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Human Kinetics
ORIGINAL RESEARCH

Auditing the Representation of Females Versus Males in Heat Adaptation Research

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The aim of this audit was to quantify female representation in research on heat adaptation. Using a standardized audit tool, the PubMed database was searched for heat adaptation literature from inception to February 2023. Studies were included if they investigated heat adaptation among female and male adults (≥18–50 years) who were free from noncommunicable diseases, with heat adaptation the primary or secondary outcome of interest. The number and sex of participants, athletic caliber, menstrual status, research theme, journal impact factor, Altmetric score, Field-Weighted Citation Impact, and type of heat exposure were extracted. A total of 477 studies were identified in this audit, including 7,707 participants with ∼13% of these being female. Most studies investigated male-only cohorts (∼74%, $n = 5{,}672$ males), with ∼5% ($n = 360$ females) including female-only cohorts. Of the 126 studies that included females, only 10% provided some evidence of appropriate methodological control to account for ovarian hormone status, with no study meeting best-practice recommendations. Of the included female participants, 40% were able to be classified to an athletic caliber, with 67% of these being allocated to Tier 2 (i.e., trained/developmental) or below. Exercise heat acclimation was the dominant method of heat exposure (437 interventions), with 21 studies investigating sex differences in exercise heat acclimation interventions. We recommend that future research on heat adaptation in female participants use methodological approaches that consider the potential impact of sexual dimorphism on study outcomes to provide evidence-based guidelines for female athletes preparing for exercise or competition in hot conditions.

***Keywords**:* acclimation, acclimatization, exercise performance, heat stress, menstrual status, thermoregulation, women

Women remain substantially underrepresented in sports science and sports medicine (SSSM) research, with just 4%–23% of studies across subdisciplines examining female-only populations (Cowley et al., 2021; Hutchins et al., 2021; Kuikman et al., 2022, 2023; Smith et al., 2022a). This is likely underpinned by numerous factors, including limited access to female participants (Emmonds et al., 2019), alongside deterrents around the perceived or real complexity and costs of implementing studies that consider menstrual status (Bruinvels et al., 2017). There is now recognition of the need to address the underrepresentation of female participants in SSSM research, including investigations of their specific responses to evidence-based protocols (Elliott-Sale et al., 2021). Indeed, SSSM guidelines are largely developed from research undertaken on male participants, without consideration of differential responses that may arise with sexual dimorphisms or sex-related sporting characteristics (Smith et al., 2022a). To streamline and prioritize research, a standardized audit protocol has been developed (Smith et al., 2022b) to identify themes in SSSM where there is minimal information on female-specific responses and the likelihood of unique or different sex-related considerations associated with optimal practice.

A research theme which would benefit from an audit of female representation is heat adaptation. Heat adaptation is induced via repeated exposures to artificial (i.e., heat acclimation) or naturally (i.e., heat acclimatization) occurring hot environments, that induce physiological adaptations and subsequent improvements in exercise performance (Périard et al., 2021). Anecdotally, most heat adaptation literature appears to be conducted in men, meaning that current heat adaptation guidelines (Racinais et al., 2015) are likely underpinned by male-focused research. If correct, this may not be optimal for female athletes, given that they differ to males in body

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surface area (Anderson, 1999; Gagnon & Kenny, 2012a), sweating capacity (Gagnon & Kenny, 2011; Gagnon & Kenny, 2012b), and their thermoregulatory profile across the menstrual cycle (MC; Charkoudian & Stachenfeld, 2014; Giersch et al., 2020). Furthermore, there is debate regarding whether the heat adaptation time course differs between sexes (Mee et al., 2015; Shapiro et al., 1980), with a recent female-only meta-analysis suggesting some physiological adaptations are likely induced more rapidly than previously stated (Kelly et al., 2023). Accordingly, to improve our understanding of the evidence base underpinning current guidelines, we conducted an audit to assess the quantity and impact of female representation in the published heat adaptation literature.

Methods

This audit was conducted according to established methods (Smith et al., 2022b).

Search Strategy

An electronic literature search of PubMed was conducted using standardized search terms of the audit methodology (Smith et al., 2022b), with heat adaptation terms of (a; acclim * OR adapt * OR thermoreg * OR sweat * OR training) AND (b; heat OR hot OR warm). A complete list of search terms is available in Supplementary Material S1 (available online). Searches were exclusive to original research papers of human participants, published in English, without date restrictions and current to February 14, 2023. Review articles were screened for additional relevant papers not detected in the primary search.

Data Extraction

Papers were screened using Covidence systematic review software (version 2636, Veritas Health Innovation) by a combination of two independent authors (Kelly, Smith, Brown, Jardine, Convit, Carr, and Snow), with conflicts resolved by a third author (Carr and Snow). Inclusion criteria comprised:

a. Heat adaptation being the primary or secondary outcome of interest and heat adaptations induced and/or observed via exercise-based heat acclimation (Périard et al., 2021), passive heat acclimation (i.e., sauna and spa; Heathcote et al., 2018), and heat acclimatization. Heat acclimatization studies were separated into either heat acclimatization (relocation) or seasonal heat acclimatization (Brown et al., 2022). Studies employing multiple methodological approaches (i.e., exercise and passive heat acclimation) were termed "combined heat exposure."

b. A minimum ambient temperature or wet-bulb globe temperature of 25 °C (Benjamin et al., 2019; Guy et al., 2015) was required for heat adaptation intervention studies.

If a paper included several separate studies, each data set was individually analyzed. Hereafter "paper" refers to the entire publication, and "study" refers to the discrete investigations within a paper. A summary of extracted data per the audit framework (Smith et al., 2022b) is displayed in Table 1.

Statistical Analyses

Analyses were conducted using Stata 17 (StataCorp. 2021. Stata: Release 17. Statistical Software. StataCorp LLC) with significance accepted at an α level of $p < .05$. Frequency-based metrics (population, athletic caliber, menstrual status, research theme, and heat adaptation exposure) were reported as counts and percentage(s) of the total studies/participants. Inspection of histograms for journal impact factor (IF), Altmetric scores, Field-Weighted Citation Impact (FWCI), and male/female sample sizes revealed a positive skew. A Mann–Whitney U test was used to examine median numbers of male and female participants, and a Kruskal–Wallis test used to determine significant differences in journal IF, Altmetric scores, and FWCI. A post hoc Dunn test with Bonferroni correction was used to assess differences, with data reported as median ± interquartile range. The number of studies reaching Altmetric scores >20 was assessed in a binary manner to describe studies receiving greater attention than others.

Results

A total of 477 studies involving 7,707 participants across 595 heat exposures were included (Figures 1 and 2a). The majority of participants were male (86.8%; $n = 6{,}686$ males; Figure 2a), while 26.4% of studies included at least one female participant. A comprehensive summary of results is provided in Supplementary Material S2 (available online).

Population and Sample Size

Male-only participants are included ∼16 times more than female-only cohorts in heat adaptation research ($n = 5{,}672$ and $n = 360$, respectively; Figure 2a). In studies evaluating sex differences, the number of male and female participants was similar; however, males outnumbered females in mixed-sex cohorts and male versus female (MvF) subanalysis (Figure 2b). Female-only cohorts accounted for 6.1% of studies, while of the 126 studies that included one (or more) female participant(s), 54.0% utilized a mixed-sex cohort design (Figure 2b).

Female- and male-only studies had a median sample size of 12 and 13, respectively ($p = .318$, Figure 2c). In mixed-sex cohort studies, there was a consistently larger median (±interquartile range) sample size of men (9 ± 7) than women (4 ± 6, $p < .001$), with no difference in the median sample sizes in MvF design features and subanalyses ($p = .579$ and $p = .872$, respectively, Figure 2c). There were 36 male and seven female para-athletes represented in studies, with no female-only para-athlete studies. Since 1943, the annual average number of participants involved in heat adaptation research has been 82 men compared to 12 women. The more recent average, from 2012 to 2022, involves an increase in total participants (322 men and 44 women, annually) without any change in this ratio (∼7 male: 1 female participant). There was an annual average (±standard deviation) of 0.4 (±0.6) studies in which females were investigated in isolation, compared to 4.4 (±5.3) male-only studies (Figure 2d). From 2012 to 2022, there were 0.8 (±0.9) female-only studies compared to 15.1 (±5.4) male-only studies published yearly (Figure 2d).

Athletic Caliber

Only 31.0% ($n = 2{,}387$) of all participants were able to be classified to a specific tier, irrespective of sex, with the remainder of studies providing insufficient information. Of the total classifiable population, most ($n = 986$) were classified as Tier 2 caliber (Table 2), with 39.9% ($n = 407$) of female participants and 29.6% ($n = 1{,}980$) of male participants classified (Table 2).

Table 1 A Summary of Extracted Data From Heat Adaptation Studies Included in this Audit According to Established Methods (Smith et al., 2022b)

Data extraction variables	Subcategories
Study design	• Females • Males • Mixed-sex cohorts • MvF design features • MvF subanalysis
Athletic caliber as established by McKay et al. (2022)	• Tier 0 (sedentary) • Tier 1 (recreationally active) • Tier 2 (trained/developmental) • Tier 3 (highly trained/national) • Tier 4 (elite/international) • Tier 5 (world class)
Menstrual status and grade	*Menstrual status* • NM or eumenorrheic females (meeting specified criteria; Elliott-Sale et al., 2021) • HC users • Menstrual irregularities • Combination of menstrual statuses *Grade* • Gold standard (best practice as previously established; Elliott-Sale et al., 2021) • Silver/bronze (achieve some methodological considerations but not all) • Ungraded (menstrual status defined but insufficient methodological control to award bronze/silver/gold) • Unclassified (insufficient information to classify participants)
Research theme	• Performance outcomes (performance outcome following an intervention or associated with a topic of interest) • Health outcomes (related to health status or condition) • Indirect markers of performance/health (studies measuring a physiological/psychological adaptation or response)
Study impact	• Journal publication dates • 4-year impact factor • Altmetric score (retrieved May 3, 2023) • Field-Weighted Citation Impact (updated April 26, 2023, retrieved May 3, 2023)
Sample size	• Male participant number • Female participant number
Heat adaptation exposure	• Exercise heat acclimation • Passive heat acclimation • Heat acclimatization (relocation) • Seasonal heat acclimatization • Combined heat exposure For studies with multiple heat adaptation exposures, each investigation was included, and total number of exposures counted separately.

Note. NM = naturally menstruating; HC = hormonal contraceptive; MvF = male v female.

Menstrual Status

Forty-seven of the 126 studies (37.3%) that included female participants attempted to define menstrual status, comprising 20 studies examining naturally menstruating (NM) women, five with hormonal contraceptive (HC) users, 21 utilizing a mixed but identifiable female cohort, and one examining menstrual irregularities. Regarding classification, 34 studies that defined menstrual status were ungraded (unable to classify menstrual status due to insufficient information), with 11.5 studies rated as bronze and 1.5 studies as silver standard (Figure 3). No studies achieved a gold standard of menstrual classification (Smith et al., 2022b; Figure 3). Studies including NM women achieved a mean of 0.35 of the five criteria required to justify eumenorrheic classification (Elliott-Sale et al., 2021), with a high score of 4 achieved by one female-only study.

Performance Versus Health Research Themes

The majority of participants (70.4%, $n = 5{,}427$) were in studies examining indirect markers of performance/health, with female participants accounting for 11.9% ($n = 647$) of the total sample in this theme (Table 3). When stratified by study design, the percentage of studies investigating indirect makers of performance/health outcomes was 69.0% for female-only, 74.9% for male-only, and 61.8% for mixed-sex cohort studies (Figure 4). There were no studies in female-only or MvF investigations targeting health outcomes (Figure 4).

Journal and Study Impact

The median (±interquartile range) IF of journals where studies were published was 3.19 (±0.93), with no differences between populations (all $p > .05$; Table 4). Forty-nine percent of studies were eligible for Altimetric scores (based on year of inception). The median Altmetric score was 8.0 (±20.0) across all studies and populations, with no between-population differences (all $p > .05$; Table 4). There were 38 (10.8%) male-only studies, five (17.2%) female-only studies, 17 (25.0%) mixed-sex cohorts, one (4.3%) MvF design features, and zero (0%) MvF subanalysis with Altmetric scores >20, with no between-population differences (all

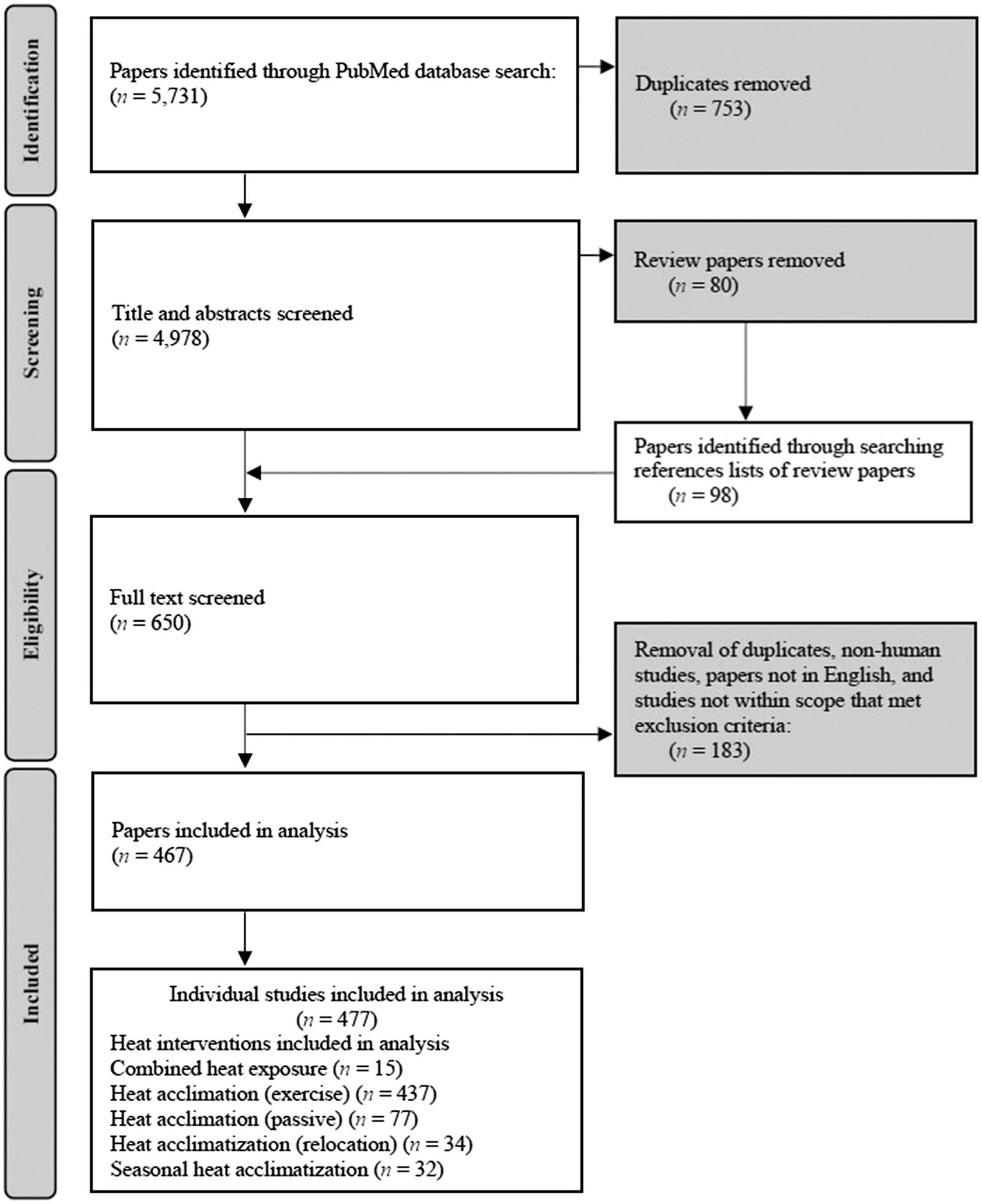

Figure 1 — Flowchart demonstrating the screening process for the audit and the total number of individual studies included for extraction. The total number of heat adaptation exposures included within each study was counted, with studies often investigating one or more heat adaptation exposures.

$p > .05$). Sixty-one percent of studies were eligible for FWCI (based on year of inception), with a median score of 0.75 (±1.26) across all studies. There were no between-population differences (all $p > .05$), with MvF subanalysis the only population to achieve a median FWCI >1 (median score of 1.74; Table 4).

Heat Adaptation Exposure

Our examination of the type of heat exposure involved in studies found 437 exercise heat acclimation interventions, while 77 involved passive heat acclimation (e.g., spa and sauna), 34 examined heat acclimatization (relocation), 32 seasonal heat acclimatization, and 15 used a combination of heat exposures. Exercise heat acclimation interventions included 5,405 participants, with ∼14% of those being female (Figure 5a). The percentage of studies within population groups investigating exercise heat acclimation ranged between ∼71% and 93%, compared to ∼3% and 17% for passive heat acclimation (Figure 5b). There was no heat acclimatization (relocation) or combined heat exposure studies involving MvF design features (Figure 5b). There were 25 female-only exercise heat acclimation interventions (compared to 314 male-only interventions). Of the 23 studies that utilized MvF design features, 21 studies focused on exercise heat acclimation, one examined seasonal heat acclimatization, and one investigated passive heat acclimation exposure.

Discussion

We examined the representation of female and male participants involved in investigations of heat adaptation using a recently

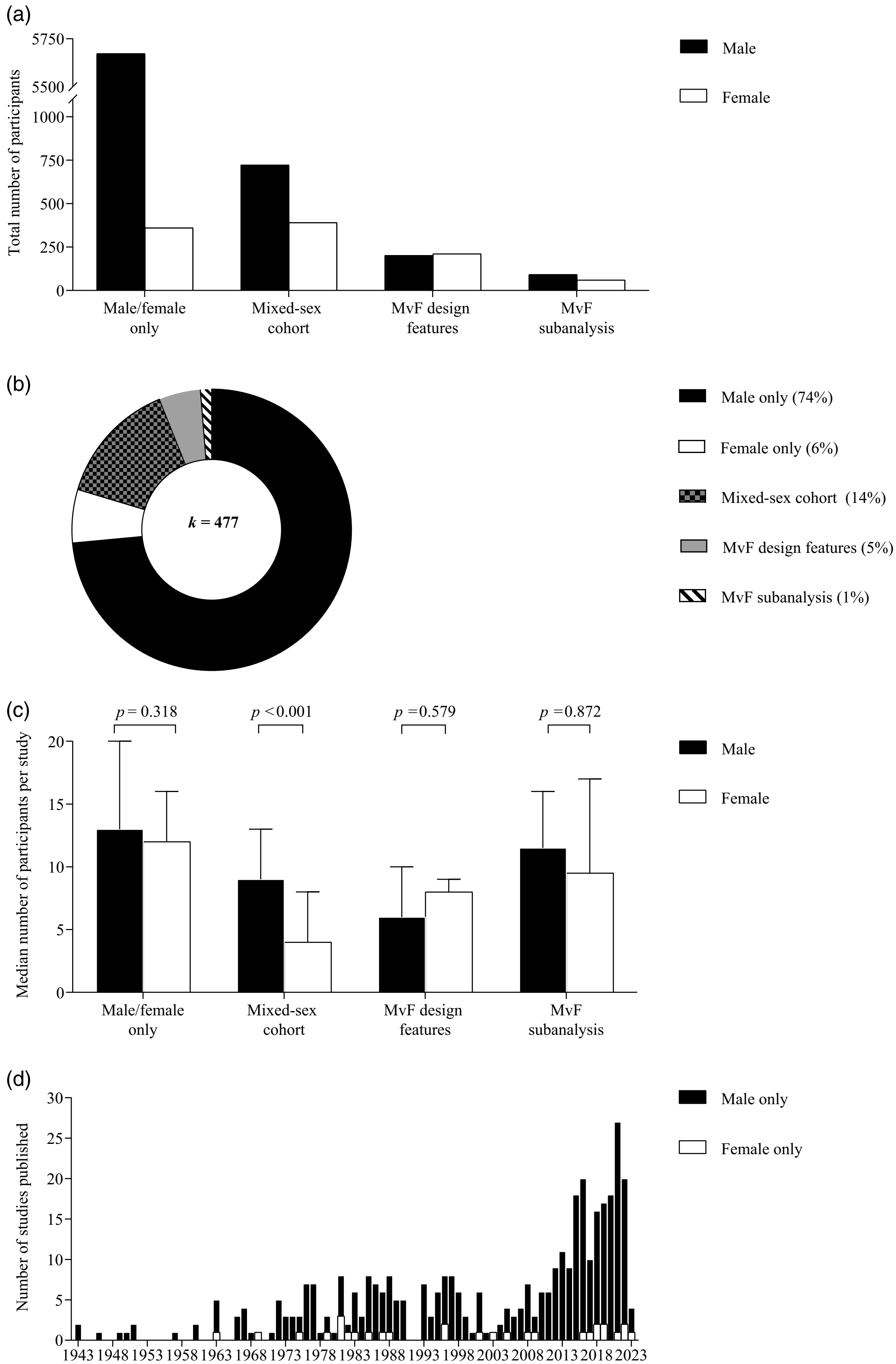

Figure 2 — (a) The total number of male and female participants included in the audited studies, (b) the percentage of studies published in each population, (c) the median (±*IQR*) number of male and female participants per study, and (d) a histogram displaying the number of heat adaptation studies published per year in male or female-only cohorts between 1943 and 2023. MvF design features refer to studies with a purposeful methodological design to investigate differences in the intervention response between the sexes, while MvF subanalysis describes studies in which sex-based comparisons were completed within the statistical procedures, but were not a primary study aim. *IQR* = interquartile range; MvF = male v female.

Table 2 Total Number and Percentage of Male and Female Participants Classified Into Exercise Training Tiers (McKay et al., 2022)

Tiers	Male	Female
Tier 0 (sedentary)	105 (5.3%)	61 (15.0%)
Tier 1 (recreationally active)	530 (26.8%)	89 (21.9%)
Tier 2 (trained/developmental)	862 (43.5%)	124 (30.5%)
Tier 3 (highly trained/national)	209 (10.6%)	25 (6.1%)
Tier 4 (elite/international)	259 (13.1%)	96 (23.6%)
Tier 5 (world-class)	15 (0.8%)	12 (2.9%)

Note. Only classified participants are displayed in table.

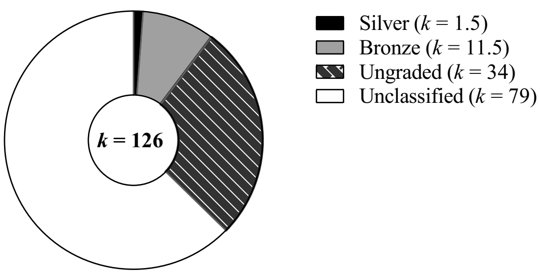

Figure 3 — The number of studies including females classified according to the standard of the methodological control concerning ovarian hormonal profiles (Smith et al., 2022b).

Table 3 The Total Number and Percentage of Male and Female Participants in Each Research Theme: Performance (Direct Performance Outcomes), Health (Outcomes Related to Health Status/Condition), and Indirect Associations With Performance/Health (Physiological or Psychological Adaptation/Response That May Subsequently Transfer to Athletic Performance/Health; Smith et al., 2022b)

Theme	Male	Female
Performance	1,762 (85.1%)	308 (14.9%)
Health	144 (68.6%)	66 (31.4%)
Indirect	4,780 (88.1%)	647 (11.9%)

developed audit methodology (Smith et al., 2022b). We aimed to assess the quantity and impact of female representation in the published heat adaptation literature currently underpinning best-practice guidelines. Women accounted for only ∼13% of the total participants, with most studies investigating exposures involving exercise heat acclimation. No study achieved gold-standard methods for the classification and control of menstrual status. Of all female participants, only 13% could be classified as Tier 3 (highly trained/national) or greater. These results demonstrate that the direct relevance of current guidelines for heat adaptation practices for female athletes is limited.

Population and Sample Size

Women accounted for ∼13% of the total participant pool, consistent with prior work examining female representation in the broader exercise thermoregulatory research (11.6%–17.8%; Hutchins et al., 2021), and at the lower end comparatively to other studies profiling female inclusion using the same audit tool (11.0%–71.0%) among other SSSM subdisciplines (Kuikman et al., 2022, 2023; Smith et al., 2022a, 2022c). Female-only heat adaptation regimens accounted for 6.1% of all studies, consistent with the prevalence of female-only studies previously reported for carbohydrate fueling (∼4%–6%; Kuikman et al., 2022, 2023), and in SSSM research more broadly (Cowley et al., 2021). Of note, we identified 22 papers that failed to state participant sex or male-to-female ratios, including seven papers published between 2016 and 2021, alluding to a default interpretation of male participants as the norm in heat adaptation research.

Studies examining mixed-sex cohorts included approximately twice as many males as female participants. Possible explanations for this may be that females are harder to recruit (Emmonds et al., 2019), a reduced capacity to fund/support the involvement of women (e.g., costs to facilitate MC control; Smith et al., 2022a), or that females are included to boost total sample sizes rather than to allow between-sex investigations. Given the differing body surface area (Gagnon & Kenny, 2012a), sweating capacity (Gagnon & Kenny, 2011; Gagnon & Kenny, 2012b), and varied thermoregulatory profile across the MC or with HC use (Charkoudian & Stachenfeld, 2014; Giersch et al., 2020), a mixed-sex cohort design without statistical power to examine responses between sexes may not be appropriate in some investigations of heat adaptation, particularly those of a mechanistic nature. Heat adaptation studies comparing responses between the sexes were also limited (6.1%), consistent with previous audits (Kuikman et al., 2022; Smith et al., 2022a, 2022c). The complex and often costly nature of study designs associated with high-quality female research (e.g., MC phase verification via blood samples and ovulation testing) may discourage researchers from undertaking such investigations. The current gap in knowledge around sexual dimorphisms in heat adaptation calls for urgent attention of heat researchers, and for careful consultation of the current best-practice guidelines for including females in SSSM research, including a degree of MC phase control and HC use reporting (Elliott-Sale et al., 2021).

Athletic Caliber

The training/performance level of participants was unable to be classified in 69% of the studies included in this audit indicating that, irrespective of sex, there is currently poor consideration or identification of the caliber of athletes involved in heat adaptation research. The absence of appropriate classification of study participants (De Pauw et al., 2013; Decroix et al., 2016; McKay et al., 2022) may prevent study results from being correctly applied or translated to relevant athletic populations (Kuikman et al., 2022; Smith et al., 2022a, 2022c). Of those who could be classified, most participants were categorized to lower athletic calibers (Tiers 0–2; 75.6% male and 67.3% female participants), suggesting that caution is needed when transferring the results of studies to high-performance athletes. However, of the studies of female athletes classed in Tiers 3–5 (32.7%; $n = 133$), ∼53% of studies ($k = 9$) were published since 2012, suggesting that in recent years, there has been an increased focus within the literature on female-specific research, more robust study designs, and/or increased reporting of heat adaptation interventions. There was one female-only study classified as Tier 5 ($n = 12$), compared to three male-only studies ($n = 15$) identifying a general lack of investigations of participants of the highest athletic caliber, irrespective of sex. Given the near parity between sexes as competitors in major sporting competitions

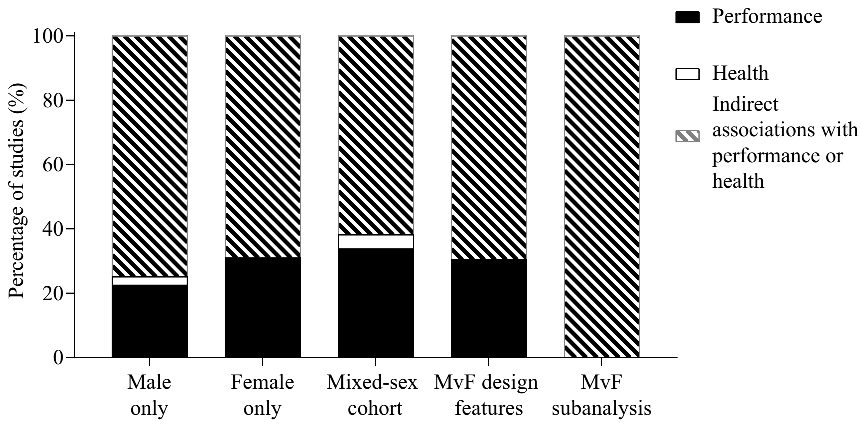

Figure 4 — The percentage of studies in each research theme: performance (direct performance outcomes), health (outcomes related to health status/condition), and indirect associations with performance/health (physiological or psychological adaptation/response that may subsequently transfer to athletic performance/health; Smith et al., 2022b). MvF design features refer to studies with a purposeful methodological design to investigate differences in the intervention response between the sexes, while MvF subanalysis describes studies in which sex-based comparisons were completed within the statistical procedures, but this was not a primary study aim.

Table 4 Median (±IQR) 4-Year Journal Impact Factor, Altmetric Score, and FWCI, Separated by Population Studied

Theme	Impact factor	Altmetric score	FWCI
Male only	3.19 (0.93)	6.5 (18.0)	0.76 (1.19)
Female only	3.54 (1.40)	19.0 (24.0)	0.57 (1.28)
Mixed-sex cohort	3.19 (0.79)	13.5 (25.0)	0.78 (1.37)
MvF design features	2.97 (0.57)	20.0 (41.0)	0.56 (1.42)
MvF subanalysis	3.19 (0.55)	9.0 (11.0)	1.74 (1.86)

Note. FWCI = Field-Weighted Citation Impact; IQR = interquartile range; MvF = male v female. MvF design features refer to studies with a purposeful methodological design to investigate differences in the intervention response between the sexes, while MvF subanalysis describes studies in which sex-based comparisons were completed within the statistical procedures, but this was not a primary study aim.

(e.g., ∼49% of athletes at the 2020 (2021) Tokyo Olympic Games were female; International Olympic Committee, 2021), the underrepresentation of high-caliber female athletes in heat adaptation research presents a key area for future study. The challenges of conducting high-quality research in this population, which include the difficulty of making changes to periodized training programs that are specifically targeted to major national or international events and championships, while maintaining the requirements for robust research study designs, are acknowledged.

Menstrual Status

The classification and methodological control of menstrual status was extremely poor, with only 10% of studies reporting adequate methodological design around the categorization of menstrual status. Of the 126 studies including female participants, ∼63% made no attempt to classify menstrual status which is consistent with previous SSSM audits (Kuikman et al., 2022; Smith et al., 2022a, 2022c). The highest level of classification and methodological control identified across studies in this audit of both NM females and those using HC was "silver standard," defined as achieving some methodological considerations but not all (Smith et al., 2022b). Moreover, no study achieved the five criteria required to justify NM females as eumenorrheic (Elliott-Sale et al., 2021), meaning their true menstrual status was unconfirmed or inconclusive. Twenty-one studies (∼45%) included female participants with varying menstrual status (e.g., NM females and those using HC), which is likely representative of the current ratio of females using HC (∼50%), who are NM or with menstrual irregularities (∼50%; Martin et al., 2018), and reflective of the challenges of recruiting a sufficiently large population with uniform MC status. Importantly, when investigating this population, appropriate reporting of the MC phases for female participants is suggested within the current literature as outlined in recently published recommendations (Elliott-Sale et al., 2021) to account for the different hormonal profiles of females.

The consideration and control of the MC and HC use in mechanistic heat adaptation research are an important design factor, especially for measures of resting and exercise core temperature. The dynamic hormonal profile of the MC leads to changes in core temperature, including ∼0.3 °C increase in resting core temperature during the luteal phase (Kolka & Stephenson, 1997; Stephenson & Kolka, 1993). This temperature increase at rest (Giersch et al., 2020) could potentially be mitigated by behavioral thermoregulation-mediated adjustments in pacing during self-paced exercise in the heat (Lei et al., 2017). Moreover, the type of progestin and ratio of progestin to estradiol in HC use can also influence resting and exercise core temperature (Baker et al., 2020; Rogers & Baker, 1997). A key design consideration is the scheduling of testing sessions, such as heat tolerance tests, which are typically conducted at fixed intensities, to occur within the same phase of the MC and/or HC use. If they were to occur in differing phases of the MC, that is, follicular compared to luteal phase, and/or differing phases of HC use, the change in core temperature at comparative time points may mask any influence of heat adaptation, that is, identification of possible core temperature reductions with heat adaptation. While "gold standard" (Smith et al., 2022b) is the highest level of MC control, "silver standard" (Smith et al., 2022b) is likely a more feasible method to implement within mechanistic heat adaptation research of females, allowing physiological changes to be more confidently attributed to the heat adaptation exposure.

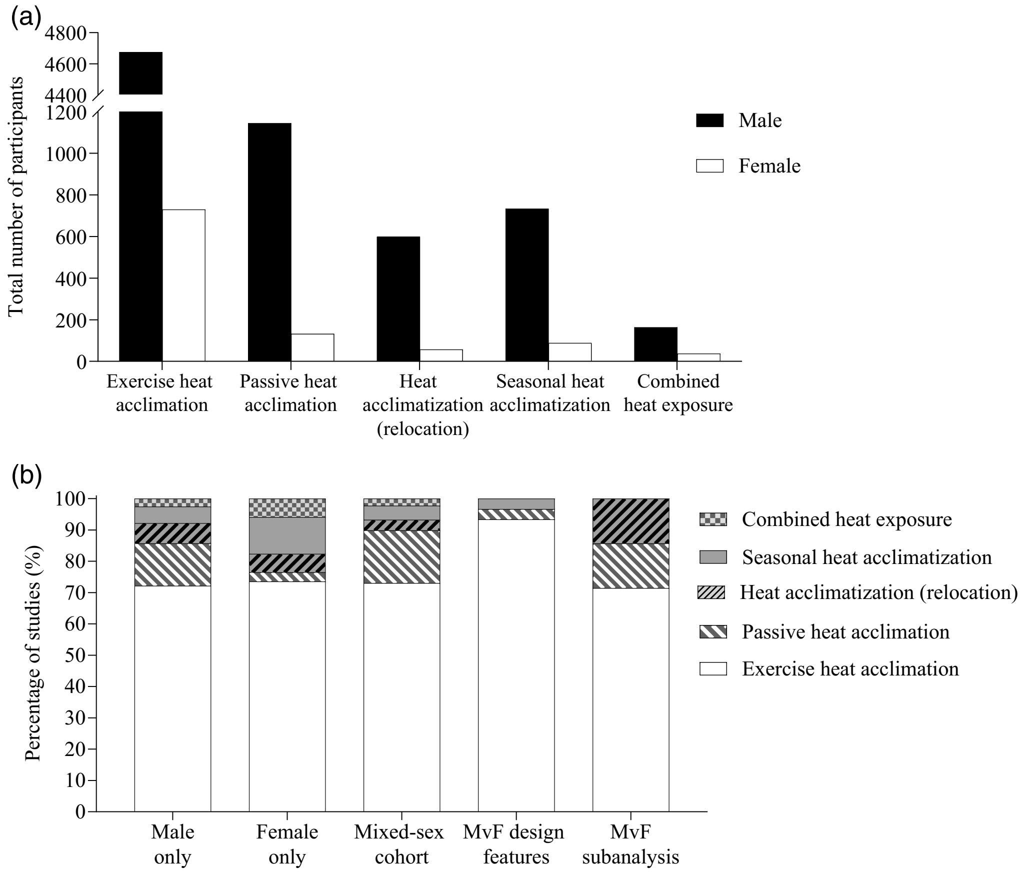

Figure 5 — (a) Total number of male and female participants and (b) the percentage of studies in each heat adaptation exposure. MvF design features refer to studies with a purposeful methodological design to investigate differences in the intervention response between the sexes, while MvF subanalysis describes studies in which sex-based comparisons were completed within the statistical procedures, but this was not a primary study aim.

Research Themes

Outcomes of heat adaptation research typically focus on physiological changes such as core temperature, heart rate, and sweat rate. Accordingly, ~73% of studies in this audit examined indirect markers of performance/health, with the distribution similar for female-only (69.0% of studies), male-only (74.9%), and mixed-sex cohorts (61.8%). There were 79 male-only studies ($n = 1{,}384$ males) investigating performance outcomes compared to just nine female-only ($n = 125$ females) investigations. The classification of only 133 female athletes as Tiers 3–5 (highly trained/national or greater; McKay et al., 2022) in this audit likely limits the applicability of current study findings to high-performance female athletes. The inclusion of elite female athletes in studies examining performance outcomes following heat adaptation exposures therefore presents a clear area for future research.

There were no female-only or MvF investigations (either subanalysis or design features) in the health research theme. Yet, in the 2020 (2021) Tokyo Olympic and Paralympic Games, females were reported to be at a significantly greater risk of all illness (Soligard et al., 2023) and registered more illnesses compared to males (Derman et al., 2023), respectively. Unsurprisingly, investigation of immune and/or wellness markers following heat adaptation is limited in females (Alkemade et al., 2022). For high-caliber female athletes, an evidence-based understanding of illness risk following heat adaptation is likely of great interest, and an area of future research.

Journal and Study Impact

The IF of journals in which studies were published was similar to that previously reported across other SSSM disciplines (Smith et al., 2022a, 2022c), with a range from 3.54 for female-only studies and 2.97 for MvF design feature studies. The absence of between-population differences in this audit might suggest minimal incentive for researchers to conduct more challenging research designs, such as including adequate MC control in heat adaptation investigations, for a potential reward for publication in higher IF journals. However, this is speculative.

Altmetric scores were available for ~49% of studies in this audit (i.e., those published since 2012), with a median Altmetric score of 8.0 and no between-population differences. When considering studies achieving Altmetric scores >20 (delineating studies receiving greater attention than their peers; Smith et al., 2022b), there were also no statistically significant population differences. This suggests that despite the small absolute number of female-only and MvF studies in this audit, interest does not differ between populations in heat adaptation literature.

In this audit, ~61% of studies were eligible for FWCI (i.e., those published since 1996), with a median score of 0.75, with no between-population differences. MvF subanalysis was the only population to achieve a median FWCI >1 (median score of 1.74), identifying the outputs of this research are more cited than expected according to global averages. It should be noted, however, that this subgroup had the lowest representation of studies ($k = 6$ studies in total) and therefore should be interpreted with caution.

Heat Adaptation Exposure

Exercise heat acclimation was the most frequently investigated exposure, with 437 regimens across 363 studies, including 5,405 participants, of which 730 (13.5%) were female. The representation of women ranged between ∼9% and 19% for all heat adaptation exposures, with no studies employing MvF design features for heat acclimatization (relocation) and combined heat exposures.

The use of heat adaptation protocols (i.e., heat acclimation/acclimatization) prior to competition in the heat by elite athletes, both male and female, has been investigated in recent years (Galan-Lopez et al., 2023; Périard et al., 2017; Racinais et al., 2020, 2022), with a greater percentage of females training in the heat than males prior to some competitions (Périard et al., 2017; Racinais et al., 2020). However, in one recent study, females were reported to exhibit less heat-related best-practice knowledge compared to males, with females more likely to report not knowing the maximum environmental conditions and wet-bulb globe temperature expected at the competition location (Galan-Lopez et al., 2023). In the same study, only 33.3% of female athletes reported undertaking heat acclimatization and only 12.5% reported utilizing heat acclimation (Galan-Lopez et al., 2023). Given the limited number of heat acclimatization (relocation) studies including female participants in this audit, and no studies utilizing MvF design features, future research is required to help inform evidence-based heat adaptation recommendations for female athletes. This includes a specific focus to improve educational resources available to female athletes to translate research knowledge to practice.

Recommendations for Female Heat Adaptation Research

This audit has confirmed and emphasized that females are underrepresented in heat adaptation research. This finding highlights the need for more female-focused heat adaptation research to form the basis for evidence-based guidelines for females preparing for exercise and/or sporting competition in hot conditions.

The following specific recommendations are therefore provided to sports science researchers:

- Researchers are encouraged to refer to current best-practice guidelines on the inclusion of females in sport and exercise research (Elliott-Sale et al., 2021) when designing research studies, and to employ methodological designs that appropriately consider and report the potential impact of the female MC on study outcomes.
- Researchers are encouraged to investigate heat adaptation research of high-caliber female athletes (Tiers 3–5) with a focus on performance outcomes. This should include the profiling of thermoregulatory and physiological adaptations to inform evidence-based guidelines for heat adaptation protocols to prepare female athletes for competition in hot environments.

Conclusions

Our audit demonstrates the underrepresentation of women across all categories of heat adaptation research, with females accounting for just 13% of all participants. This is compounded by inadequate classification and control of menstrual status, alongside a lack of elite female athletes as participants. As such, the specific applicability of current research to the high-performance female athlete is limited. Researchers planning future heat adaptation interventions in female athletes are advised to adopt methodological approaches that consider the potential impact of sexual dimorphism on study outcomes. Methodological considerations include MC control within study designs and robust classification of participants, specifically regarding athletic caliber. The inclusion of these elements within the study design will contribute valuable data on the time course of physiological adaptations, providing a basis for future recommendations and evidence-based guidelines for female athletes preparing for exercise, or competition in hot conditions.

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