a 10-year period (2013–2022).

distances performed at a slower pace.[33] This is particularly relevant for ultratrail running (Table 6).

One cannot rule out the importance of other anthropometrical differences; males have longer upper and lower limbs than females,[34] allowing for greater torque production. It is unclear how this latter difference affects the running/walking mechanics and if this is really improving uphill performance for which increasing stride frequency is a prerequisite, as it reduces the vertical oscillation of the center of mass and the external mechanical work. Conversely, longer and heavier limbs are detrimental, leading to a larger increase in the internal mechanical work.[35]

Women are known for having a higher percentage of slow-twitch oxidative fibers. This is usually associated with a lower fatigability and potentially a better ability to recover, particularly from isometric[36] and eccentric[37] contractions. These sex differences are, however, less clear for dynamic concentric exercises.[38] As uphill running at least in slopes steeper than 20% to 25% is less determined by the stretch-shortening-cycle mechanism than level running[35,39] and therefore more determined by concentric than eccentric contractions, this may be disadvantageous for women who have a lower force production capacity.

This hypothesis is in line with the lower eccentric/concentric strength ratio found in men compared with women (eg, 1.38 vs 1.47),[40] which can be explained by the greater sex difference in muscle strength in concentric than eccentric contractions,[41] thus affecting uphill locomotion to a greater extent.

One additional factor is the lower- versus upper-body sex difference in muscle mass. Smaller differences in muscle mass and maximal strength between sexes have been reported in lower than upper body.[42] In 3 sports analyzed (ie, speed climbing, vertical kilometer in running, and short climb in cycling), the upper-body contribution is either very important (sport climbing) or at least more important than in the level locomotion (ie, use of poles in vertical km; standing "out of the saddle" vs seated position in short cycling maximal intensity cycling). Of interest is that the upper versus lower body difference seems to increase with greater power demands and shorter exercise duration.

Unfortunately, there are not many sports in which uphill and flat displacement can be directly compared. The analysis of the cross-country results is extremely interesting. In a sport with many confounding factors (eg, snow quality, wind, and ski techniques), the consistent differences between the flat (9.4% [2.6%]) and the uphill (18.4% [2.2%]) portions measured during the same competitions on the same days (and therefore minimizing the bias) appear to be a robust result, in line with the known sex differences (8%–12%) in many "endurance" sports and coherent with the results in the other uphill endurance sports.

In cycling, we did not find any other events for a comparison over 10 years in order to guarantee strong validity of our analysis (over 100 male vs 100 female elite performances) and the possibility to analyze the evolution over this time period. However, the present results are in line with the sex differences calculated from the power output values (absolute power output in W: 32.6%; relative power output in W/kg: 16.0%) reported in the literature in male[43] and female[44] professional cyclists.

Of interest is that, in trail running, uphill and downhill sex differences are very close (Table 6). If the above-described sex dimorphisms obviously apply for the uphill sections, one may question why the sex differences are not smaller downhill. One potential explanation arises from the observation that a safety factor occurs and that "fine motor control is needed to maintain body trajectory on a rough and slippery terrain."[39] There are likely some perceptual–emotional factors and risk-taking strategies that may differentiate male and female ultratrail runners, but these points are beyond the scope of the present study.

The ecological approach of the present study obviously has some important limitations. For example, we cannot evaluate the extent to which uphill performance is influenced by the fatigue generated during preceding level or downhill sections or if male and female athletes are similarly affected. However, we have no strong reasons to suspect sex differences in this matter and expect the present results to boost further investigation on this topic.

There are 2 other points worth being discussed: First, the sex differences calculated on the top-10 performances is systematically larger than the ones based on the winners' performances (Tables 1–6), showing that the top-10 intracategory differences among elite athletes remain larger in women than in men in the 6 sports analyzed. This may arise from economic, cultural, or sociological brakes that limit or make more difficult the professionalization of elite female athletes. Conversely, one may argue that the observed larger diversity in women may be due to some super-women who have advantages greater than the best men, when being compared with competitors within their sex.

Second, over 10 years (2013–2022), the uphill sex differences appear quite stable (Tables 1–6). This result is in line with previous reports on other sports[20,21] and suggests that a biological threshold may have been reached.[23]

Also in this case, the descriptive nature and ecological approach of the present study introduce some important limitations. First, comparisons of performance between flat and uphill performance were not statistically tested (except for cross-country skiing). The same limitation applies to the comparison across events of different characteristics and between different sections of the same event. So, results should be interpreted with caution. Second, most of the discussion remains speculative as our data collection was limited to field performances without any measured physiological or biomechanical variables.

Practical Applications

Despite the above-described limitations, this study has some important practical applications. It highlights the need for careful optimization of body composition in female athletes engaged in events with uphill components. However, one should be careful in promoting the idea that most of the larger sex differences in uphill sports may arise from a higher fat mass in female athletes. If misunderstood, this message may increase the number of women trying to improve performance by reducing weight too much, with negative health outcomes associated with relative energy deficiency in sports.[45] An alternative solution lies in individualizing strength and concurrent training (ie, combined strength and endurance) for female endurance athletes in mountain sports as they have specific neuromuscular characteristics compared with men.

Conclusion

This novel analysis over 10 years of elite endurance performance in different sports with uphill displacement shows that the sex differences are generally larger (18%–22%) than in endurance sports performed primarily on flat terrains, which can primarily be explained by the lower lean–fat mass ratio in women. On shorter uphill events (eg, sport climbing, vertical kilometer, and short climb in cycling), the sex differences appear to be even more pronounced (28%–35%), potentially caused by additional factors (eg, altered anaerobic capacity, muscle composition, and/or upper body contribution in men).

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Queries

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Q2. Keywords "uphill, women, and performance" were deleted, as repeats of words in journal and article title are not allowed in keywords section, per journal style. Provide additional keywords so that the total number of keywords equals at least 3, ideally 4–5.

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Q7. "*35.±2.8*" in Table has been changed to 35 (2.8). Please check if this is okay.

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